ESTIMATION OF CHLOROPHENOLS IN EFFLUENT FORMED UNDER DIFFERENT CONDITIONS OF BLEACHING

A THESIS

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of
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By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"ESTIMATION OF CHLOROPHENOLS IN EFFLUENT FORMED UNDER DIFFERENT CONDITIONS OF BLEACHING"** in fulfilment of the requirements for the award of the degree of Doctor of Philosophy and submitted in the Department of Paper Technology of the Indian Institute of Technology Roorkee is an authentic record of my own work carried out during the period from July 1999 to July 2005 under the supervision of **Dr. Satish Kumar**.

The matter presented in the thesis has not been submitted by me for the award of any other degree in this or any other Institute.

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ABSTRACT

The use of chlorine and chlorine containing bleaching agents in the production of bleached chemical pulp leads to the formation of a variety of chlorinated organic compounds that are discharged in bleach-plant waste waters. Hence bleach plant effluents are known to be the main contributors of toxicity, colour and BOD in bleached kraft mill effluent. The chlorinated organic compounds formed during bleaching of pulp have proved to be highly toxic to aquatic organisms and adversely affecting on human health as well. These are quite persistent in the environment and readily accumulate in organisms. In addition, they can be responsible for the deterioration of flavour of sea food. They, therefore, are of great environmental concern.

The end of pipe treatment methods employed by Indian paper mills consist of primary and secondary treatment plants which reduce the suspended solids and BOD significantly, with small reduction in COD, AOX and colour loads. The aim of the present investigation is to identify a set of pulp chlorination conditions in which the production of chlorinated phenolics would be minimal without any adverse impact on pulp quality. Most of these studies have been carried out on softwood and hardwood pulps. A very little information is available on non-woods and agro-residue pulps, which are important in Indian context due to decreasing wood resources.

In view of the above, following objectives were formulated for this study:

I. To identify and quantify various chlorophenols formed during different stages of pulp bleaching.

II. To study the impact of change in chlorination condition on the production of toxic chlorinated phenolics in C, E and H stages.

III. To study the integration of Oxygen deliginification stage with conventional CEH bleaching sequence and its impact on the generation of chlorophenolics.

IV. To study the impact of partial or complete replacement of chlorine by chlorine dioxide on the generation of chlorophenolic compounds.

V. To study the effect of change in chlorination condition on :

- Pulp characteristics
- Pollution load generation

The study was carried out on wheat straw (Triticum aestivium) and sarkanda (Saccharum munja) soda pulps.

The retention time of pure chlorophenol standards have been determined on HR-1 capillary column. The retention value indicates that most of the chlorophenolic compounds studied can be resolved on capillary column of HR-1. The estimation of various chlorophenolic compounds have been carried out in C, E, H bleaching stage effluents. Also, the impact of change in C stage bleaching conditions have been investigated on C, E, H bleaching stage effluents and combined CEH effluent. The results indicate that six categories of chlorophenolics are present in various bleaching effluent. These are simple chlorophenols, chlorocatechols. chloroguaiacols, chlorosyringaldehyde and chlorovanillins. The result shows that the impact of change in C stage bleaching conditions on C, E, H bleaching stage effluents and combined CEH bleaching effluent were similar in both wheat straw and sarkanda pulps, with exception of the formation of syringaldehydes and vanillins which were higher in sarkanda in comparison to wheat straw. Besides these, chlorinated compounds have also been categorized into mono,di,tri,tetrachlorophenolic compounds. The change in C stage bleaching conditions showed that:

- an increase in C stage pH from 1.5 to 4, resulted in the decrease of the quantities of total chlorophenolic compounds formed in C, E, H stage effluents and combined CEH effluent, with 20% reduction in effluent colour and COD and a drop in pulp viscosity. But it was observed that an increase in C stage temperature (15^0C - 35^0C) and consistency (2.5% - 4%) increased the formation of total chlorophenolic compounds generated in C, E, H stage effluents and combined CEH effluent.
- the formation of total chlorophenolic compounds decrease appreciably with increased substitution of chlorine by chlorine dioxide in C stage, about 80% reduction of chlorophenolic compounds at

75% substitution level. There is a substantial reduction in effluent COD (40%) and colour (80%) in C, E, H stage effluents and combined CEH effluent indicating drastic drop in pollution load. The pulp viscosity and brightness improved substantially.

- by distributing the bleaching chemical between C and H stages, it was observed that chlorophenolic compounds in C, E, H stage effluents and combined CEH effluent increase with increase in proportion of chlorine in C stage from 40% to 80%. It was also observed that the quantity of chlorinated phenolic compounds formed in H stage effluent decrease with decrease in proportion of hypochlorite from 60% to 20%.
- the results show that splitting of chlorine dose gives 48% lower formation of chlorinated phenolic compounds in C, E, H stage effluents and combined CEH effluent. The effluent COD and colour is reduced by 13%. The pulp brightness and viscosity are improved indicating that splitting of chlorine dose reduces the pollution load by 13% and gives a stronger and brighter pulp.
- the complete replacement of hypochlorite by chlorine dioxide will change the bleaching sequence from CEH to CED. The bleaching results and environmental loads from C and E stage effluents remain unchanged. The contribution of H stage effluent to the bleaching sequence in terms of chlorinated phenolic compounds, effluent COD and colour is small, but the biggest gain is in terms of pulp viscosity and brightness.
- the introduction of oxygen pre-bleaching stage reduces the formation of mono, di, tri, tetra phenols, guaiacols, catechols and other chlorinated compounds by 75% in C, E, H stage effluents and combined CEH effluent. The effluent COD and colour reduce by 30% and 44% respectively. It was observed that there was slight improvement of brightness by 0.6% and drop in viscosity by 2%.

Hence there exists a possibility of reducing the generation of chlorophenolics by altering the C stage conditions.

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INTRODUCTION

1.1 PRESENT SCENARIO OF PAPER INDUSTRY IN INDIA

The Paper Industry is one of the oldest chemical industries and has travelled a long way in the last two decades. Based on the raw material usage, the Indian Pulp and Paper Industry can be classified into three categories viz. wood based, agro-based and waste paper based. Of the total mills, 36% use wood, 35% use recycled fibres and remaining 29% rely on agricultural residues as raw materials. The dependence on agricultural residues and secondary fibres has increased significantly in the last 15 years primarily due to shortage of forest based raw materials.(1)

There are more than 500 paper mills in India as on today with an installed capacity of around 6.2 million tones of paper per annum of which 1.1 million capacity is said to be idle.(2) Therefore, the average capacity utilization is only 82%. The present level of paper consumption in India is 4.8 million tones annually.(3) The Indian paper industry employs more than 0.3 million people directly and about 1 million people indirectly. The projected demand trend shows that India will need around 8.5 million tones of paper, board and newsprint per annum by 2010 and 10 million tones per year by 2015.(1)

Pulp and Paper industry is amongst the top 20 highly polluting industries in India. The Paper industry is confronted with environmental issues which differ from one segment to another. The problem is most acute with regard to liquid effluent as the requirement of water is very high. A rough estimate shows that a large Kraft paper mill where chemical recovery forms an integral part, the water requirement varies from 175 - 200 m^3 /ton of paper, where as in a small paper mill based on agricultural residue with no chemical recovery, water requirement is 200 - 300 m^3 /ton of paper.(1) As such, these small paper mills are discharging liquid effluent to the receiving streams causing a high pollution load. Some of the key problems that the Indian paper mills confront with are AOX and color in discharge effluents, disposal of lime sludge and also toxic gases and odour during pulping stage. Due to these reasons pulp and paper industry in its present form is considered to be a major polluting industry. However, to control water pollution, presently the Indian pulp and paper mills have set up effluent treatment plants.

1.2 CHARACTERISTICS OF BLEACH PLANT EFFLUENT

The fibrous raw materials essentially consist of cellulose, lignin and other extraneous substances. During pulping process mostly 80% of the lignin and other extraneous substances are dissolved in the cooking liquor (as black liquor). The aim of the pulping process is to remove maximum lignin selectively without affecting the cellulose. The residual lignin imparts brownish colour to the pulp, due to the presence of chromophoric compounds which are the functional groups of degraded and altered lignin bound to the fibres. This must be removed or converted in the bleaching process to be followed to obtain a pulp of high brightness which can be further used in the manufacture of high grade white paper. This is done by multi-stage bleaching process using oxidizing chemicals such as Chlorine, Chlorine dioxide, Hypochlorite, Hydrogen peroxide, Ozone and Oxygen. In India, due to economical reasons, the conventional CEH or CEHH bleaching sequences are commonly used to bleach the pulp to the desired brightness level.

The bleaching of pulp with chlorine or chlorine based chemicals generate various chlororganics which include chlorinated resin and fatty acids, chlorinated phenolics, dioxins and furans which are found to have high toxic effects on the receiving environment. Hence bleach plants are a major source of environmental pollution and the effluents released from the bleach plant have high BOD, COD, AOX and colour loads. The AOX, EOX and POX are used normally to indicate the level of the organochlorine compounds formed in the bleaching process in the environmental samples. Regulation to limit the discharge of AOX has been established in many countries,(4) while some countries are still debating on it.(5) In India, the maximum discharge limit for TOCl in mill effluent has been specified to be 2 kg/T.(46)

The nature and extent of formation of chlorophenolic compounds is determined primarily by the residual lignin content in the pulp and type of bleaching chemical employed. There have been attempts to minimize the generation of organochlorine compound during pulp bleaching by substituting Chlorine gas by Chlorine dioxide or by eliminating the use of Chlorine containing compounds.(6,7) In response to environmental concerns, Governmental regulations on emission of chlorinated organic matter, pulp and paper mills are forced to develop and introduce a number of new processes and process modifications in order to minimize the discharge of chlorinated phenolics.

1.3 TOXICITY OF BLEACH PLANT EFFLUENT

Since last few decades, the toxicity in effluents of pulp and paper mills have attracted increased attention and intensive researches have been going on to identify and study the toxicity of various chemicals coming from different sections of pulp and paper mills. Toxicity is a vague and variable parameter. The toxicity of the whole mill effluent of a given mill will directly depend upon the total organically bound chlorine, the extractive content of the raw material being used and to what extent these extractives are removed during pulping and other processes.(40) A small increase in the concentration of chlorinated phenolic compounds will change the lethal effect from zero to 100%. Chlorinated phenolic compounds are the most toxic substance in the bleached plant effluent and the toxicity level of the effluent will depend on the lignin content of the pulp which invariably is the result of the increase in the kappa number of unbleached pulp.(13) Quantification of toxicity in effluent is difficult as the results are strongly influenced by the intricacies in the test methods. Lethal Concentration (LC) is usually expressed as $^{96}LC_{50}$ which indicates the level of effluent toxicity. The sub-lethal effects of bleach plant effluents are probably of more importance for the environment than the lethal effects, because they show the long term effects from the accumulation of toxic substances in the organisms.(17)

Among the chlorinating agents used for the bleaching process, molecular chlorine is the most reactive. It undergoes a complex and series of reactions involving chlorination, oxidation and de-methylation which result in the formation of a wide range of structurally diverse organic compounds. Some of them are considered to be harmful to the environment due to the following reasons:

1. Highly resistant to biotic and abiotic degradation.
2. Toxic to biota.
3. Bio-accumulation at higher level.(8-16)

The effluents from chlorination and first alkaline extraction stages are the main contributors to the toxicity of bleached plant effluent.(18,19) The compounds responsible for the toxicity of C stage effluent are mainly chlorophenols, which contributes 80% of the toxicity at a charge equivalent to 50% of chlorine demand.(14) About 90% of the toxicity of E stage effluent is due to 3,4,5–trichloroguaiacol, tetrachloroguaiacol and several fatty acids (e.g. mono and dichlorohydroabietic acid and epoxystearic acid).(20,21) The chlorinated phenols are generally biologically degradable. The bio-degradation rate decreases as the level of chlorine substitution (i.e. the number of chlorine atoms which have been added to the basic phenolic structure) increases.(20)

One of the key impacts of the discharge of bleached plant effluent to the sorrounding eco-system is that the toxic compounds such as poly-chlorinated dibenzodioxin (PCDD) and dibenzofuran (PCDF) persistently bio-accumulate in higher level organisms such as crabs, clams, mussels and fish. Among the congeners, 2,3,7,8–tetrachlorodibenzo-p-dioxin (TCDD) is the most toxic. Chlorinated dioxins and furans are two particular forms of chlorinated compounds which warrant special mention, based on the focus of public discussions. Research has indicated that the major part of dioxin/furan formation occurs in the first chlorination stage (C) and is then carried through successive bleaching stages.(20,22-26) .

The chlorinated organic compounds are found to be carcinogenic, mutagenic and causing acute and chronic toxicity to aquatic life. They also persist in the environment and pose the threat of bio-accumulation.(27-36) 2,4-dichlorophenol, 2,4,5-trichlorophenol, pentachlorophenol, chlorinated dioxin, dibenzofurans and chloroforms are carcinogenic, where as chlorocatechols are strongly mutagenic.(37)

A large number of organic compounds present in pulp and paper mill waste waters are acutely toxic to fish. Low molecular weight chlorinated organic compounds, such as resin acids, fatty acids, neutral diterpenes, phenols and their chlorinated analogues are major contributors to the poisoning of fish. The toxicity of compounds in pulp and paper mill effluents is related to bio-accumulation.(38) Chlorinated phenolics and other chlorinated compounds in bleaching waste waters accumulate in fish tissues, particularly in liver.(36) Recent studies have even shown that reproduction of fish is affected at concentrations of the pulp mill effluents. The analysis of samples of stationary fish species showed that they contained small amounts of chlorinated phenols and guaiacols in their extractable fats.(39) Similarly mill effluents were found to have an inhibitory effect on growth of plants and animals. Inhibition of photosynthesis may be caused due to increased light absorption and/or also by altered pH or toxic properties of the effluent. It has been found that physical parameters such as pH, temperature etc., in the aquatic environment may strongly influence the toxicity of pollutants.(17)

In view of the above, it is pertinent to identify these organically bound chlorine compounds to minimize their effects on the environment.

1.4 ORIGIN AND IDENTIFICATION OF CHLORORGANICS

Chlorinated phenolic compounds such as chlorophenols, guaiacols and catechols are produced as degradation products of lignin during pulp bleaching using chlorination procedures. Native lignin is a polymer comprised of p-coumaryl, coniferyl and sinapyl alcohols. Softwood lignin is guaiacyl lignin derived mainly from coniferyl alcohol while hard wood lignin is guaiacyl – syringyl lignin formed by co-polymerisation of coniferyl and sinapyl alcohols. 1 – 5 % of p-coumaryl alcohol also participates in the formation of both softwood and hardwood lignins. Grass lignins appear to be like hardwood lignins but some grass lignins are thought to contain p-coumaryl units as well.(41)

The chlorination and first alkaline extraction stages together are generally considered as a continuation of the delignification process where as the later bleaching stages mainly serve to bleach the pulp. Reactions of chlorine with lignin involve oxidation, substitution and addition. The last two reaction types i.e.

substitution and addition leads to the formation of chlorinated organics. These reactions are important from the chloro-bleaching point of view, since they are responsible for the breakdown of lignin macro molecule to small fragments to be soluble in acidic C stage filtrate or serve to modify the lignin that it becomes soluble in the ensuing alkaline extraction stage.(42)

Although the contents of chlorophenolics in spent bleaching liquors mainly depend on the Kappa number of unbleached pulps, yet the characteristics of fibre morphology and texture and the characteristics of lignin structure also strongly influence the formation of chlorinated phenolics during pulp bleaching. In addition to this, the chlorination conditions such as pH, temperature, chlorine dosage and use of chlorine dioxide have significant effect on the structures and quantity of chlorinated phenolic compounds generated in spent bleach liquor.(15,41)

About 80% of organically bound chlorine that is formed during the bleaching of pulp is associated with high molecular weight lignin material (MW>1000D).(12,43-45) The main environmental concern is the generation of low molecular weight chlorolignins which have the capacity to penetrate the cell membranes and are potentially toxic.(45,46)

New developments in the field of analytical chemistry, applying computer assisted Gas Chromatography – Mass Spectrometry (GC-MS) and capillary columns of Gas Chromatography have led to successful identification and estimation of the presence of chlororganics in the bleach effluent. Lindstrom and Nordin were the first to categorise chlororganics present in spent bleach liquor.(47) The maximum studies conducted after Lindstrom and Nordin further confirmed and extended their findings.(14-16)

1.5 ABATEMENT OF BLEACH PLANT POLLUTION

The aim of all pollution control efforts is to leave the natural environment unaltered. The presence of high amount of toxic chlorinated organic compounds in the bleach plant effluent has become a great environmental concern. All the pollution reduction strategies of the bleach plant effluent are based on developing and introducing a number of new processes and process modification in order to minimize the discharge of chlorinated organic compounds. An effective abatement of bleach plant effluent can be achieved in two ways, as explained hereunder:

1. Internal measures
2. External measures

1.5.1 Internal Measures

The main strategy behind the development of internal process changes has been to remove as much lignin as possible before the pulp enters the bleach plant and also to replace elemental chlorine in bleaching process by other bleaching agents. To achieve this, the following measures should be considered to be taken:

1.5.1.1 Control of contaminations, spills and leakages

- The quality of the chips should be improved to prevent dirt and shives from entering the bleach plant.
- Pentachlorophenol which is used as wood preservative should be prohibited as chlorinated dioxins which are known to be highly toxic are formed as byproducts in the production of pentachlorophenols.(48-50)
- Care should be taken to avoid spillage and leakage of fibre and liquor to minimize loading on the external effluent treatment facilities.
- Oil based defoamers, improved deknotting and screening result in reduced environmental load in bleach plant effluent.(51,52)

1.5.1.2 Extended delignification prior to bleaching

Extended delignification can be obtained by introducing modified cooking like Modified Continuous Cooking (MCC),(18,53) Extended Modified Continuous Cooking (EMCC),(18,54) Cold Blow Cooking,(18) Rapid Displacement Heating (RDH)(18,55) systems and Oxygen Delignification(18,56,57,75) to reduce kappa number of pulp before bleaching. The combination of oxygen and extended delignification result in reduction in Total Organo Chlorine (TOCl) formation.(18) Anthraquinone (AQ) or Poly sulphide (PS) or both are used as additives in pulping processes to give low kappa pulps.(58)

1.5.1.3 Improved Pulp Washing

Better washing of the pulp after cooking minimizes the carryover of organic matter with the pulp to bleach plant, thus decreasing the amount of chlorine and chlorine based bleaching chemicals due to which the concentration of chlorinated organics generated in the bleach plant effluents is reduced.(59,60)

1.5.1.4 Improved Chemical Mixing

Proper mixing of chemicals in bleach plant helps a rapid and uniform distribution of chemicals through the pulp, thus giving a uniform bleaching with decreased formation of Tetrachlorinated phenolic compounds(46,63) and dioxins.(24)

1.5.1.5 Modification of Lignin Before Bleaching

The acid pretreatment(61) and enzymatic pretreatment(62) of pulp modify the lignin structure, thus reducing the chemical consumption in the Bleach Plant, consequently generating less amount of chlororganics without affecting the pulp properties.

1.5.1.6 Modification of Bleaching Process and Use of Newer Bleaching Chemicals

1.5.1.6.1 Effect of Chlorination Conditions

The total chlororganics generation can be reduced by lowering the chlorination temperature, by raising end pH of C stage(64) and by splitting the chlorine dosage into two or three portions.(24) By splitting the chlorine dosage in C stage, the rate of chlorination reaction slows down due to lower chlorine concentration; hence the reduction in the formation of chlororganics. By carrying out the bleaching processes at medium or high consistency, the effluent load generated can be reduced. (63)

1.5.1.6.2 High or Total Substitution of First Chlorination Stage with Chlorine dioxide

High substitution of Chlorine dioxide in chlorination stage lowers the formation of chlorinated organics. The presence of Chlorine dioxide in chlorination stage improves strength and colour stability of the pulp and also reduces chlororganics formation and colour of the effluent. Concentration of chlorinated phenolic compounds and dioxins in the filtrates of first two bleaching stages (CE) decreases in proportion to the increase in the level of substitution of Chlorine by Chlorine dioxide to the extent of 100%.(38,65-70) It was reported that about 50% reduction in chlororganics including AOX and monomeric chlorinated phenols was achieved by dropwise addition of a mixture of Chlorine and Chlorine dioxide in the ratio of 50: 50 as compared to the conventional addition of a single charge.(71) In order to minimize the formation of chlorinated organic material, 100% substitution by Chlorine dioxide was done on the Oxygen delignified pulp.(72) The formation of organically bound chlorine during the bleaching of chemical pulp with Chlorine dioxide can be reduced by equimolar replacement of a part of the Chlorine dioxide by Chlorite.(73)

1.5.1.6.3 Oxidative extraction

Oxidants such as Oxygen, Hydrogen peroxide etc., are added to the first caustic extraction stage for improving the quality of bleach plant effluent. Oxygen can be combined with Hydrogen peroxide for additional fortification. Modified extraction stages are designated as (E_O), (E_P) and (E_{OP}).(74) Oxidative extraction enhances delignification, thus minimising use of chlorine consumption in the next bleaching stage and ultimately reduces the colour and toxicity of the effluent.

1.5.1.6.4 Chlorine Free Bleaching

Oxygen, Peroxide and Ozone are few of the Chlorine-free bleaching agents.(75) As Ozone is a powerful oxidant, the bleaching conditions must be carefully controlled to prevent pulp degradation.(76,77) Oxygen bleaching seems to be very efficient for the removal of chlorinated phenolics. Inclusion of an Oxygen stage in a bleaching sequence reduces concentration of chlorides in the total bleachery effluent.(78) The

BOD, COD and colour of the effluent in which Oxygen is used as a bleaching agent are found to be considerably lower than those effluents generated from conventional bleaching.(79-80) Therefore, Oxygen bleaching is well accepted commercially.

1.5.2 External Measures

The waste water contains relatively large amounts of suspended solids and substances which raise the level of oxygen consumed for biological or chemical oxidation. The mills usually employ a combination of the following methods to control water pollution:

a) Pre-treatment

Pre-treatment wherein coarse solids are removed by screening. Excessive acids or alkaline content can also be neutralized at this stage.

b) Primary Treatment:

Primary treatment comprises of removal of suspended solids by sedimentation using settling ponds or clarifiers.

c) Secondary Treatment:

Secondary treatment is the purification process in which the dissolved organic matter in the waste water is reduced by biological treatment carried out under contained and controlled conditions usually at accelerated rates.

For achieving this, following methods of treatment are applied in the mills:

1) Oxidation lagoon
2) Aerated stabilization basin (ASB)
3) Activated sludge process (ASP)
4) Anaerobic process
5) Biological filter process, such as Trickling filter, Rotatory Disc etc.,

Aerated lagoons have a mechanical aeration device to increase the supply of oxygen. Anaerobic lagoons have methane bacteria to carry out the reduction. Anaerobic biological treatment has shown promise as one option for the dechlorination of organochlorine compounds found in bleached Kraft mill effluent.(81,82) The activated sludge process utilizes microorganisms for treatment of organic matter. It has been reported that in the activated sludge process, maximum AOX reduction was occurred due to microbial metabolism.(83) Microbial waste treatment system helps in detoxification of mill discharges.(84) The reductions in AOX and in chlorinated phenolic compounds were found to be lower in the aerated lagoon treatment than in the activated sludge treatment.(85)

The secondary treatment methods are not capable of reducing colour and toxicity.

d) Tertiary treatment:

The tertiary treatment techniques (Physio-chemical treatments) have been developed to control the discharge of deleterious substances from chemical pulp bleach plants which are slow to bio-degradation and are usually little affected by conventional secondary treatment methods.

The major tertiary treatment includes:(85,86)

- Adsorption and ion exchange methods
- Flocculation and chemical precipitation methods
- Membrane methods

The tertiary treatment is mainly applied for removal of effluent colour, COD and Toxicity.

e) Other Techniques:

A few micro-organisms are capable of degrading lignin in aqueous medium. Pure and mixed algal culture of algal species like Microcystis aeroginosa and Anabaena flos-aqua reduced colour of dilute bleach kraft mill effluent.(88) Tranetes versicolor and Phanerochaete chrysosporiun are some of the fungi used for the treatment of effluent from pulp mills. These have been reported to degrade a variety of chlorinated toxics.(89) Actinomycetes such as Streptomyces, Nocardia and Actinomyces are known to exhibit chlororganic degradation.(90)

Treatment with SO_2 or $Na_2 SO_3$ reduces or eliminates the acute toxicity and mutagenic activity of bleaching effluents.(91) Ozone treatment in combination with ultra filtration reduces colour as well as biological active chlorinated compounds such as chlorinated phenols and guiacols.

Traditionally Indian Paper mills use the End of Pipe Treatment Plant (ETP) to reduce the pollution. Generally it is a combination of primary and secondary treatment plants and aims at reducing or eliminating the entire pollution from a plant at the end of the waste water pipe or the smoke stack. This kind of ETP reduces the release of suspended solids and BOD significantly, with a small reduction of COD, AOX and colour loads. Though the tertiary treatment techniques are quite efficient for removal of AOX and colour loads, yet being expensive it is not viable for Indian Paper Mills under the present operating conditions.

Considering all the above aspects, it can be safely concluded that to minimize formation and discharge of toxic substances, the best way is to adopt in-plant controls and process modifications. Though the in-plant technologies are generally more efficient than external methods, the latter may still be necessary as a supplement to in-plant methods to further reduce and minimise the pollution load to meet the environmental Regulations.

1.6 BACKGROUND OF PROBLEM

Bleach Plant effluent has been found to be highly polluted. It consists of both easily and slowly biodegradable compounds. Around 65% of the total BOD and 90% of the total colour discharged from the pulp and paper mills are from the Bleaching Section. The chlorination and first extraction stage often account for the largest amount of chlorinated organic compounds.(18,19) These chlorinated organic compounds exhibit mild acute toxicity, some are persistent, some bio-accumulate and some cause sub-lethal effect.(9-16) The coloured compounds in bleach plant reduce light penetration into water and therefore, affect photosynthetic activity of the aquatic eco-systems.

The large integrated pulp and paper mills in India are using forest based materials for paper making where as small and medium sized mills are dependent on non-wood or agro residue raw materials for their pulp manufacturing. But in all these sectors, still conventional pulping and bleaching technologies are employed, as modern technologies developed in the West are prohibitively expensive for Indian Mills, particularly because the production technologies applied in these mills are many times old and poorly maintained. Moreover, these modern technologies may not be suitable for the raw materials available or incompatible with existing production set up.(92)

The bleaching process used by Indian Paper mills is chlorination, followed by alkali extraction and calcium hypochlorite. The bleaching sequences include CEH, CEHH, CE_PHH and CE_OHH. The oxygen delignification as a pre-bleaching stage is being attempted by some mills. Use of Chlorine dioxide, Hydrogen peroxide and Oxygen reinforced alkali extraction is limited to a very few large mills which are producing rayon grade pulp and high brightness quality pulp. An estimate indicates that approximately 2.5 million tones of chemical pulp are produced in India. 60% of this is high brightness bleach pulp, mostly bleached by chlorine and chlorine based chemicals.(46)

Many of the Indian Paper Mills are now producing paper of brightness above 80% ISO to compete with international brands, as a result of globalization. This high level brightness is achieved at the cost of increased chlorine consumption resulting in high level of AOX generation.

During the research for identification of pollutants in bleach plant effluents, it has been observed that chlorinated phenolics are toxic to aquatic organisms and hence the chemical and biological characterization of these effluents has been extensively studied. It has been found that toxicity of most of the first chlorination effluents are due to tri and tetrachlorocatechols, 2,6-dichlorohydroquinone and a group of polychlorodihydroxybenzenes and the caustic extraction effluents have a toxicity which may be described to tri and tetrachloroguaiacol and mono and dichloro dehydroabietic acid.(13)

Traditionally the bleaching is performed using elemental chlorine which is most effective delignifying agent and least expensive of all the bleaching chemicals.

Moreover, due to the existing infrastructure of mills and very high cost in altering the infrastructure for other bleaching stages(93,94) Chlorination as the first bleaching step will continue for some years to come. Despite this, due to environmental factors, Chlorine is gradually being replaced by several other chemicals such as Chlorine dioxide, Hydrogen peroxide, Oxygen and Ozone. Now-a-days, Hydrogen peroxide or Oxygen is used at alkali extraction stage and is being practiced by many of the large mills in the country.

Very little data are available on agricultural residue pulps which are important in Indian context due to decreasing wood resources. Therefore, there is need to study the generation of various pollutants formed during bleaching of non-wood pulps in Indian mills.

Generally in India, paper industries are using clarification method for reducing suspended solids and biodegradation method which effectively remove BOD. The need for AOX and colour reduction is almost overlooked in most cases. The various biological treatment methods currently in operation are stabilization pond, aerated lagoon, activated sludge process etc., so the effluent discharged is highly coloured and expected to contain large amounts of pollutants contributing to high COD and AOX.

Therefore, it is imperative to develop suitable methods to reduce colour, COD and toxic chlororganics from bleach plant effluent which may be simpler, cost effective and readily adaptable by pulp and paper mills in India.

1.7 OBJECTIVE OF EXPERIMENTAL RESEARCH

The experimental investigations have primarily been undertaken in the current study to identify and estimate different chlororganic compounds generated during C, E and H stage bleaching from wheat straw and sarkanda soda pulps.

The main objective of the work is to aim for environmental friendly bleaching to reduce generation of chlororganics from bleach plants. To achieve the above, the two agro residue pulps – wheat straw and sarkanda soda pulps were chosen. The work planned is as under:

I. To identify and quantify various chlorophenols formed during different stages of pulp bleaching.

II. To study the impact of change in chlorination condition on the production of toxic chlorinated phenolics, in C, E and H stages.

III. To study the integration of Oxygen deliginification stage with conventional CEH bleaching sequence and its impact on the generation of chlorophenolics.

IV. To study the impact of partial or complete replacement of chlorine by chlorine dioxide on the generation of chlorophenolic compounds.

V. To study the effect of change in chlorination conditions on :

   - Pulp characteristics
   - Pollution load generation

The experimental results of this research study are expected to form a basis for establishing suitable process sequences, optimizing operational parameters and integrating them with existing mill configurations. All these are expected to provide significant benefits in terms of improved product quality and better environmental management.

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CHAPTER 2

MATERIALS AND METHODS

2.1 CHEMICALS

- GC Standards

  Various isomers of Chlorophenols (Aldrich, USA), chloroguaiacols, chlorocatechols, chlorovanillins, chlorosyringaldehydes, chlorosyringols (all from Helix, Canada) were used as reference compounds.

- Solvents

  n-hexane, acetone of HPLC grade and di-ethylether of LR grade.

- Analytical grade acetic anhydride was used after redistillation.
- Other Reagents used were of Laboratory grade.

2.2 TEST METHODS

- TAPPI (T-236) was used to determine the Kappa number of pulp.
- SCAN-C15:62, was used to determine Viscosity (CED) of pulp.
- Brightness of pulp (ISO Standard 2469) was measured on TECHNIBRITE ERIC 950 from Technibrite Corpn. U.S.A.
- COD of bleach effluent was estimated by Standard Method (Open Reflux Method).

2.3 TEST PROCEDURES

2.3.1 Analysis of Bleach liquor

In 10 ml of diluted bleach liquor, 10 ml of 10% Potassium iodide and 10 ml of 10% Acetic acid were added. This solution was titrated with standard 0.1N Sodium thiosulphate solution with 0.5% starch as indicator. The end point was determined when the colour of the solution changed from blue to colourless.(1)

The gpl active Chlorine was calculated = Normality of Bleach liquor * 35.5.

2.3.2 Disintegration of Pulps

The air-dried pulp, which was soaked in water overnight, was disintegrated in a laboratory Disintegrator for 2 minutes to break the fibre clots and bundles before bleaching and oxygen delignification. Then the water was drained through a screen and the pulp suspension was kept in a refrigerator in plastic bags for around 7 days, which was used for further bleaching experiments.

2.3.3 Preparation of sheets for kappa number determination

The consistency of the disintegrated pulp was adjusted to 1%.The pulp suspension was then transferred to a Buchner funnel. Water was drained through a filter of 22 mesh and the sheet thus prepared had oven-dry weight of about 5 gm. This wet sheet was pressed between two blotting papers and air-dried, which was then cut into test pieces. It was ensured that these sheets were guarded from contamination. The kappa number of these test samples was then determined.

2.3.4 Preparation of sheets for measurement of brightness

The disintegrated pulp of 1% consistency was transferred to a Buchner funnel. Water was drained through a filter of 22 mesh. The sheet thus prepared was pressed between two blotting papers and air-dried. The sheet was protected against dirt. The brightness was measured within 4 to 5 hours after drying.

2.3.5 Oxygen delignification procedure

The disintegrated wet pulp was mixed with 20 gpl Sodium hydroxide (NaOH) at various doses and Magnesium sulphate @ 0.2 gm per 100 gm OD pulp. The pulp consistency was brought to around 10%. These pulps were transferred to autoclaves fitted on stands, which had the capacity to hold about 100 gm of wet pulp. After expelling air, autoclaves were filled with Oxygen to a pressure of 6 kg/cm^2. These leak-proof autoclaves were then immersed into a pre-heated (to the level of required temperature) glycol bath for a period of 75 minutes.(1) Thereafter, the autoclaves were taken out from the oil bath and washed on a screen. The pulp was then squeezed to drain extra water and stored in polythene bags for further bleaching experiments.

The oxygen and non-oxygen treated pulps were then characterized for kappa number, viscosity and brightness, as shown in Table: 2.001.

2.3.6 Bleaching of pulps

The purpose of the bleaching operation is to impart the desired final physical and chemical properties to the pulp, the most obvious being the whiteness or brightness. This is done by removal of some constituents of the unbleached pulp and by modification of the remaining ones. In principle, it consists of chlorination for the degradation of the lignin followed by an alkali stage for the neutralization and dissolution of the degraded product and finished by an oxidative stage with intermediate alkaline extractions. After the oxidation, the final discolouration is removed and full high brightness is obtained.

2.3.6.1 Chlorination (C) stage bleaching

The wet disintegrated pulp equivalent to 40 gm OD was dispersed and taken in a plastic bottle and diluted with desired quantity of water to get a final 3% consistency. The pH of the pulp suspension was reduced to 2 by adding required quantity of HCl, where after requisite amount of bleach liquor was poured into the bottle containing the pulp suspension. The bottle was shaken well and chlorination was performed at room temperature for 45 minutes. The pulp was then washed on a Buchner funnel using water in fractions of 100 ml each and the effluent was collected for identification and estimation of chlororganics by GC and for evaluation of effluent quality.

a) Split dose of bleach liquor in C stage

The process of Chlorination (C) stage bleaching was modified by splitting the dose of bleach liquor. Half of the required amount of bleach liquor was added to the pulp suspension and bleaching under chlorination conditions was continued for 15 minutes, where after the remaining quantity of bleach liquor was added to the pulp suspension and bleaching was continued for another 45 minutes.

b) Partial substitution by chlorine dioxide in C stage

The Chlorination (C) stage bleaching was repeated by partially substituting chlorine by chlorine dioxide as active chlorine. Partial substitution was varied from 10 – 75% while all other test conditions were allowed to remain the same. In this process, chlorine dioxide was added first, shaken and immediately followed by chlorine and shaken again. The other conditions such as pH, temperature and consistency followed in this experiment were as per chlorination (C) stage bleaching.

2.3.6.2 Alkali extraction

The pulp suspension was mixed with required quantity of Alkali (NaOH) and water to get 11% consistency. The pH of this suspension was between 10 – 11. The pulp suspension was then transferred to a polythene bag. The pulp was repeatedly kneaded to uniformly distribute alkali into pulp suspension. The polythene bag was then vertically suspended in a water bath maintained at 70^0 C for 60 minutes. After every 10 – 15 minutes polythene bag was removed, the pulp was kneaded and again placed in the water bath. With this, the alkali extraction was complete. Then the pulp was washed with water in fractions of 100 ml each and the effluent was collected for further analysis.

2.3.6.3 Hypochlorite (H) stage bleaching

The washed pulp after alkali extraction was then mixed with requisite amount of bleach liquor and water to adjust the pulp consistency to 10%. The initial pH was adjusted between 10 – 11. The contents were transferred to a plastic bag and it was placed in a water bath for 3 hrs. which was pre-heated to 40^0 C. After each half hour, the pH of the pulp was checked and adjusted to pH 10 so as to give a final end pH of around 9.5. The bag was removed, the pulp was washed with water in fractions of 100 ml each and the effluent was collected for further analysis.

2.3.6.4 Chlorine dioxide (D) stage bleaching

The disintegrated pulp was mixed in a plastic bag with requisite amount of bleach liquor and water so as to ensure the pulp consistency at 10%. The pH was adjusted to 5. The pulp bag was kept in water bath which was pre-heated at 70^0 C and kneaded frequently. The bleaching was performed for 3 hours. The end pH was estimated to be around 4. The pulp was then washed and the effluent was collected for further analysis.

The non-oxygen wheat straw and sarkanda pulps were bleached to 80% brightness using different sequences like CEH and CED, where as the oxygen deliginified wheat straw and sarkanda pulps were bleached to 80% brightness using conventional CEH bleaching sequence.

The bleaching conditions used are summarized in Table 2.002 and 2.003.

2.3.7 Characterization of bleaching effluents

The bleach effluents generated during each stage of bleaching were collected and analysed for COD and colour.

2.3.7.1 Colour measurement

To prepare a standard solution of 2500 Pt-Co coloured units, 250 mg of platinum wire (purity 99.99%) was dissolved in hot aqua-regia. This solution was heated to dryness to extricate nitric acid (as oxides of nitrogen) by repeated evaporation and addition of fresh quantity of conc. HCl. The residue was dissolved in distilled water and thereafter, 500 mg of $CoCl_2.6H_2O$ (equivalent to 125 mg Co) was added along with 5 ml of concentrated HCl. The total volume of the solution was made upto 100 ml with distilled water to yield a standard solution of 2500 Pt-Co colour units. (2,3,4)

Standard solutions of 50, 250, 350, 500, 1000, 1500, 2000 Pt-Co units were prepared by diluting 0.5, 2.5, 3.5, 5, 10, 15 and 20 ml of standard stock solution to 25 ml in a volumetric flask.

Absorbance of different standard solutions was determined at 465 nm on Schimadzu Spectrophotometer Model UV 2100/s and calibration curve was plotted as shown in Fig 2.001. This curve was used to determine the colour of the effluent. The pH of effluent was adjusted to 7.6 and then the suspended particles were removed by centrifuging the effluent for 5 minutes at 1500 RPM. The absorbance of the solution was then determined at 465 nm and colour of the effluent was calculated from the calibration curve. (Fig 2.001)

2.3.8 Analysis of various chlorophenolics

Modern analytical methods such as, High Performance Liquid Chromatography, Thin Layer Chromatography and Gas Chromatography alone or in combination with Mass Spectrometry have been used for determining chlorophenolic compounds in the pulp and paper mill effluents. Of these methods, GC or GC-MS are the more commonly used techniques. In GC, the selective detection of the chlorophenols has been done using Flame Ionization Detector (FID) and Electron Capture Detector (ECD).

In principle, solvent extraction should provide a simpler and faster method of isolation for waste water sample. Mainly two extraction procedures are in use today for chlorophenolic analysis in pulp and paper mill effluent. One proposed by BCRC (British Columbia Research Canada) and another by Lindstrom et al. For present study, extraction of various chlorophenolic compounds has been done, as per procedure suggested by Lindstrom et al, by diethyl ether.

The chlorophenols are converted into derivatives to make them readily volatile prior to GC analysis. Different procedures for derivatising phenols directly in the water sample have been suggested including extractive alkylation with pentafluorobenzyl bromide and acylation with tri-chloroacetic anhydride, heptafluorobutyl anhydride or acetic anhydride. For the present study, acetylation was done with acetic anhydride based on procedure suggested by Abrahamsson and Xie.(5-7)

2.3.8.1 GC conditions

Shimadzu Gas Chromatograph Model GC-9A was used to analyze various chlorophenolics like chlorophenols, chloroguaiacols, chlorocatechols, chlorovanillins, chlorosyringols and chlorosyringaldehydes as acetyl derivatives.

The GC parameters were determined for analyzing the standards of pure chlorophenolics by using the Ulbon HR-1 Glass Capillary Column (30 m x 0.32 mm ID). The injection was splitless for two minutes.

2.3.8.2 Derivatization Procedure

4.5 ml of the sample of standard chlorophenolics were taken in a PTFE lined screw capped glass tube and 0.5 ml of buffer solution of 0.5 M Na_2HP0_4 was added. 1ml of n-hexane and 0.05ml of acetic anhydride were added to derivatize and extract the chlorophenolics. The mixture was shaken for 3 minutes and $1\mu l$ of the acetyl derivative was taken from the hexane layer through a syringe and it was injected into the capillary column for GC analysis.(5)

2.3.8.3 Retention Time Determination

Standard solutions of various chlorophenolic compounds (20 to 30 mg/l) were prepared in 10% acetone water. 1ml of this solution was diluted to 4.5 ml and derivatized and extracted as explained under 2.3.8.2 Derivatization Procedure. $1\mu l$ of the derivative was injected into the capillary column and the retention time was recorded.

2.3.8.4 Separation of chlorophenols from the effluent

The procedure suggested by Lindstrom K et al was followed to achieve the separation of chlorophenolics from the effluents. A schematic presentation of the method followed is depicted in the ensuing Flow Chart.(2.001). 2 litres of C-stage, 1 litre of E-stage and 1 litre of H-stage effluent were taken. The pH of these effluents was adjusted to 2 with 2M H_2SO_4 solution. Then each of the effluent was transferred into a separating funnel and extracted with 400 ml of 90% ethyl ether and 10% acetone mixture per litre of effluent for 48 hours. The emulsion formed in ether layer was broken by using a heatgun. Then the whole etheral extract of the effluents was transferred into another separating funnel and shaken with 5ml of 0.5M $NaHCO_3$ solution to remove acidic impurities. Thereafter, the ether layer in each was shaken with 5 ml of 0.5M NaOH to extract the chlorophenolics.

Aqueous NaOH layer, which contained chlorophenolics from bleaching effluent,was separated and washed with 10 ml of fresh diethyl ether to remove the neutrals. (6)

The extracted chlorophenolics was derivatized as under:

4 ml of the extracted sample was acetylated using 0.1 ml of acetic anhydride. The remaining derivatization process was same as per 2.3.8.2 Derivatization Procedure. $1 \mu l$ of the derivatized sample was injected into the column for identification and quantitative analysis of chlorophenolics.

2.3.8.5 Quantitative Analysis of various Pollutants

The Response Factor and Extraction Efficiency percentage of various chlorophenols were determined for quantitative analysis of the chlorophenolics.

a) Response Factor

1 ml of the standard solution of chlorophenol was derivatized as per procedure described under 2.3.8.2, out of which $1 \mu l$ of the sample was injected into the column. The area of the peak was recorded and the Response Factor (RF) was calculated as under:

$$RF= \frac{\text{Area of the peak}}{\text{Wt of the sample injected (pg)}}$$

b) Extraction Efficiency

For extraction of various standard chlorophenolics, 1 ml of standard solution of various chlorophenols was diluted to 1 litre with distilled water. The pH of the solution was adjusted to 2. The solution was then extracted with 400 ml of 90% ethyl ether and 10% acetone mixture for 48 hours and derivatized as acetyl derivative as described under 2.3.8.4 for chlorophenolics. $1 \mu l$ of the derivatized sample was injected into the column and the peak area was recorded. From the area of peak the quantity of chlorophenolics present in the extracted sample was determined. The percentage extraction efficiency was calculated as under:-

$$\% \text{ Extraction Efficiency} = \frac{\text{Quantity in the extracted sample}}{\text{Quantity in the sample before extraction}} \text{ X } 100$$

TABLE 2.001: Conditions for oxygen prebleaching and pulp characteristics of oxygen delignified pulps

Parameter		Wheat straw	Sarkanda
O_2 charge (kg/cm^2)		6	6
Consistency (%)		10	10
Time (min)		75	75
Temperature (^{0}C)		100	110
Alkali Charge (kg/t)		30	40
Magnesium sulphate (kg/t)		2	2
Kappa number	non oxygen	22.69	21.7
	oxygen delignified	13.18	12.9
Viscosity (cp)	non oxygen	28	25
	oxygen delignified	19	17
Brightness(%ISO)	non oxygen	26.3	27.2
	oxygen delignified	35.2	36.4

TABLE 2.002: Pulp bleaching conditions for wheat straw soda pulp

Parameter	Unit	C_{stage}	E_{stage}	H_{stage}
Cl_2 applied	%	5.1	-	2.06
NaOH applied	%	-	2.86	-
Consistency	%	3	11	10
pH	-	2	10-11	10-11
Temperature	^0C	30	70	40
Time	Minutes	45	60	180

Unbleached pulp kappa number 22.69

TABLE 2.003: Pulp bleaching conditions for sarkanda soda pulp

Parameter	Unit	C_{stage}	E_{stage}	H_{stage}
Cl_2 applied	%	4.5	-	2
NaOH applied	%	-	2.25	-
Consistency	%	3	11	10
pH	-	2	10-11	10-11
Temperature	^0C	30	70	40
Time	Minutes	45	60	180

Unbleached pulp kappa number 21.7

TABLE 2.004: GC Conditions for the separation of Chlorophenolics

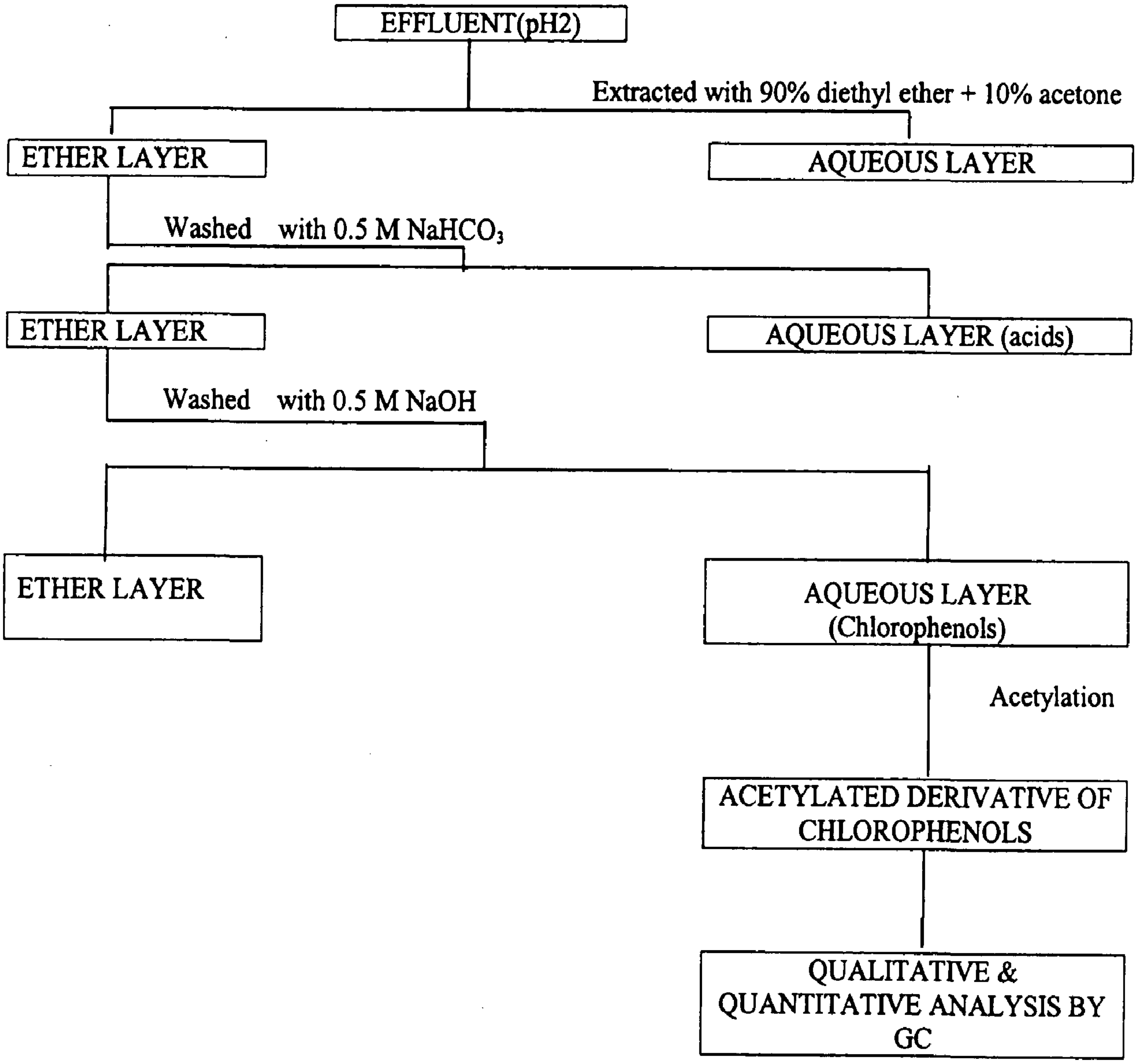
Parameters	
Detector	FID
Detector range	10^0
Carrier gas (N_2) flow rate	20 ml/min
Injection & Detector temperature	275^0 C
Column temperature	80^0 C for 3 min.
	80^0 C – 160^0 C at 2^0 C/min
	160^0 C for 5 min.
	160^0 C – 260^0 C at 10^0 C/min.
	260^0 C for 15 min.
Injection (splitless)	2 min.
Sample size	1 μl
Chart speed	2 cm/min.

TABLE 2.005: Retention time,Extraction efficiency and Response factors of various chlorophenols

Chlorophenolic	Retention Time	Extraction Efficiency	Response Factor
	min	%	Pg
2,4-Dichlorophenol	7.26	34	1.67
2,5-Dichlorophenol	7.43	73	1.48
2,3-Dichlorophenol	7.64	98	2.33
3-Chloroguaicol	8.12	59	1.96
2,6-Dichlorophenol	8.52	35	1.96
4-Chlorophenol	8.87	95	0.44
3-Chlorophenol	8.97	42	1.05
4-Chloroguaicol	11.53	93	3.50
5-Chloroguaicol	12.15	102	1.52
6-Chloroguaicol	13.44	98	0.88
2-Chlorophenol	14.29	14	2.26
2,3,5-Trichlorophenol	14.58	89	3.28
2,4,6-Trichlorophenol	15.17	31	1.73
2,4,5-Trichlorophenol	15.68	63	1.28
3,5-Dichloroguaiacol	15.70	50	2.44
2,3,4-Trichlorophenol	16.02	85	1.68
2,3,6-Trichlorophenol	16.79	72	3.40
3,6-Dichloroguaiacol	17.17	105	2.57
3,4-Dichloroguaiacol	17.22	103	1.97
3,4-Dichlorocatechol	19.40	76	1.12
3,4-Dichlorophenol	20.12	106	1.35
4,5-Dichloroguaiacol	22.04	98	2.58
4,6-Dichloroguaiacol	22.27	52	2.10
5-Chlorovanillin	23.54	47	0.31
5,6-Dichloroguaiacol	24.34	57	1.69
4 – Chlorocatechol	24.94	87	0.24
3,5-Dichlorocatechol	25.52	08	0.53
2,3,5,6-Tetrachlorophenol	25.65	53	2.91
2,3,4,5-Tetrachlorophenol	25.98	51	3.45
2,3,4,6-Tetrachlorophenol	26.08	76	1.48
3,5,6-Trichloroguaiacol	26.80	68	2.18
3,4,6-Trichloroguaiacol	27.15	81	1.71
3,5- Dichlorosyringol	27.45	57	2.63
3,4,5-Trichloroguaiacol	27.71	31	2.54
3 – Chlorocatechol	28.20	103	0.30
6-Chlorovanillin	28.48	38	1.23
3,6-Dichlorocatechol	30.61	81	0.42
4,5,6-Trichloroguaiacol	34.16	99	1.12
2-Chlorosyringaldehyde	35.10	34	1.16
4,5-Dichlorocatechol	35.57	33	1.63
Pentachlorophenol	36.63	100	0.27
3,4,5-Trichlorocatechol	37.15	75	0.84
Tetrachloroguaiacol	38.21	49	0.87
Trichlorosyringol	39.29	17	1.14
3,4,6-Trichlorocatechol	40.62	76	0.48
2,6-Dichlorosyringaldehyde	40.74	100	0.38
5,6,-Dichlorovanillin	41.80	109	0.44
Tetrachlorocatechol	43.11	31	0.54

Flow Sheet 2.001

Separation of phenolic compounds from effluents



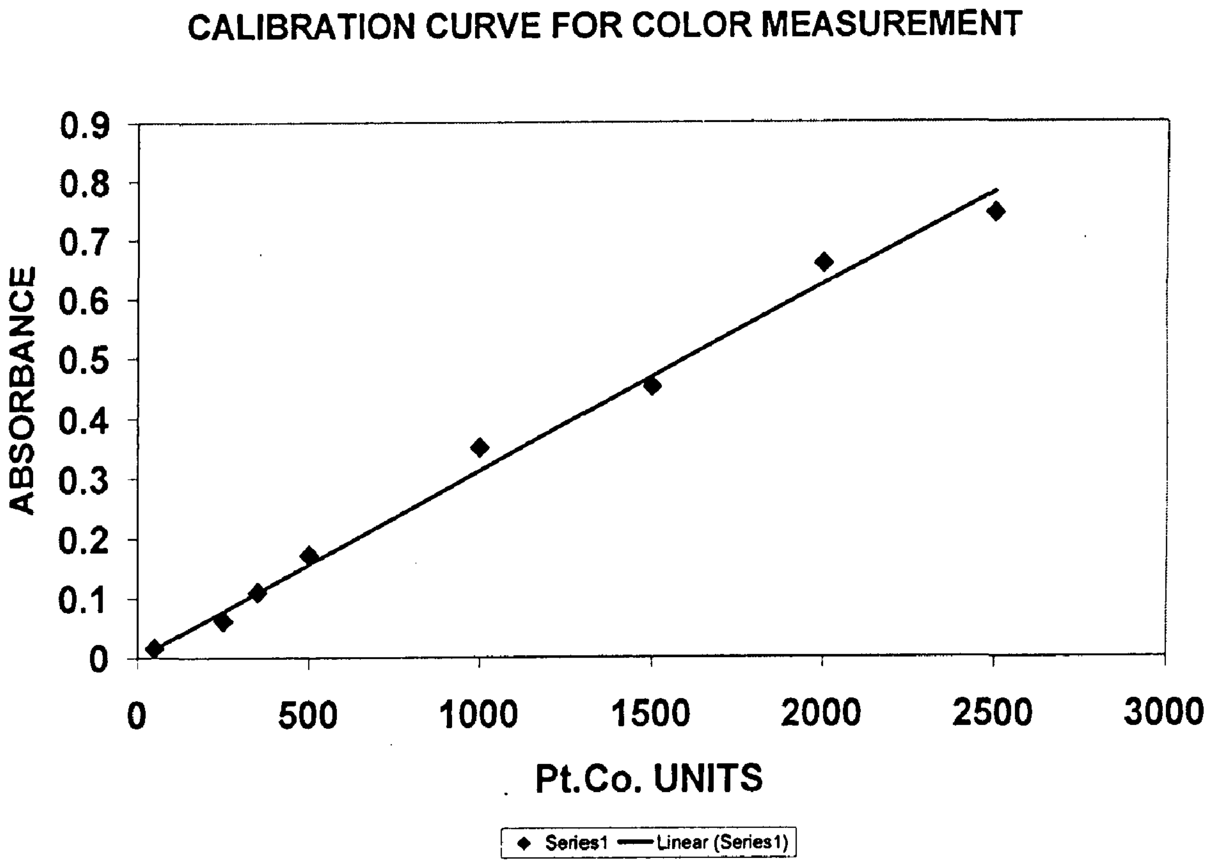


Fig.2.001

SL.NO.	CONC.	ABS
1	50	0.010
2	250	0.059
3	350	0.110
4	500	0.172
5	1000	0.351
6	1500	0.452
7	2000	0.660
8	2500	0.745

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CHAPTER 3

IDENTIFICATION AND ESTIMATION OF CHLORORGANICS IN WHEAT STRAW (*Triticum aestivium*)

3.1 INTRODUCTION

Wheat straw (*Triticum aestivium*) is used by the Indian small and medium size paper mills to make writing and printing paper in the absence of sufficient wood resources. It is one of the major cellulosic agricultural by-products available in the country. The random estimates suggest that 3 tons of wheat straw is produced per ton of wheat.(1) In India wheat is grown mainly in states like Punjab, Haryana, Uttar Pradesh, Rajasthan and Bihar. It is sown in October-November and harvested during March-May. Even if the theoretical availability of straw is high, there are limitations in its use because of its seasonal availability, problems of collection, handling, transportation and storage, investments in pollution control equipments etc.(2)

The crop residue ratio of the wheat straw is about 1: 50. Out of this, less than 1% is being used by paper industry (1) for the manufacture of writing & printing paper, wrapping paper and straw board & building board. Most of the straw is fed to livestock as roughage. The straw is also used as bedding for cattle, padding as in mattresses, for packing fragile goods, for thatching and for many other minor purposes. There is also a practice of burning the unused straw and ploughing it back to supply humus and soil nutrients.(3)

Wheat straw is heterogenous in nature when compared with wood. Straw consists of stem and leaves. The internodal section is called stalk. Although stalk is thin and long yet it has the tensile strength to withstand all but the fiercest storm during the growth of the ear. It consists largely of cellulose and hemicellulose, with some lignin, particularly at the nodes and even a water-proof wax coat.(4) The wheat straw is normally converted to chemical pulp using soda process in the Indian Paper Industry. The pulp contains fibres, parenchyma, vessels and epidermal cells. The fibres are slender and long and ends are pointed. The fibre lumen varies from broad to narrow. The fibres have an average length of 1.22 mm and the range is from 0.52 to 2.37 mm. The average fibre diameter is 14.9 μm. The ratio of fibre length to diameter is 111:1 in case of cereal straw. The excellent paper formation characteristics of straw fibres are attributable to their relatively high ratio of average length to diameter.(5) The parenchyma is abundant and barrel shaped. The epidermal cells vary in size and form, sparsely pitted, have more or less serrated margins and appear in either groups or singles. The vessel elements are slender and long. Chemical analysis of a fibre showed ash 8.48%, cellulose 51.46%, lignin 21.52% and Pentosans 23.5%. In comparison to wood, straw contains less cellulose but the total holocellulose content is almost the same. Pentosan contents are higher and lignin contents are lower in straw compared to wood.(5)

Indian wheat straw based industries use the conventional CEH or CEHH bleaching sequences where the elemental chlorine used in the bleaching of pulp reacts with lignin and produces chlorinated phenolic compounds such as chlorophenols, chloroguaiacols, chlorocatechols etc., The presence of large amounts of chlorophenolics in non-wood pulp bleaching effluents, as reported by Xie, indicate that grass lignins contain more p-hydroxyphenyl units.(6) These organochlorine compounds formed during the conventional CEH bleaching are known to be toxic, mutagenic, persistent and bio-accumulating and causing numerous harmful disturbances in biological systems.(7-9) The presence of potential hazardous organic substances in wheat straw pulp mill effluent has also been detected by Folke.(10) It has also been reported that in wheat straw pulp the residual lignin is characterized by lower molecular weight and a higher content of acid groups which is solubilized in the bleaching processes to be followed.(11) These low molecular weight organic compounds in the bleach effluent are of great environmental concern as they are highly toxic to aquatic life. Bleaching of straw pulps leads to an exposure to large amounts of organohalides, 70% of which is slowly bio-degradable.(10)

Wheat straw requires more chemicals for pulping as well as for producing bleached pulp at satisfactory brightness levels, in spite of having low percentage of lignin compared to wood. The fresh water requirement in the bleachery is also higher than what is required for wood pulps.(12) Owing to high dosage of chemicals and heavy water consumption, the pollution load in the waste water released from these mills is also exorbitant. As wheat straw has high silica content, it causes high wear and tear of equipments.(13) Chemical recovery systems are not technically or economically viable in small and medium Indian paper mills, where wheat straw is used and hence these are discharging liquid effluent to the receiving streams causing high pollution.(14)

The effluents containing these highly toxic compounds are coming under increasing scrutiny and regulations around the world.(15) Many studies have been conducted to identify a set of pulp chlorination conditions in which the production of chlorinated phenolics (and other toxic compounds) would be minimal. Most of these studies are on soft wood and hard wood.(16-18) A very little information is available on non-woods and agro residues. This work is planned to study the formation of different chlorophenolic compounds formed as a function of C stage bleaching conditions and to identify and estimate the different chlorophenolic compounds formed and present in different bleaching effluent viz. C, E, H, D etc.,

3.2 RESULTS AND DISCUSSION

The retention time, response factor and extraction efficiencies of pure chlorophenolic compounds are given in Table 2.005. These values are the averages of minimum three values. The retention value indicates that most of the chlorophenolic compounds studied can be resolved on capillary column of HR-1. The various chlorphenols have been identified by matching time (± 0.1 min) of a component with that of pure standard.

The chlorinated compounds are formed during pulp chlorination. The quantities of various chlorophenolic compounds formed will depend upon nature of lignin, raw material used and pulping process, the bleaching chemical and bleaching conditions.(6,15,19-21) The estimation of various chlorophenolic compounds have been carried out in C, E, H bleaching stage effluents. The impact of change in C stage bleaching conditions has been investigated and the results are given in Tables 3.111 to 3.136 and Figures 3.211 to 3.282. The bleached pulp brightness, CED pulp viscosity, effluent COD and colour values are given in Tables 3.222 to 3.273. The various chlorophenolic compounds identified in different bleaching stage effluents are given in Tables 3.311 to 3.334.

The results show that six categories of different chlorophenolic compounds are present in various bleaching effluents. These are phenols, catechols, guaiacols, vanillins, syringaldehyde and syringols. The quantities of different categories are given in Tables 3.219 to 3.281 and Figures 3.213 to 3.266. These chlorinated compounds have also been categorized into mono, di, tri, tetrachlorophenolic compounds. The results of these compounds are given in Tables 3.215 to 3.277 and Figures 3.219 to 3.270. Some important chlorophenolic compounds, whose concentrations are higher or whose toxicity values are high i.e. lower $^{96}LC_{50}$ values have also been chosen for analysis. The results of these individual compounds are given in Tables 3.312 to 3.334 and Figures 3.311 to 3.326.

The effect of bleaching conditions on the formation of chlorophenolic compounds have been investigated under the following heads:

Changes in C stage conditions

- pH
- Temperature
- Pulp Consistency
- Substitution of Chlorine in C stage by Chlorine dioxide
- Distribution of total Chlorine dosage between C and H stages
- Splitting of chlorine dose in C stage.

Changes in bleaching sequence

- Replacement of Hypochlorite by Chlorine dioxide.
- Oxygen deliginification stage prior to CEH sequence.

The above studies have been carried out by changing one bleaching parameter and maintaining other bleaching parameters/conditions constant. For each bleaching performed, bleached pulp has been characterized by determining brightness and CED viscosity and the effluent generated has been characterized by estimating different chlorophenolic compounds formed, COD and colour.

3.2.1 Effect of C Stage bleaching conditions

3.2.1.1 pH

Study has been performed at different pH between 1.5 and 4. The results are shown in Tables 3.111 to 3.115 and Figures 3.211 to 3.222.

The results show (Table 3.211 and Figure 3.213) that with the increase in C stage pH from 1.5 to 4, the quantities of total chlorophenolic compounds formed decrease both in C, E, H stage effluents and combined CEH effluent. Looking at Figures 3.215 to 3.218, we find that quantity of tetra, tri, dichlorophenolic compounds in C, E, H stage effluents and combined CEH effluent decrease with increase in pH. Monochlorophenols also show the similar trend in E and H stages. Monochlorophenols in C stage effluent decrease with increase in pH up to 2.5 and then decrease with further increase in pH.

The results given in Tables 3.219 to 3.222 and Figures 3.219 to 3.222 further show that the quantities of different categories of chlorophenolic compounds viz. phenols, catechols, guaiacols, other chlorinated compounds (vanillin, syringaldehyde and syringols) decrease substantially with increase in pH. The exception being other chlorinated compounds in H stage effluent which increase with increase in pH.

The presence of different categories of chlorophenolic compounds in wheat straw effluents have been reported by Folke, Chhaya and Xie, the order being C>E>>H.(10,21,6) A similar behaviour has been reported by Voss et al in the CEH bleaching of hard wood and soft wood pulps, showing that the quantity of total chlorophenolic compounds decreases with increase in end pH in C stage ranging from 1 to 2.5, when bleaching is performed at 25^{0}C and 80% of chlorine demand is charged in C stage.(16,18)

The change in the proportions of some individual chlorophenolic compounds which are present in higher amounts or have high values of toxicity are shown in Figures 3.309 to 3.325. The results show that the amounts of 2,4 dichlorophenol, 2,4,6 trichlorophenol, 3,6 dichlorocatechol, 3,4 dichlorocatechol, 3,4,6,trichlorocatechol and tetrachloroguaiacol decrease with increase in pH from1.5 to 4 in C, E, H stage effluents and combined CEH effluent. The exception being 3, 4, 6 trichlorocatechol in H stage effluent which increases with increase in pH. In chlorination, alkali extraction and hypochlorite stage effluents and in most of combined CEH effluent, the quantity of chlorinated guaiacols also decreases with increase in pH.

The di and trichlorinated phenolic compounds contribute largest share of above 75% to total chlorinated phenolic compounds, the share being 39 and 36% respectively, tetra and mono chlorinated phenolic compounds contribute 18 and 7% respectively.

There is a decrease in proportion of dichlorophenolic compounds from 39% to 32%. The proportion of trichlorophenolic compounds increases from 36 to 38% and that of tetrachlorophenolic ompounds increases from 18 to 23% respectively. The proportions of monochlorophenols remain unchanged. The results (Table 3.211 and Figure 3.211) further indicate that the proportion of total chlorophenolic compounds between the C, E, H stage is about 60, 35 and 5%, which changes to 75, 20 and 5% respectively when the C stage pH is raised from 1.5 to 4.0. The results given in Tables 3.211 to 3.222 and Figures 3.219 to 3.222 also indicate that much higher proportions of phenols (38%), catechols and guaiacols being 26% and 21% respectively, the other chlorinated compounds are much lower being only 16% at pH 1.5. There is not much change in these proportions with increase in C stage pH.

Effluent toxicity depends upon concentration of individual compounds. The $_{96}LC_{50}$ values given in Table 3.001 indicate that the toxicity of pentachlorophenol, catechols, tri and tetrachloroguaiacol and 2,4,6 trichlorophenol are relatively much higher than 2,4, dichlorophenol and dichloroguaiacol.

Appreciable reduction in the quantities of di, tri and tetra chlorophenolic compounds observed, when the pH is raised from 1.0 to 2.5, which is likely to give substantial reduction in effluent toxicity.

The COD and colour values of C, E, H stage effluents and combined CEH effluent decrease by nearly 20% with increase in C stage pH from 1.5 to 4.0 indicating reduction in pollution load.

The pulp brightness drops by one point between pH 2.5 and 4 but the brightness is nearly constant in the pH range 1.5 to 2.5. The pulp viscosity drops by 20% indicating increased pulp degradation with increase in pH in C stage.

The chlorine acts on lignin in two steps. First a fast electrophillic substitution followed by slower oxidation step leading to fragmentation of lignin macromolecule and formation of chlorinated phenolic compounds. At higher C stage pH lesser quantity of molecular chlorine is available which is responsible for lower electrophillic substitution and leads to lower formation of all categories of chlorinated phenolic compounds which is in agreement with the results given in Tables 3.312 to 3.314 and Figures 3.311 to 3.314.

The lower quantity of molecular chlorine available at higher pH in C stage reduces the hydrophillic character of lignin which may be responsible for lower dissolution of lignin leading to reduction in effluent COD & colour at higher pH

3.2.1.2 Temperature

Study has been performed at C stage temperatures between 15 - 35^{0}C. The results are shown in Tables 3.116 to 3.120 and Figures 3.223 to 3.318.

The results as shown in Table 3.223 and Figure 3.225 indicate that the total chlorophenolic compounds generated in C, E, H stage effluents and combined CEH effluent increase with increase in C stage temperature in the range 15 - 35^{0}C. The quantity of mono, di, tri and tetrachlorinated phenolic compounds also increase in C, E, H stage effluents and combined CEH effluent with increase in temperature. Likewise the quantities of phenols, catechols, guaiacols and other chlorinated phenolic compounds also increased with increase in temperature in case of C, E, H stage effluents and combined CEH effluent.

The results are similar to those reported by Voss et al on the CEH bleaching of softwood and hardwood pulp. The total chlorophenolic compounds formed at end pH 2 and at temperature of 60^0C are higher than at 25^0C when 50 or 80% of chlorine demand is applied in C stage.(16,18)

The amounts of 2,4 dichlorophenol, 2,4,6 trichlorophenol, 4,5 dichloroguaiacol, 3,4,5 trichloroguaiacol, 4,5,6 trichloroguaiacol, tetrachloroguaiacol, 3,4,6 trichlorocatechol, tetrachlorocatechol, 2,6 dichlorosyringaldehyde, 5,6 dichlorovanillin, 3,5 dichlorosyringol, also increase with increase in temperature in C,E,H stage effluents and combined CEH effluent.

There is a steady increase in the values of COD and effluent colour in C, E, H stage effluents and combined CEH effluent (30%) indicating that pollution load increases with increase in temperature. However the increase is much smaller in the temperature range 25-35^0C.

The CED pulp viscosity drops by 15% indicating increased pulp degradation with increase in C stage bleaching temperature in the range15-35^0C. There is also marginal increase in the pulp brightness but the brightness at 25 and 30^0C are comparable.

The increase in temperature increases the attack of bleach chemicals on both lignin and carbohydrates thereby giving additional dissolution of lignin and cellulose/hemicellulose components forming higher amounts of chlorinated phenolic compounds, COD and effluent colour and improvement in pulp brightness.

Consistency

Studies have been performed at C stage pulp consistency between 2.5 and 4.0. The results are given in Tables 3.121 to 3.124 and Figures 3.235 to 3.320.

The total chlorophenolic compounds generated in C, E, H stage effluents and combined CEH effluent increase with increase in C stage consistency. The quantities of mono, di, tri and tetrachlorophenolic compounds also increase with increase in pulp consistency in C, E, H stage effluents and combined CEH effluent. Similarly the quantities of phenols, catechols, guaiacols and other chlorinated compounds also increase with increase in C stage pulp consistency in C, E, H stage effluents and combined CEH effluent.

This is in agreement with the results of Earl and Douglas Reeve wherein higher chlorophenolic compounds are reported at 10% Cy than 4% Cy. The quantity of dichloro and trichlorophenolic compounds increase where as that of tetrachlorophenolic compounds decrease when the pulp consistency is raised from 4% to 10%.(15,17)

The amount of 2,4 dichlorophenol, 2,4,6 trichlorophenol, 3,6 dichloroguaiacol, 4,5 dichloroguaiacol 3,4,5 trichloroguaiacol, 4,5,6 trichloroguaiacol, tetrachloroguaiacol, 3,6 dichlorocatechol, 3,4,6 trichlorocatechol, tetrachlorocatechol, 2,6 dichlorosyringaldehyde, 5,6 dichlorovanillin, 3,5 dichlorosyringol, also increase with increase in consistency in C,E,H stage effluent and combined CEH effluent.

The effluent COD and colour also increases by approx 25 and 30% respectively with increase in pulp consistency. The brightness increases by merely 0.7 points and CED viscosity drops by about 12%.

The increase in pulp consistency at the same bleach chemical charge gives increased concentration of bleach chemicals and increased reaction. This may be responsible for increased formation of chlorinated phenolic compounds, effluent COD and color and small increase in pulp brightness.

3.2.1.3 Substitution of chlorine by chlorine dioxide in C stage

The study has been performed by substituting chlorine by chlorine dioxide in C stage to the extent of 75%. The results are given in Table 3.125 to 3.128 and Figures 3.247 to 3.324.

The results (Table 3.347 and Figure 3.249) indicate that formation of total chlorophenolic compounds decrease appreciably with increased substitution of chlorine by chlorine dioxide in C stage i.e. about 80% reduction of chlorophenolic compounds at 75% substitution level.(23-25,28-30)

Some reports indicate that the amount of total chlorinated phenolics formed increases with increase in chlorine dioxide substitution passed through a maximum at 50% substitution and decreases rapidly to a near zero at 100% chlorine dioxide substitution.(16,22,27)

The formation of mono, di, tri and tetrachlorinated phenolic compounds decrease with increase in substitution of chlorine by chlorine dioxide (Table 3.251 to 3.254 and Figure 3.251 to 3.254). The exception being mono chlorophenolic compounds at 75% substitution in case of C stage effluent and combined CEH effluent, tri and tetra chlorinated phenolic compounds at 50 and 75% substitution levels in case of H stage effluent (Table 3.253 and 3.254). Like wise the formation of phenols, catechols, guaiacols and other chlorinated phenolic compounds also reduces very significantly (Table 3.255 to 3.258 and Figure 3.255 to 3.258). The exception being mono chlorophenols which increase with increased substitution in C stage and guaiacols in E stage effluent which increases till 50% substitution and decreases rapidly at 75 % substitution .

The amount of 3,6 dichloroguaiacol, 3,4 dichlorocatechol, 4,5 dichlorocatechol, 3,4,6 trichlorocatechol increase with increase in substitution of chlorine by chlorine dioxide in C stage in C,E,H stage effluents and combined CEH effluent. The quantity of 4,5,6 trichloroguaiacol, 3,4,5 trichloroguaiacol and tetrachloroguaiacol decrease with increase in chlorine dioxide substitution, where as quantity of 4,5 dichloroguaiacol increase with chlorine dioxide substitution, pass through a maxima at 50% substitution and fall rapidly to zero at 100% chlorine dioxide substitution. The amount of 5,6 dichloroguaiacol increases with increase in substitution in all the effluents, The amount of 2,4 dichlorophenol and 2,4,6 trichlorophenol increase with increase in substitution up to 50% and then drops substantially at 100% substitution in C stage effluent.

There is a substantial reduction in effluent COD (40%) and colour (80%) in C, E, H stage effluents and combined CEH effluent indicating drastic drop in pollution load.(25,26,28)

The pulp viscosity improves by 60% and brightness by 2%. Chlorine dioxide is highly selective in its attack on lignin and is a strong de-colourization agent. Increased substitution of chlorine by chlorine dioxide will reduce the attack on cellulose that reduces very significantly the drop in pulp viscosity (gives higher pulp viscosity) and dissolution of cellulose fragments giving much lower effluent COD and colour. Chlorine dioxide being strong bleaching agent gives higher pulp brightness.

3.2.1.4 Distribution of bleaching chemical between C and H Stage

Studies have been performed by varying the distribution (40:60 to 80:20) of total chlorine demand between C and H stages of CEH sequence. The results are given in Tables 3.129 to 3.133 and Figures 3.259 to 3.326.

The results given in Table 3.359 and Figure 3.261 show that the quantity of chlorinated phenolic compounds formed in C, E, H stage effluents and combined CEH effluent increases with increase in proportion of chlorine in C stage from 40% to 80%. The quantity of chlorinated phenolic compounds formed in H stage effluent decrease with decrease in proportion of hypochlorite from 60% to 20%.(16,18)

Similar trend is observed with different categories of chlorophenolic compounds i.e. mono, di, tri and tetrachlorophenols, guaiacols and catechols and other chlorinated compounds in C, E, H stage effluents and combined CEH effluent (Figures 3.263 to 3.266). The exception being dichlorophenols and other chlorinated compounds in H stage effluent.

The amount of 2,4 dichlorophenol, 2,4,6 trichlorophenol, 3,6 dichloroguaiacol, 4,5 dichloroguaiacol 3,4,5 trichloroguaiacol, 3,4,6 trichloroguaiacol, 4,5,6 trichloroguaiacol, tetrachloroguaiacol, 3,6 dichlorocatechol, 3,4 dichlorocatechol, 3,4,6 trichlorocatechol, tetrachlorocatechol, 2,6 dichlorosyringaldehyde, 3,5 dichlorosyringol, increase with increase in proportion of hypochlorite in C,E,H stage effluent and combined CEH effluent, but 5,6 dichlorovanillin decreases. The exception being 5,6 dichloroguaiacol, 3,4,6 trichlorocatechol, tetrachlorocatechol and tetrachloroguaiacol in H stage effluent where the quantities of these chemicals decrease with increase in proportion of hypochlorite.

The effluent COD and colour also increase in C, E, H stage effluents and combined CEH effluent. The exception being COD which decreases with change in proportion from 40:60 to 80:20. There is a small decrease in pulp brightness by 0.6 points and viscosity drop by 9%.

The change in proportion from 40:60 to 80:20 means charging more chlorine in C stage and less hypochlorite in H stage. The formation of chlorinated phenolic compounds results from the action of chlorine on lignin in C stage. Increase in proportion of chlorine will give rise to increased formation of chlorinated phenolic compounds in C stage and E stage effluents. Alkali extraction stage involves the dissolution of undissolved portion of chlorinated phenolic compounds formed during C stage pulp bleaching, thus this stage becomes the major contributor to pollution in terms of COD, colour and TOCl. The lower quantity of hypochlorite charged in H stage will give lower amounts of chlorinated phenolics in H stage effluent.

Increased quantity of chlorine in C stage gives more hydrophilic lignin, which is fragmented by hypochlorite. As a result, dissolution of lignin is increased giving higher effluent COD and effluent colour.

3.2.1.5 Splitting of chlorine dose in C Stage

The chlorine dose in C stage has been divided into two equal parts. Chlorination has been performed with half the dose and then again performed with remaining half dose. However, there was no change in the conditions in the ensuing extraction and hypochlorite stages. The results are shown in Table 3.134 and Figure 3.277.

The results shown in Tables 3.375 to 3.378, further show that quantity of mono, di, tri and tetrachlorinated phenolic compounds, phenols, catechols, guaiacols and other chlorinated compounds in C, E, H stage effluents and combined CEH effluent all decrease with the use of split chlorine dose in C stage, which is in agreement with the findings of Liebergott that splitting of chlorine dosage into two portions showed a decrease in the amount of chlorophenols. The exception being tetrachlorophenols in H stage effluent which increase with split chlorine dose.(31,32)

The results show a very large decrease in the amounts of 2,4 dichlorophenol, 2,4,6 trichlorophenol, 2,6 dichlorosyringaldehyde, 5,6 dichlorovanillin, 3,5 dichlorosyringol and appreciable decrease in 3,6 dichloroguaiacol, 3,4 dichlorocatechol and Tetrachlorocatechol and decrease in the amounts of 5,6 dichloroguaiacol, 4,5,6 trichloroguaiacol formed in C,E,H stage effluents and combined CEH effluent when chlorine dose in C stage is split in two equal doses. The exception being 4,5 dichloroguaiacol in C stage.

The results show that splitting of chlorine dose gives 48% lower formation of chlorinated phenolic compounds in C, E, H stage effluents and combined CEH effluent.(31-34) The effluent COD and colour is reduced by 13%. The pulp brightness is improved by 0.8 point and viscosity is improved by about 25% indicating that splitting of chlorine dose reduces the pollution load by 13% and gives a stronger and brighter pulp. The splitting of chlorine dose means applying lower concentration of chlorine over longer period making mild attack on cellulose and hemicellulose giving lower dissolution of carbohydrate fraction giving lower effluent COD and colour. Mild attack on cellulose gives lower pulp degradation and will yield stronger pulp - higher viscosity.

3.2.2 Changes in bleaching sequence

3.2.2.1 Replacement of hypochlorite by chlorine dioxide in H stage

The complete replacement of hypochlorite by chlorine dioxide will change the bleaching sequence from CEH to CED. The results of this replacement are given in Table 3.135 and Figure 3.278.

The results show that there is practically no change in the quantity of various chlorophenolic compounds formed in H stage and combined CEH effluent, but there is decrease in the quantity of 2,4,6 trichlorophenol, 4,5 dichloroguaiacol, Tetrachloroguaiacol and Tetrachlorocatechol in H stage and combined CEH effluent. The quantity of 5,6 dichlorovanillin decreases substantially.

The bleaching results and environmental loads from C and E stage effluents remain unchanged. The contribution of H stage effluent to the bleaching sequence in terms of chlorinated phenolic compounds, effluent COD and colour is small, about 2 -5%. The replacement of H by D reduces the formation of chlorophenolic compounds, effluent COD and colour but the overall impact remain small i.e. improvement of 2 –5%.

The biggest gain is in terms of pulp viscosity and brightness. Hypochlorite is strongly pulp degrading where as chlorine dioxide is inert to pulp thus giving a stronger pulp. The improvement in pulp viscosity was by 65%. Chlorine dioxide is also known to give lower PC No. pulp-lower colour reversion tendency. The chlorine dioxide also improves the pulp brightness by 0.8 points.

Oxygen deliginification stage prior to CEH

The results on bleaching are given in Table 3.136 and Figure 3.279. The results show that introduction of oxygen pre-bleaching stage reduces the formation of mono, di, tri, tetraphenols, guaiacols, catechols and other chlorinated compounds by 75% in C, E, H stage effluents and combined CEH effluent.(35,36) The effluent COD and colour reduce by 30% and 44% respectively. The pulp brightness is nearly the same, rather minor improvement by 0.6% and viscosity drops by 2%.

The results indicate that the quantities of all the individual chlorophenolic compounds decrease on using an oxygen deliginification stage, but there is large reduction in the quantities of 2,4 dichlorophenol, 2,4,6 trichlorophenol, 4,5 dichloroguaiacol 3,4,5 trichloroguaiacol, 3,4 dichlorocatechol, tetrachlorocatechol, 2,6 dichlorosyringaldehyde, 5,6 dichlorovanillin, 3,5 dichlorosyringol and the reduction of other compounds is substantial.

Oxygen deliginification is known to reduce the pulp kappa number by 40 - 50% which in turn reduces the bleach chemical demand in the following C,E and H stages to nearly the same extent which reduce the environmental loads – chlorophenolic compounds, COD and colour very significantly.

3.3 CONCLUSIONS

The following conclusions are drawn from the results on bleaching of wheat straw pulp:

a) pH

1) Increase in C stage pH from 1.5 to 4 gives about 20% reduction in effluent COD, colour and substantial reduction in various categories of chlorophenolic compounds.
2) The proportion of dichlorophenolic compounds decreases and that of tri and tetrachlorophenolic compounds increases.
3) The contribution of chlorophenolic compounds in C stage effluents decrease by 15% and that in E stage effluent increases by similar amount but the proportion of H stage remains unchanged.
4) The pulp brightness remains unchanged between pH 1.5 and 2.5 but drops by one point in pH range, 2.5 to 4.0. A 20% drop in CED viscosity points towards increased pulp degradation.

b) Temperature and consistency

1) Raising of C stage temperature/consistency increases the rate of reaction and the quantity of chlorophenolic compounds, effluent COD and colour.
2) A reduction in pulp viscosity is indicative of increased pulp degradation.

c) Chlorine dioxide substitution

1) The substitution of chlorine by chlorine dioxide reduces appreciably the formation of chlorophenolic compounds, effluent COD, colour and toxicity.
2) Higher pulp viscosity is indicative of protective action by chlorine dioxide.

d) Increasing C: H ratio

1) Reduces the formation of chlorophenolic compounds in H stage effluent.
2) Increases effluent COD and colour.
3) Improves pulp viscosity by approximate 9%.

e) Splitting of chlorine dose

1) 48% reduction in quantity of chlorophenolic compounds.
2) 13% reduction in effluent COD and colour.
3) 25% improvement in pulp viscosity.
4) A minor improvement in brightness.

f) Replacement of hypochlorite by chlorine dioxide

1) Small reduction (2 – 5%) in the quantity of chlorophenolic compounds.
2) Small reduction (2 – 5%) in effluent COD and colour.
3) A very significant improvement in pulp viscosity (65%).
4) A minor improvement (0.8 point) in pulp brightness.

g) Oxygen deliginification stage

1) 75% reduction in the quantity of chlorophenolic compounds.
2) Substantial reduction in effluent toxicity.
3) 30% COD reduction and 44% reduction in effluent colour.
4) Viscosity reduction by 2%.

Table-3.001

LC_{50} values for various chlorophenols

Sl.No.	Compounds	$^{96}LC_{50}$ (mg/l)
1	Dichlorocatechol	0.5 – 1.0
2	Dichloroguaiacol	2.3
3	2,4-dichloropohenol	2.8
4	Pentachloropehnol	0.047 –0.106
5	2,4,6-trichlorphenol	0.45 – 2.6
6	Tetrachlorocatechol	0.25 – 1.5
7	3,4,5-trichlorocatechol	0.89 – 1.5
8	Trichloroguaiacol	0.7 – 1.0
9	Tetrachloroguaiacol	0.2 – 1.7

Table 3.111

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage pH of 1.5

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	5.11	0.10	3.49	0.14	-	-	8.60
2	3-chlorophenol	3.77	0.08	2.62	0.10	0.15	0.01	6.54
3	4-chloroguaiacol	-	-	-	-	0.25	0.01	0.25
4	5-chloroguaiacol	-	-	-	-	0.02	0.001	0.02
5	2,3,5-trichlorophenol	0.67	0.01	0.98	0.04	-	-	1.65
6	2,4,6-trichlorophenol	12.71	0.25	5.49	0.22	0.92	0.04	19.12
7	3,6-dichloroguaiacol	0.19	0.004	0.3	0.01	-	-	0.49
8	3,4dichlorocatechol	4.09	0.08	1.73	0.07	-	-	5.82
9	4,5-dichloroguaiacol	0.64	0.01	1.89	0.08	0.41	0.02	2.94
10	5,6-dichloroguaiacol	2.74	0.05	0.76	0.03	0.45	0.02	3.95
11	2,3,4,6-tetrachlorophenol	1.41	0.03	0.28	0.01	-	-	1.69
12	3,4,5-trichloroguaiacol	1.87	0.04	0.98	0.04	-	-	2.85
13	3,4,6-trichloroguaiacol	3.78	0.07	0.54	0.02	-	-	4.32
14	3,5-dichlorosyringol	2.75	0.05	1.43	0.06	0.29	0.01	4.47
15	3,6-dichlorocatechol	-	-	1.07	0.04	-	-	1.07
16	4,5,6-trichloroguaiacol	2.81	0.06	2.80	0.11	-	-	5.61
17	tetrachloroguaiacol	3.31	0.07	1.45	0.06	0.43	0.02	5.19
18	3,4,6-trichlorocatechol	3.97	0.08	1.95	0.08	0.11	0.004	6.03
19	2,6-dichlorosyringaldehyde	5.18	0.10	2.39	0.10	-	-	7.57
20	5,6-dichlorovanillin	1.39	0.03	2.8	0.11	0.33	0.01	4.52
21	tetrachlorocatechol	8.83	0.18	4.33	0.17	1.01	0.04	14.17
22	2,3,4-trichlorophenol	-	-	-	-	0.26	0.01	0.26
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	65.22	1.30	37.28	1.49	4.63	0.19	107.13

C Stage bleaching conditions: Charge 5.1%, Temperature 30^{0}C, Consistency 3%

Table 3.112

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage pH of 2

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	4.17	0.08	2.77	0.11	-	-	6.94
2	3-chlorophenol	2.39	0.05	2.37	0.09	0.12	0.004	4.88
3	4-chloroguaiacol	-	-	-	-	0.09	0.003	0.09
4	5-chloroguaiacol	-	-	-	-	0.02	0.01	0.02
5	2,3,5-trichlorophenol	0.14	0.003	0.87	0.03	-	-	1.01
6	2,4,6-trichlorophenol	10.82	0.22	5.23	0.21	0.91	0.04	16.96
7	3,6-dichloroguaiacol	0.17	0.003	0.16	0.01	-	-	0.33
8	3,4-dichlorocatechol	2.98	0.06	1.18	0.05	-	-	4.16
9	4,5-dichloroguaiacol	0.31	0.01	0.89	0.04	0.37	0.01	1.57
10	5,6-dichloroguaiacol	1.48	0.03	-	-	0.11	0.004	1.59
11	2,3,4,6-tetrachlorophenol	0.96	0.02	0.07	0.003	-	-	1.03
12	3,4,5-trichloroguaiacol	1.19	0.02	0.95	0.04	-	-	2.14
13	3,4,6-trichloroguaiacol	3.66	0.07	0.28	0.01	0.04	0.001	3.98
14	3,5-dichlorosyringol	2.69	0.05	1.42	0.06	0.25	0.01	4.36
15	3,6-dichlorocatechol	-	-	0.96	0.04	-	-	0.96
16	4,5,6-trichloroguaiacol	2.20	0.04	2.36	0.09	-	-	4.56
17	tetrachloroguaiacol	3.19	0.06	0.82	0.03	0.32	0.01	4.33
18	3,4,6-trichlorocatechol	2.47	0.05	1.82	0.07	0.13	0.005	4.42
19	2,6-dichlorosyringaldehyde	4.86	0.10	1.62	0.06	-	-	6.48
20	5,6-dichlorovanillin	1.09	0.02	2.14	0.09	0.49	0.02	3.72
21	tetrachlorocatechol	8.42	0.17	3.65	0.15	0.68	0.03	12.75
22	2,3,4-trichlorophenol	-	-	-	-	0.15	0.01	0.15
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	53.19	1.06	29.56	1.18	3.68	0.15	86.43

C Stage bleaching conditions: Charge 5.1%, Temperature 30^{0}C, Consistency 3%

Table 3.113

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage pH of 2.5

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	4.01	0.08	1.10	0.04	-	-	5.11
2	3-chlorophenol	2.10	0.04	0.97	0.04	0.09	0.004	3.16
3	4-chloroguaiacol	-	-	-	-	0.05	0.002	0.05
4	5-chloroguaiacol	-	-	-	-	0.02	0.001	0.02
5	2,3,5-trichlorophenol	0.11	0.002	0.68	0.03	-	-	0.79
6	2,4,6-trichlorophenol	9.01	0.18	3.54	0.14	0.88	0.04	13.43
7	3,6-dichloroguaiacol	0.16	0.003	0.12	0.005	-	-	0.28
8	3,4-dichlorocatechol	2.57	0.05	0.96	0.04	-	-	3.53
9	4,5-dichloroguaiacol	0.27	0.005	0.74	0.03	0.24	0.01	1.25
10	5,6-dichloroguaiacol	1.08	0.02	0.62	0.02	0.09	0.004	1.79
11	2,3,4,6-tetrachlorophenol	0.83	0.02	0.05	0.002	-	-	0.88
12	3,4,5-trichloroguaiacol	1.09	0.02	0.54	0.02	-	-	1.63
13	3,4,6-trichloroguaiacol	2.84	0.06	0.25	0.01	-	-	3.09
14	3,5-dichlorosyringol	1.45	0.03	1.07	0.04	0.24	0.01	2.76
15	3,6-dichlorocatechol	-	-	0.72	0.03	-	-	0.72
16	4,5,6-trichloroguaiacol	1.98	0.04	1.46	0.06	-	-	3.44
17	tetrachloroguaiacol	2.87	0.06	0.77	0.03	0.27	0.01	3.91
18	3,4,6-trichlorocatechol	2.40	0.05	0.81	0.03	0.19	0.01	3.4
19	2,6-dichlorosyringaldehyde	4.52	0.09	1.59	0.06	-	-	6.11
20	5,6-dichlorovanillin	0.56	0.01	1.36	0.05	0.51	0.02	2.43
21	tetrachlorocatechol	7.99	0.16	2.98	0.12	0.54	0.02	11.51
22	2,3,4-trichlorophenol	-	-	-	-	0.1	0.004	0.1
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	45.84	0.92	20.33	0.80	3.22	0.13	69.39

C Stage bleaching conditions: Charge 5.1%, Temperature 30^{0}C, Consistency 3%

Table 3.211 Effect of change in C Stage pH values on the generation of Chlorophenolic compounds

Chlorophenolic compounds (kg/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	65.22	37.28	4.63	107.13
2.0	53.19	29.56	3.68	86.43
2.5	45.84	20.33	3.22	69.39
3.0	39.86	15.62	2.82	58.30
4.0	31.65	8.62	2.35	42.62

Table 3.212 Effect of change in C Stage pH values on the generation of effluent COD

COD (kg/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	40.1	38.3	22.8	101.2
2.0	39.9	35.8	21.8	97.5
2.5	36.8	30.2	20.3	87.3
3.0	35.5	26.3	19.8	81.6
4.0	34.7	24.7	18.3	77.7

Table 3.213 Effect of change in C Stage pH values on the generation of effluent Colour

Colour (kg/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	43.1	86.2	2.5	131.8
2.0	42.5	81.2	1.9	125.6
2.5	40.2	76.3	1.5	118
3.0	38.7	74.4	1.2	114.3
4.0	36.7	67.5	1.02	105.2

Table 3.214 Effect of change in C Stage pH values on Brightness and Viscosity of bleached pulps obtained by CEH bleaching

pH	Brightness (%)	Viscosity (cp)
1.5	80.4	10.1
2.0	80.1	9.4
2.5	80.4	9.2
3.0	79.9	8.7
4.0	79.4	8.1

Table 3.113

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage pH of 2.5

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	4.01	0.08	1.10	0.04	-	-	5.11
2	3-chlorophenol	2.10	0.04	0.97	0.04	0.09	0.004	3.16
3	4-chloroguaiacol	-	-	-	-	0.05	0.002	0.05
4	5-chloroguaiacol	-	-	-	-	0.02	0.001	0.02
5	2,3,5-trichlorophenol	0.11	0.002	0.68	0.03	-	-	0.79
6	2,4,6-trichlorophenol	9.01	0.18	3.54	0.14	0.88	0.04	13.43
7	3,6-dichloroguaiacol	0.16	0.003	0.12	0.005	-	-	0.28
8	3,4-dichlorocatechol	2.57	0.05	0.96	0.04	-	-	3.53
9	4,5-dichloroguaiacol	0.27	0.005	0.74	0.03	0.24	0.01	1.25
10	5,6-dichloroguaiacol	1.08	0.02	0.62	0.02	0.09	0.004	1.79
11	2,3,4,6-tetrachlorophenol	0.83	0.02	0.05	0.002	-	-	0.88
12	3,4,5-trichloroguaiacol	1.09	0.02	0.54	0.02	-	-	1.63
13	3,4,6-trichloroguaiacol	2.84	0.06	0.25	0.01	-	-	3.09
14	3,5-dichlorosyringol	1.45	0.03	1.07	0.04	0.24	0.01	2.76
15	3,6-dichlorocatechol	-	-	0.72	0.03	-	-	0.72
16	4,5,6-trichloroguaiacol	1.98	0.04	1.46	0.06	-	-	3.44
17	tetrachloroguaiacol	2.87	0.06	0.77	0.03	0.27	0.01	3.91
18	3,4,6-trichlorocatechol	2.40	0.05	0.81	0.03	0.19	0.01	3.4
19	2,6-dichlorosyringaldehyde	4.52	0.09	1.59	0.06	-	-	6.11
20	5,6-dichlorovanillin	0.56	0.01	1.36	0.05	0.51	0.02	2.43
21	tetrachlorocatechol	7.99	0.16	2.98	0.12	0.54	0.02	11.51
22	2,3,4-trichlorophenol	-	-	-	-	0.1	0.004	0.1
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	45.84	0.92	20.33	0.80	3.22	0.13	69.39

C Stage bleaching conditions: Charge 5.1%, Temperature 30^{0}C, Consistency 3%

Table 3.114

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage pH of 3

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	3.9	0.08	0.79	0.03	-	-	4.69
2	3-chlorophenol	1.90	0.04	0.78	0.03	0.08	0.003	2.76
3	4-chloroguaiacol	-	-	-	-	0.02	0.001	0.02
4	5-chloroguaiacol	-	-	-	-	0.01	0.0002	0.01
5	2,3,5-trichlorophenol	0.07	0.001	0.47	0.01	-	-	0.54
6	2,4,6-trichlorophenol	8.48	0.17	2.00	0.08	0.84	0.03	11.32
7	3,6-dichloroguaiacol	0.14	0.003	0.07	0.003	-	-	0.21
8	3,4-dichlorocatechol	2.44	0.05	0.87	0.03	-	-	3.31
9	4,5-dichloroguaiacol	0.23	0.005	0.31	0.01	0.10	0.004	0.64
10	5,6-dichloroguaiacol	0.85	0.02	0.51	0.02	0.07	0.002	1.43
11	2,3,4,6-tetrachlorophenol	0.79	0.01	0.05	0.002	-	-	0.84
12	3,4,5-trichloroguaiacol	1.10	0.02	0.39	0.02	-	-	1.49
13	3,4,6-trichloroguaiacol	2.29	0.05	0.19	0.01	-	-	2.48
14	3,5-dichlorosyringol	0.6	0.01	0.94	0.04	0.23	0.01	1.77
15	3,6-dichlorocatechol	-	-	0.50	0.02	-	-	0.5
16	4,5,6-trichloroguaiacol	1.17	0.02	1.34	0.05	-	-	2.51
17	tetrachloroguaiacol	2.69	0.05	0.53	0.02	0.12	0.005	3.34
18	3,4,6-trichlorocatechol	2.36	0.05	0.65	0.03	0.28	0.01	3.29
19	2,6-dichlorosyringaldehyde	4.16	0.08	1.56	0.06	-	-	5.72
20	5,6-dichlorovanillin	0.42	0.01	1.15	0.05	0.54	0.02	2.11
21	tetrachlorocatechol	6.27	0.12	2.52	0.10	0.47	0.02	9.26
22	2,3,4-trichlorophenol	-	-	-	-	0.06	0.002	0.06
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	39.86	0.78	15.62	0.61	2.82	0.11	58.30

C Stage bleaching conditions: Charge 5.1%, Temperature 30^0C, Consistency 3%

Table 3.115

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage pH of 4

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	2.82	0.06	0.11	0.004	-	-	2.93
2	3-chlorophenol	1.78	0.03	0.04	0.001	0.07	0.003	1.89
3	4-chloroguaiacol	-	-	-	-	0.002	0.0001	0.002
4	5-chloroguaiacol	-	-	-	-	0.007	0.00003	0.007
5	2,3,5-trichlorophenol	0.05	0.001	0.38	0.01	-	-	0.43
6	2,4,6-trichlorophenol	6.9	0.14	0.56	0.02	0.62	0.02	8.08
7	3,6-dichloroguaiacol	0.10	0.002	0.04	0.002	-	-	0.14
8	3,4-dichlorocatechol	1.94	0.04	0.38	0.01	-	-	2.32
9	4,5-dichloroguaiacol	0.19	0.004	0.26	0.01	0.09	0.004	0.54
10	5,6-dichloroguaiacol	0.64	0.01	0.47	0.02	0.05	0.002	1.16
11	2,3,4,6-tetrachlorophenol	0.59	0.01	0.01	0.0004	-	-	0.60
12	3,4,5-trichloroguaiacol	1.15	0.02	0.29	0.01	-	-	1.44
13	3,4,6-trichloroguaiacol	1.96	0.04	0.08	0.003	-	-	2.04
14	3,5-dichlorosyringol	0.17	0.003	0.28	0.01	0.20	0.008	0.65
15	3,6-dichlorocatechol	-	-	0.34	0.01	-	-	0.34
16	4,5,6-trichloroguaiacol	1.03	0.02	0.88	0.03	-	-	1.91
17	tetrachloroguaiacol	1.47	0.03	0.34	0.01	0.06	0.002	1.87
18	3,4,6-trichlorocatechol	1.33	0.03	0.23	0.01	0.30	0.01	1.86
19	2,6-dichlorosyringaldehyde	3.54	0.01	1.08	0.04	-	-	4.62
20	5,6-dichlorovanillin	0.37	0.01	0.89	0.04	0.79	0.03	2.05
21	tetrachlorocatechol	5.62	0.11	1.96	0.08	0.11	0.0004	7.69
22	2,3,4-trichlorophenol	-	-	-	-	0.06	0.002	0.06
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	31.65	0.63	8.62	0.32	2.36	0.09	42.62

C Stage bleaching conditions: Charge 5.1%, Temperature 30^{0}C, Consistency 3%

Table 3.211 Effect of change in C Stage pH values on the generation of Chlorophenolic compounds

Chlorophenolic compounds (kg/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	65.22	37.28	4.63	107.13
2.0	53.19	29.56	3.68	86.43
2.5	45.84	20.33	3.22	69.39
3.0	39.86	15.62	2.82	58.30
4.0	31.65	8.62	2.35	42.62

Table 3.212 Effect of change in C Stage pH values on the generation of effluent COD

COD (kg/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	40.1	38.3	22.8	101.2
2.0	39.9	35.8	21.8	97.5
2.5	36.8	30.2	20.3	87.3
3.0	35.5	26.3	19.8	81.6
4.0	34.7	24.7	18.3	77.7

Table 3.213 Effect of change in C Stage pH values on the generation of effluent Colour

Colour (kg/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	43.1	86.2	2.5	131.8
2.0	42.5	81.2	1.9	125.6
2.5	40.2	76.3	1.5	118
3.0	38.7	74.4	1.2	114.3
4.0	36.7	67.5	1.02	105.2

Table 3.214 Effect of change in C Stage pH values on Brightness and Viscosity of bleached pulps obtained by CEH bleaching

pH	Brightness (%)	Viscosity (cp)
1.5	80.4	10.1
2.0	80.1	9.4
2.5	80.4	9.2
3.0	79.9	8.7
4.0	79.4	8.1

Table 3.215 Monochlorophenolic compounds present in different effluents formed by bleaching at various C Stage pH values

Monochlorophenolic compounds (g/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	3.77	2.62	0.42	6.81
2.0	2.39	2.37	0.23	4.99
2.5	2.10	0.97	0.16	3.23
3.0	1.90	0.78	0.11	2.79
4.0	1.78	0.04	0.08	1.90

Table 3.216 Dichlorophenolic compounds present in different effluents formed by bleaching at various C Stage pH values

Dichlorophenolic compounds (g/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	22.09	15.86	1.48	39.43
2.0	17.75	11.14	1.22	30.11
2.5	14.62	8.28	1.08	23.98
3.0	12.74	6.70	0.94	20.38
4.0	9.77	3.85	1.13	14.75

Table 3.217 Trichlorophenolic compounds present in different effluents formed by bleaching at various C Stage pH values

Trichlorophenolic compounds (g/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	25.81	12.74	1.29	39.84
2.0	20.48	11.51	1.23	33.22
2.5	17.43	7.28	1.17	25.88
3.0	15.47	5.04	1.18	21.69
4.0	12.42	2.42	0.98	15.82

Table 3.218 Tetrachlorophenolic compounds present in different effluents formed by bleaching at various C Stage pH values

Tetrachlorophenolic compounds (g/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	13.55	6.06	1.44	21.05
2.0	12.57	4.54	1.00	18.11
2.5	11.69	3.8	0.81	16.30
3.0	9.75	3.10	0.59	13.44
4.0	7.68	2.31	0.17	10.16

Table 3.219 Category wise load of chlorophenols in different effluents formed by bleaching at various C Stage pH

Chlorophenols (g/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	23.67	12.86	1.33	37.86
2.0	18.48	11.31	1.18	30.97
2.5	16.06	6.34	1.07	23.47
3.0	15.14	4.09	0.98	20.21
4.0	12.14	1.10	0.75	13.99

Table 3.220 Category wise load of chloroguaiacols in different effluents formed by bleaching at various C Stage pH

Chloroguaiacols (g/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	15.34	8.72	1.56	25.62
2.0	12.20	5.46	0.95	18.61
2.5	10.29	4.50	0.67	15.46
3.0	8.47	3.34	0.32	12.13
4.0	6.54	2.36	0.21	9.11

Table 3.221 Category wise load of chlorocatechols in different effluents formed by bleaching at various C Stage pH

Chlorocatechols (g/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	16.89	9.08	1.12	27.09
2.0	13.87	7:61	0.81	22.29
2.5	12.96	5.47	0.73	19.16
3.0	11.07	4.54	0.75	16.36
4.0	6.15	2.91	0.41	9.47

Table 3.222 Category wise load of other chlorophenolic compounds in different effluents formed by bleaching at various C Stage pH

Other Chlorophenolic compounds (g/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	9.32	6.62	0.62	16.56
2.0	8.64	5.18	0.74	14.56
2.5	6.53	4.02	0.75	11.3
3.0	5.18	3.65	0.77	9.60
4.0	4.08	2.25	0.99	7.32

Table 3.311 Different chlorophenolic compounds formed in C stage at various pH values

		C stage pH				
S.No.	Chlorophenolic compounds(g/T)	1.5	2.0	2.5	3.0	4.0
1	2,4-dichlorophenol	5.11	4.17	4.01	3.9	2.82
2	3-chlorophenol	3.77	2.39	2.10	1.90	1.78
3	4-chloroguaiacol	-	-	-	-	-
4	5-chloroguaiacol	-	-	-	-	-
5	2,3,5-trichlorophenol	0.67	0.14	0.11	0.07	0.05
6	2,4,6-trichlorophenol	12.71	10.82	9.01	8.48	6.9
7	3,6-dichloroguaiacol	0.19	0.17	0.16	0.14	0.10
8	3,4dichlorocatechol	4.09	2.98	2.57	2.44	1.94
9	4,5-dichloroguaiacol	0.64	0.31	0.27	0.23	0.19
10	5,6-dichloroguaiacol	2.74	1.48	1.08	0.85	0.64
11	2,3,4,6-tetrachlorophenol	1.41	0.96	0.83	0.79	0.59
12	3,4,5-trichloroguaiacol	1.87	1.19	1.09	1.10	1.15
13	3,4,6-trichloroguaiacol	3.78	3.66	2.84	2.29	1.96
14	3,5-dichlorosyringol	2.75	2.69	1.45	0.6	0.17
15	3,6-dichlorocatechol	-	-	-	-	-
16	4,5,6-trichloroguaiacol	2.81	2.2	1.98	1.17	1.03
17	tetrachloroguaiacol	3.31	3.19	2.87	2.69	1.47
18	3,4,6-trichlorocatechol	3.97	2.47	2.40	2.36	1.33
19	2,6-dichlorosyringaldehyde	5.18	4.86	4.52	4.16	3.54
20	5,6-dichlorovanillin	1.39	1.09	0.56	0.42	0.37
21	tetrachlorocatechol	8.83	8.42	7.99	6.27	5.62
22	2,3,4-trichlorophenol	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	65.22	53.19	45.84	39.86	31.65

C Stage bleaching conditions: Charge 5.1%, Temperature 30^0C, Consistency 3%

Table 3.312 Different chlorophenolic compounds formed in E stage at various pH values

C stage pH						
S.No.	Chlorophenolic compounds(g/T)	**1.5**	**2.0**	**2.5**	**3.0**	**4.0**
1	2,4-dichlorophenol	3.49	2.77	1.10	0.79	0.11
2	3-chlorophenol	2.62	2.37	0.97	0.78	0.04
3	4-chloroguaiacol	-	-	-	-	-
4	5-chloroguaiacol	-	-	-	-	-
5	2,3,5-trichlorophenol	0.98	0.87	0.68	0.47	0.38
6	2,4,6-trichlorophenol	5.49	5.23	3.54	2.00	0.56
7	3,6-dichloroguaiacol	0.30	0.16	0.12	0.07	0.04
8	3,4dichlorocatechol	1.73	1.18	0.96	0.87	0.38
9	4,5-dichloroguaiacol	1.89	0.89	0.74	0.31	0.26
10	5,6-dichloroguaiacol	0.76	-	0.62	0.51	0.47
11	2,3,4,6-tetrachlorophenol	0.28	0.07	0.05	0.05	0.01
12	3,4,5-trichloroguaiacol	0.98	0.95	0.54	0.39	0.29
13	3,4,6-trichloroguaiacol	0.54	0.28	0.25	0.19	0.08
14	3,5-dichlorosyringol	1.43	1.42	1.07	0.94	0.28
15	3,6-dichlorocatechol	1.07	0.96	0.72	0.50	0.34
16	4,5,6-trichloroguaiacol	2.80	2.36	1.46	1.34	0.88
17	tetrachloroguaiacol	1.45	0.82	0.77	0.53	0.34
18	3,4,6-trichlorocatechol	1.95	1.82	0.81	0.65	0.23
19	2,6-dichlorosyringaldehyde	2.39	1.62	1.59	1.56	1.08
20	5,6-dichlorovanillin	2.80	2.14	1.36	1.15	0.89
21	tetrachlorocatechol	4.33	3.65	2.98	2.52	1.96
22	2,3,4-trichlorophenol	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	37.28	29.56	20.33	15.62	8.62

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.313 Different chlorophenolic compounds formed in H stage at various pH values

		C stage pH				
S.No.	Chlorophenolic compounds(g/T)	**1.5**	**2.0**	**2.5**	**3.0**	**4.0**
1	2,4-dichlorophenol	-	-	-	-	-
2	3-chlorophenol	0.15	0.12	0.09	0.08	0.07
3	4-chloroguaiacol	0.25	0.09	0.05	0.02	0.002
4	5-chloroguaiacol	0.02	0.02	0.02	0.01	0.007
5	2,3,5-trichlorophenol	-	-	-	-	-
6	2,4,6-trichlorophenol	0.92	0.91	0.88	0.84	0.62
7	3,6-dichloroguaiacol	-	-	-	-	-
8	3,4dichlorocatechol		-	-	-	-
9	4,5-dichloroguaiacol	0.41	0.37	0.24	0.1	0.09
10	5,6-dichloroguaiacol	0.45	0.11	0.09	0.07	0.05
11	2,3,4,6-tetrachlorophenol	-	-	-	-	-
12	3,4,5-trichloroguaiacol	-	-	-	-	-
13	3,4,6-trichloroguaiacol	-	0.04	-	-	-
14	3,5-dichlorosyringol	0.29	0.25	0.24	0.23	0.20
15	3,6-dichlorocatechol	-	-	-	-	-
16	4,5,6-trichloroguaiacol	-	-	-	-	-
17	tetrachloroguaiacol	0.43	0.32	0.27	0.12	0.06
18	3,4,6-trichlorocatechol	0.11	0.13	0.19	0.28	0.3
19	2,6-dichlorosyringaldehyde	-	-	-	-	-
20	5,6-dichlorovanillin	0.33	0.49	0.51	0.54	0.79
21	tetrachlorocatechol	1.01	0.68	0.54	0.47	0.11
22	2,3,4-trichlorophenol	0.26	0.15	0.10	0.06	0.06
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	4.63	3.68	3.22	2.82	2.36

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.314 Total chlorophenolic compounds formed in CEH bleaching at various pH values

		C stage pH				
S.No.	Chlorophenolic compounds(g/T)	1.5	2.0	2.5	3.0	4.0
1	2,4-dichlorophenol	8.6	6.94	5.11	4.69	2.93
2	3-chlorophenol	6.54	4.88	3.16	2.76	1.89
3	4-chloroguaiacol	0.25	0.09	0.05	0.02	0.002
4	5-chloroguaiacol	0.02	0.02	0.02	0.01	0.007
5	2,3,5-trichlorophenol	1.65	1.01	0.79	0.54	0.43
6	2,4,6-trichlorophenol	19.12	16.96	13.43	11.32	8.08
7	3,6-dichloroguaiacol	0.49	0.33	0.28	0.21	0.14
8	3,4dichlorocatechol	5.82	4.16	3.53	3.31	2.32
9	4,5-dichloroguaiacol	2.94	1.57	1.25	0.64	0.54
10	5,6-dichloroguaiacol	3.95	1.59	1.79	1.43	1.16
11	2,3,4,6-tetrachlorophenol	1.69	1.03	0.88	0.84	0.60
12	3,4,5-trichloroguaiacol	2.85	2.14	1.63	1.49	1.44
13	3,4,6-trichloroguaiacol	4.32	3.98	3.09	2.48	2.04
14	3,5-dichlorosyringol	4.47	4.36	2.76	1.77	0.65
15	3,6-dichlorocatechol	1.07	0.96	0.72	0.50	0.34
16	4,5,6-trichloroguaiacol	5.61	4.56	3.44	2.51	1.91
17	tetrachloroguaiacol	5.19	4.33	3.91	3.34	1.87
18	3,4,6-trichlorocatechol	6.03	4.42	3.40	3.29	1.86
19	2,6-dichlorosyringaldehyde	7.57	6.48	6.11	5.72	4.62
20	5,6-dichlorovanillin	4.52	3.72	2.43	2.11	2.05
21	tetrachlorocatechol	14.17	12.75	11.51	9.26	7.69
22	2,3,4-trichlorophenol	0.26	0.15	0.10	0.06	0.06
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	107.13	86.43	69.39	58.30	42.63

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Fig.3.211

EFFECT OF C-STAGE pH ON C.O.D. GENERATION

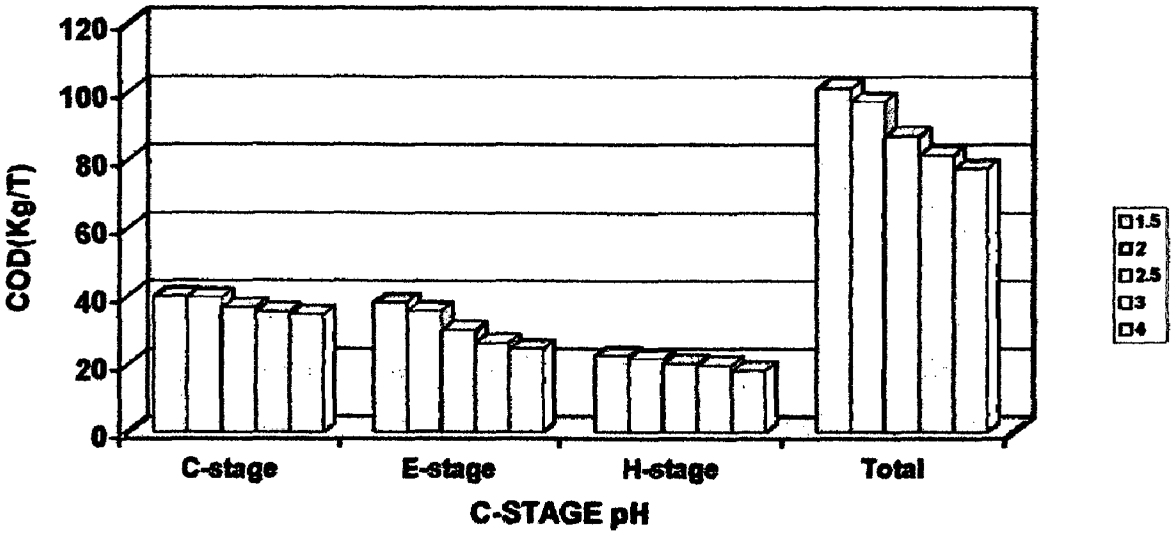


Fig.3.212

EFFECT OF C-STAGE pH ON COLOR. GENERATION

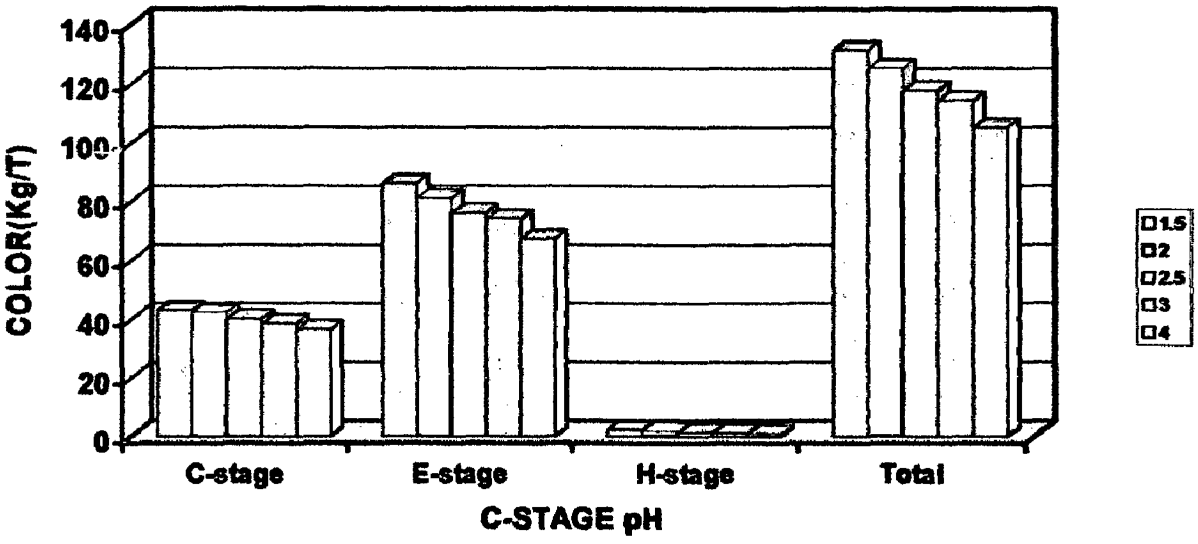


Fig.3.213

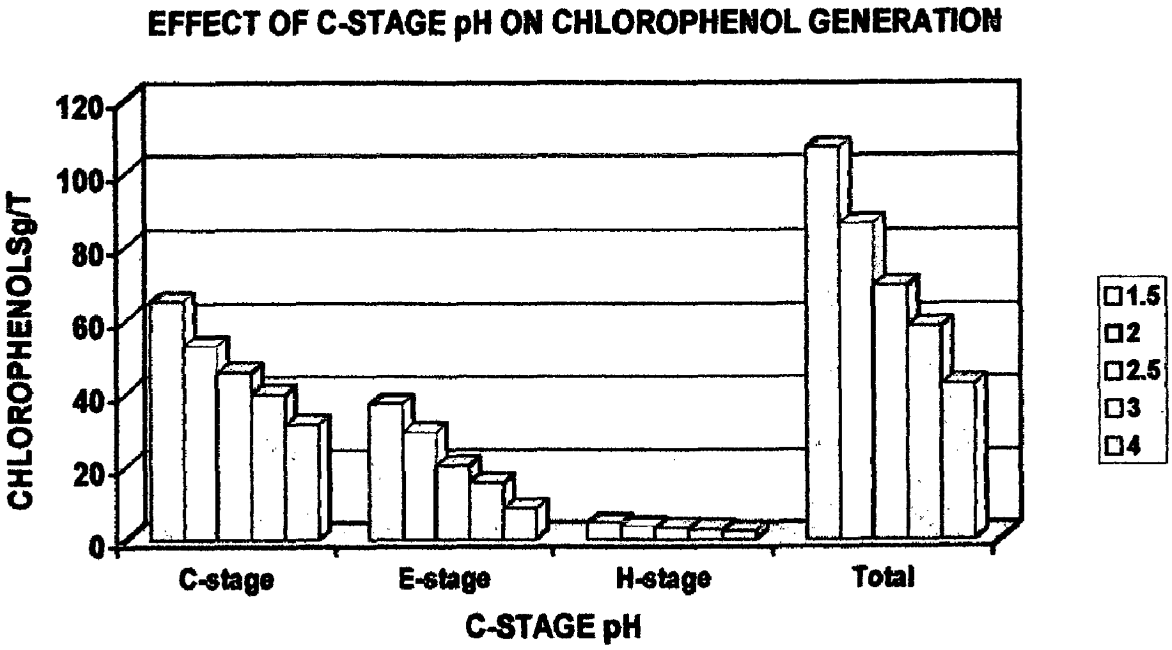


Fig.3.214

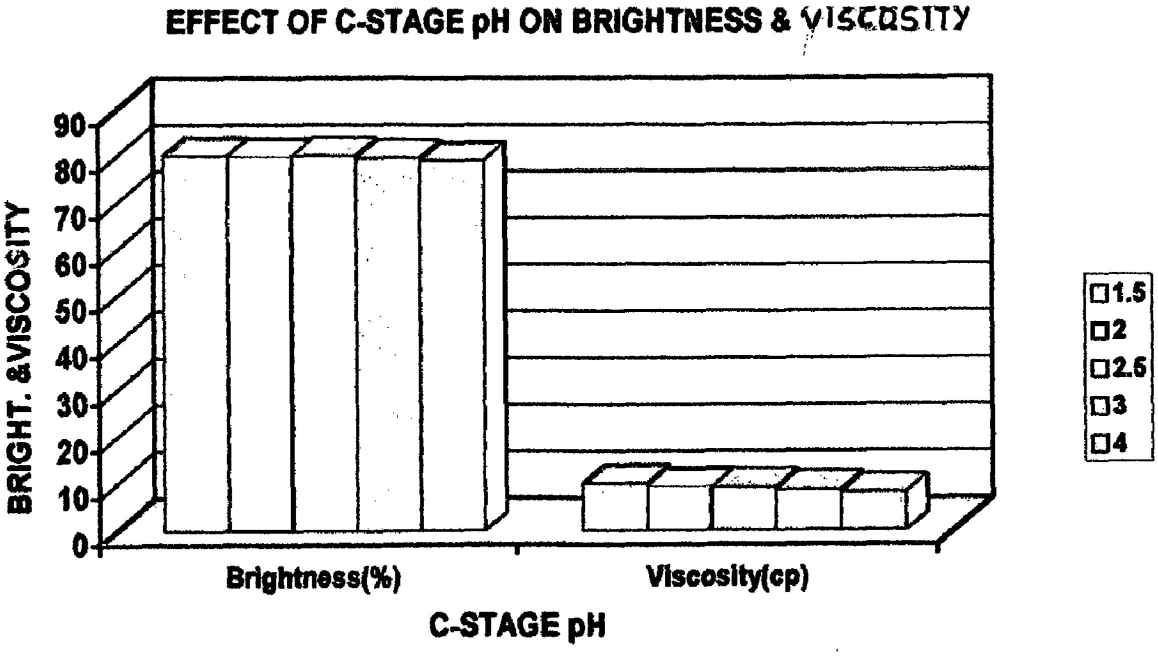


Fig.3.215

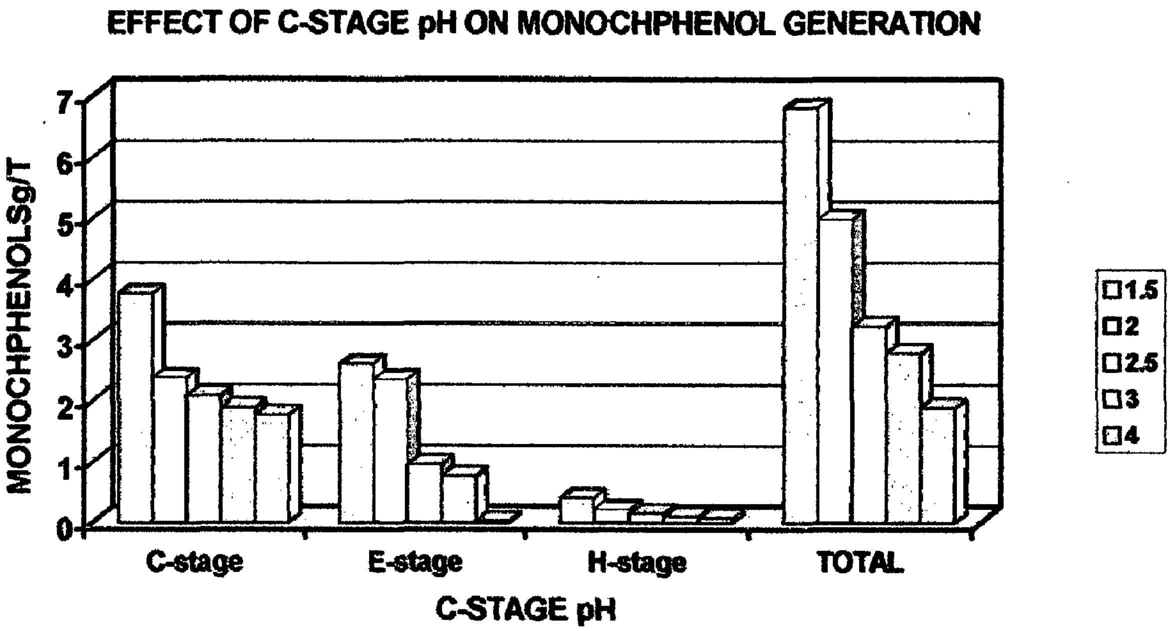


Fig.3.216

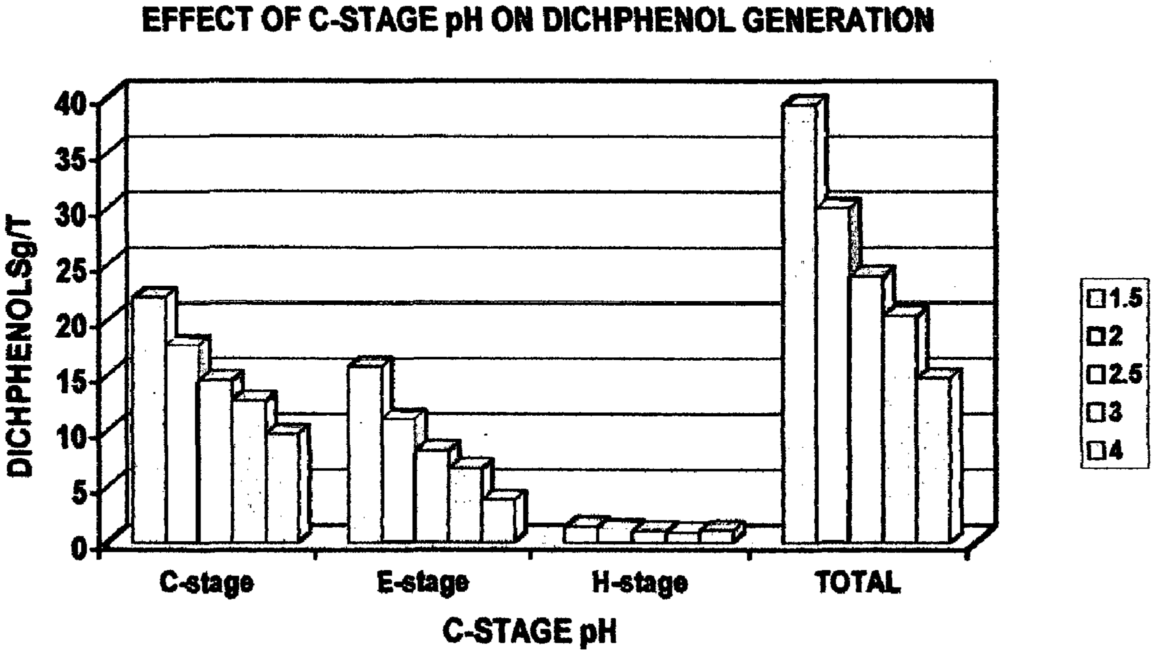


Fig.3.217

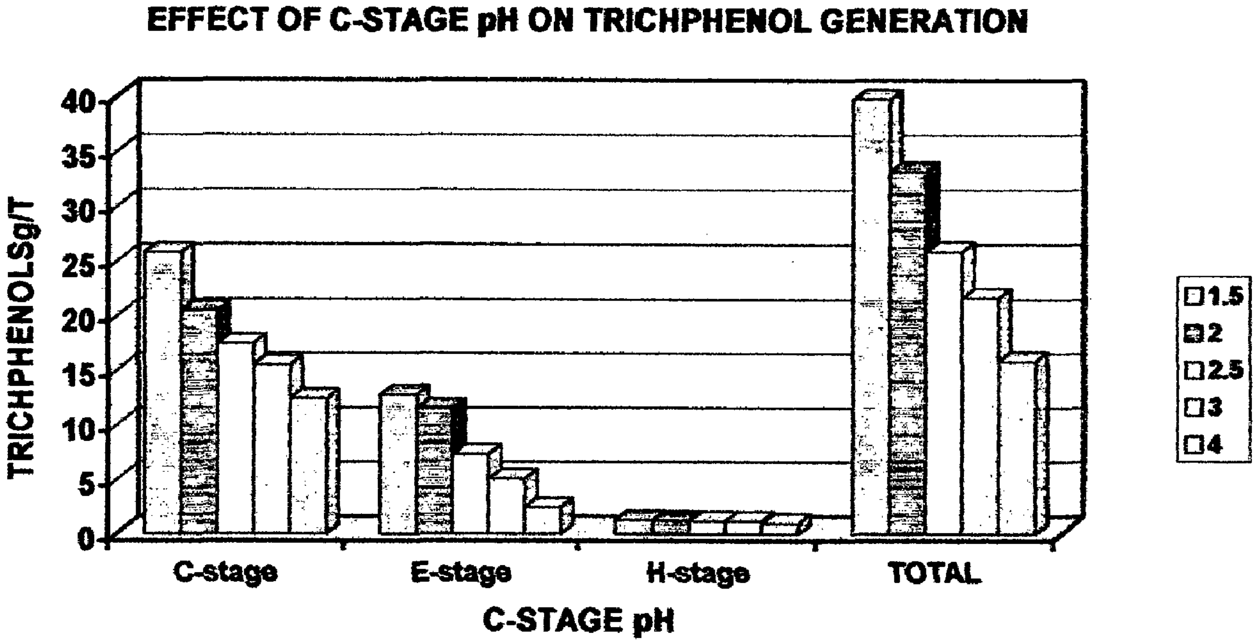


Fig.3.218

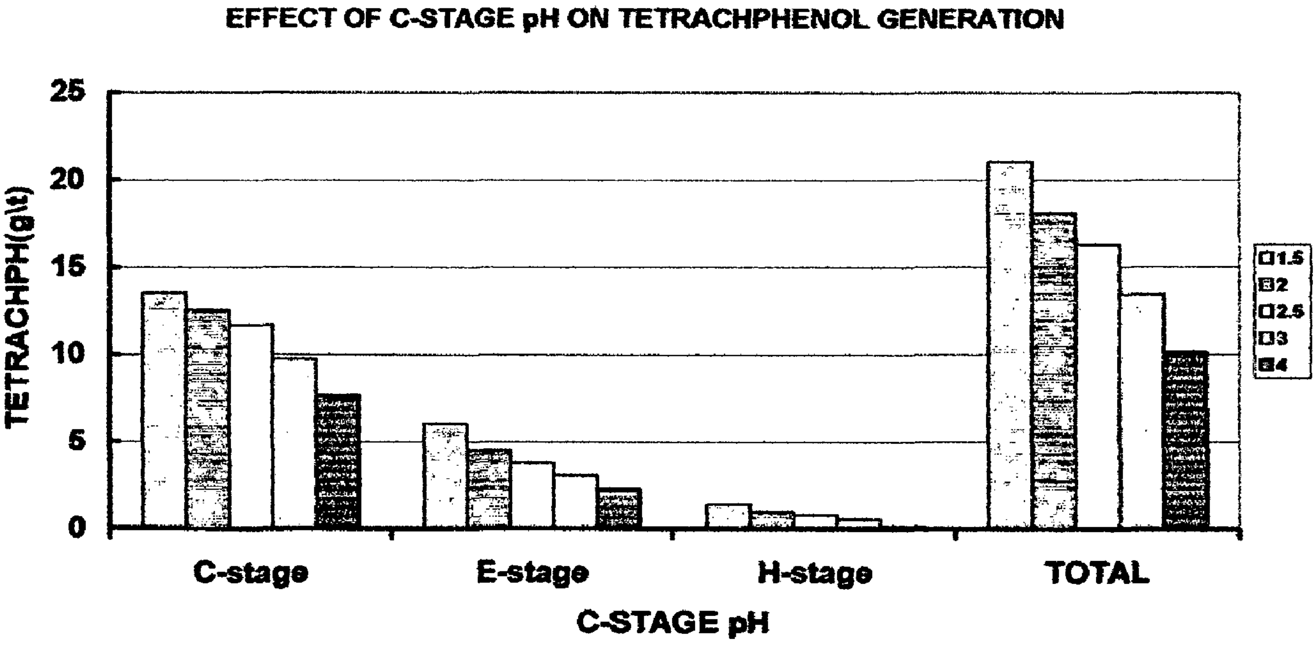


Fig.3.219

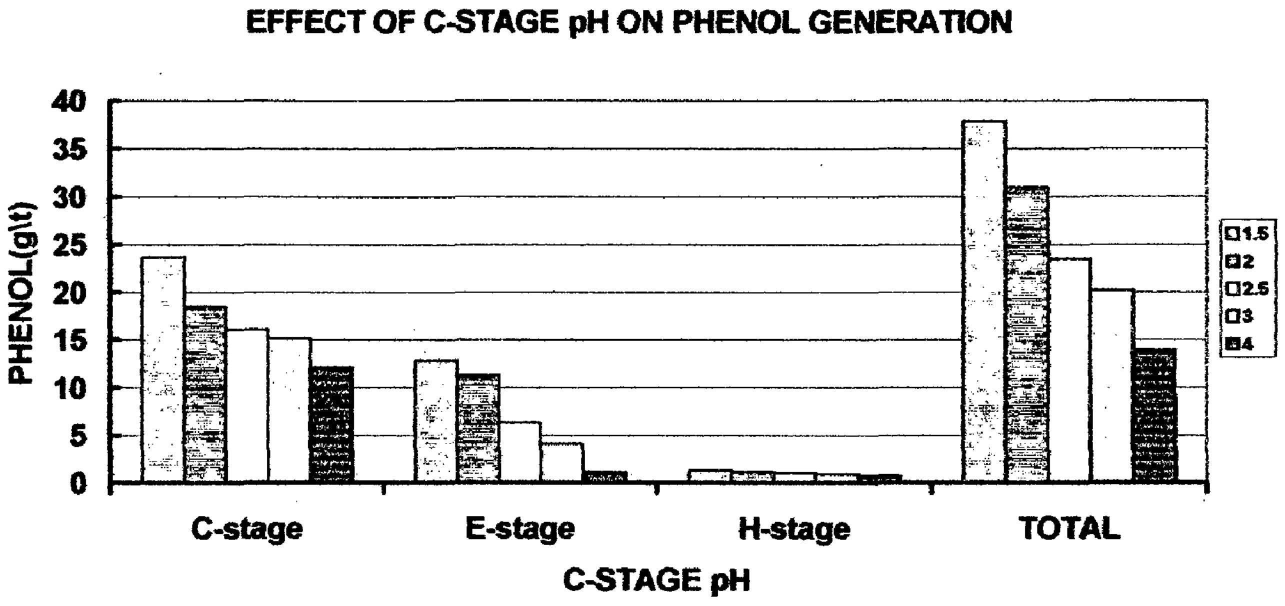


Fig.3.220

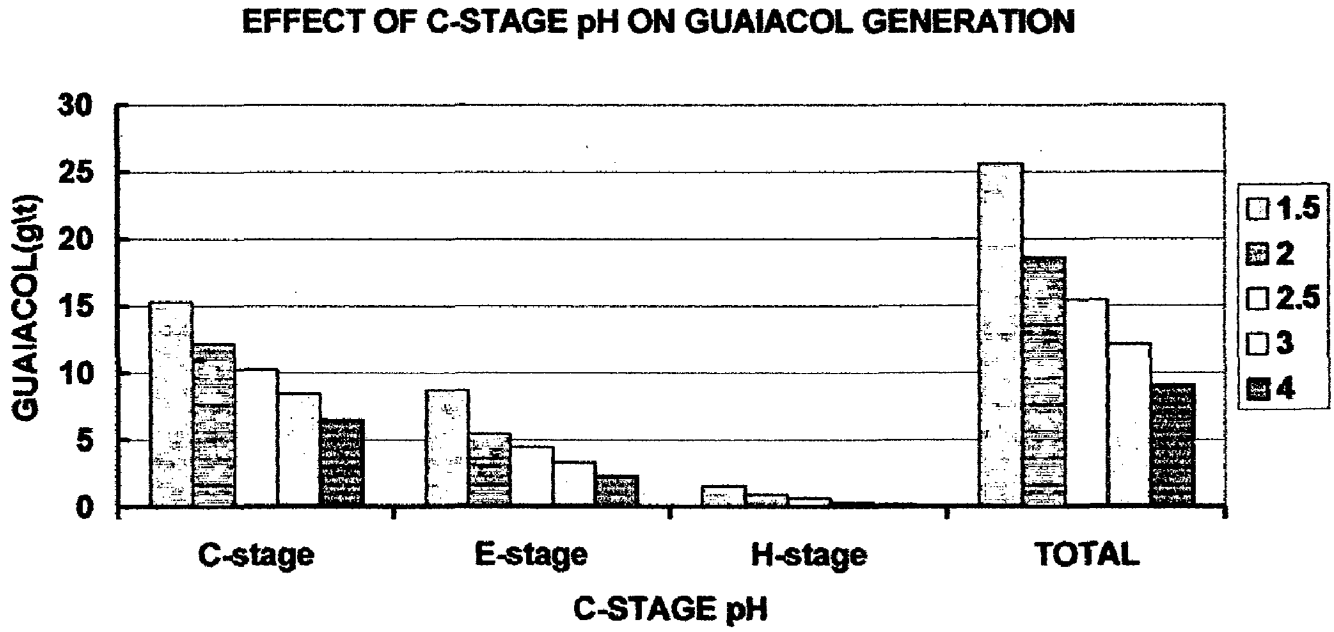


Fig.3.221

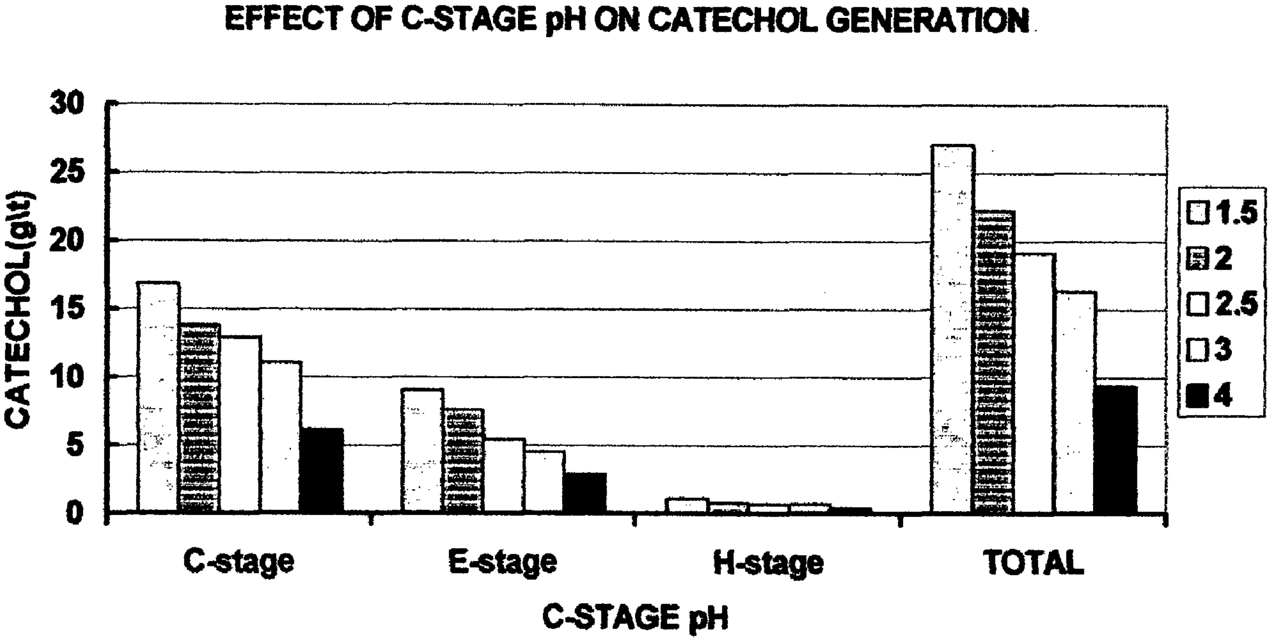


Fig.3.222

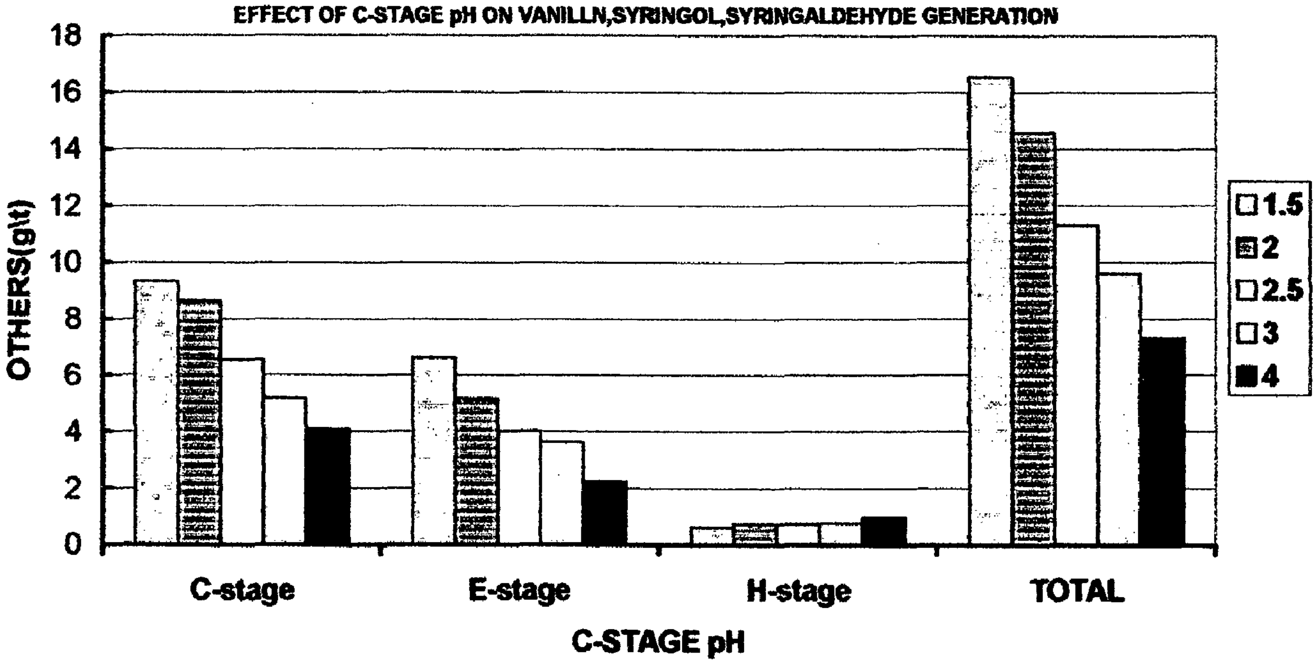


Fig.3.311

EFFECT OF C-STAGE pH ON 4,5-DCG GENERATION

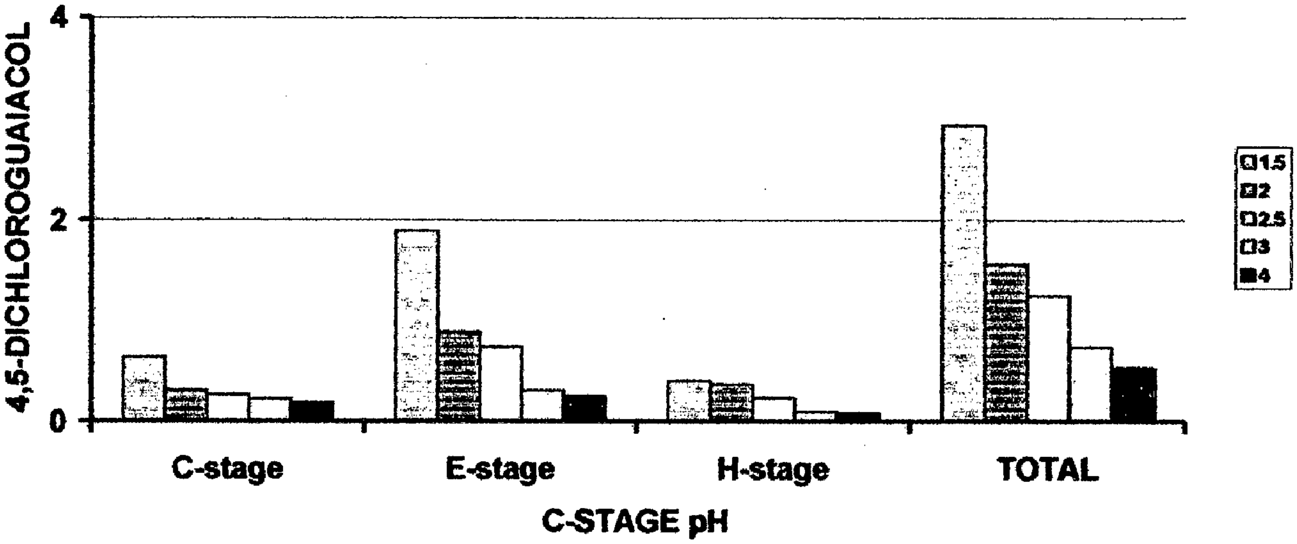


Fig.3.312

EFFECT OF C-STAGE pH ON 2,4,6-TCP GENERATION

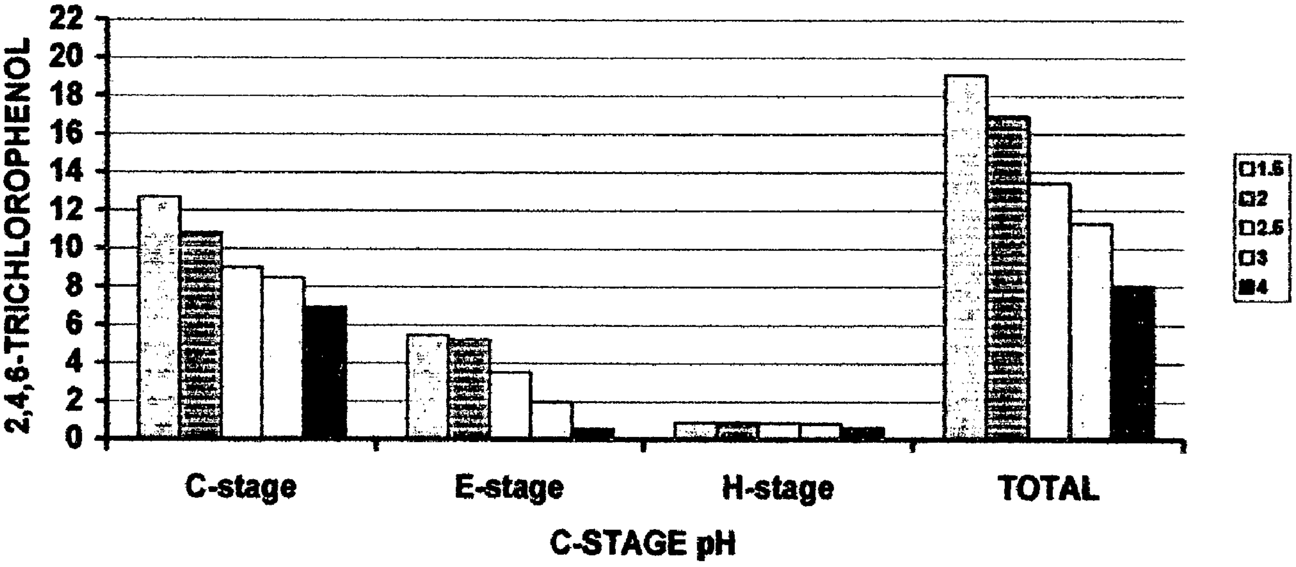


Fig.3.313

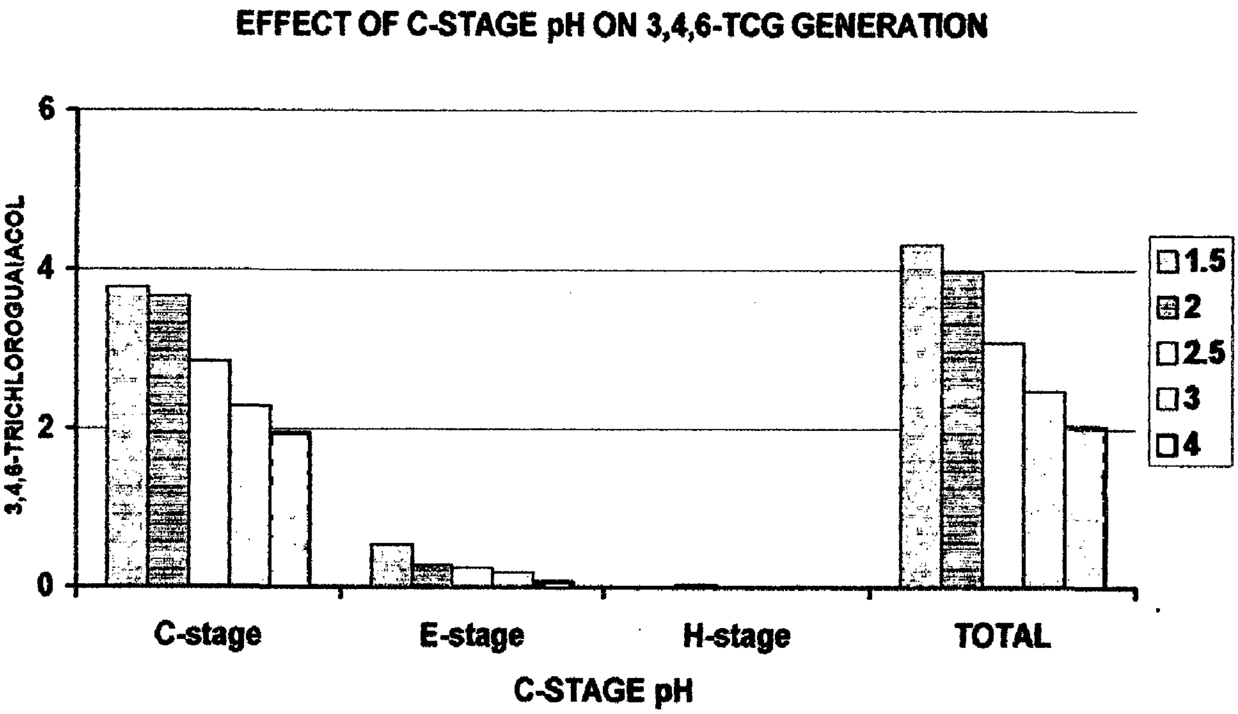


Fig.3.314

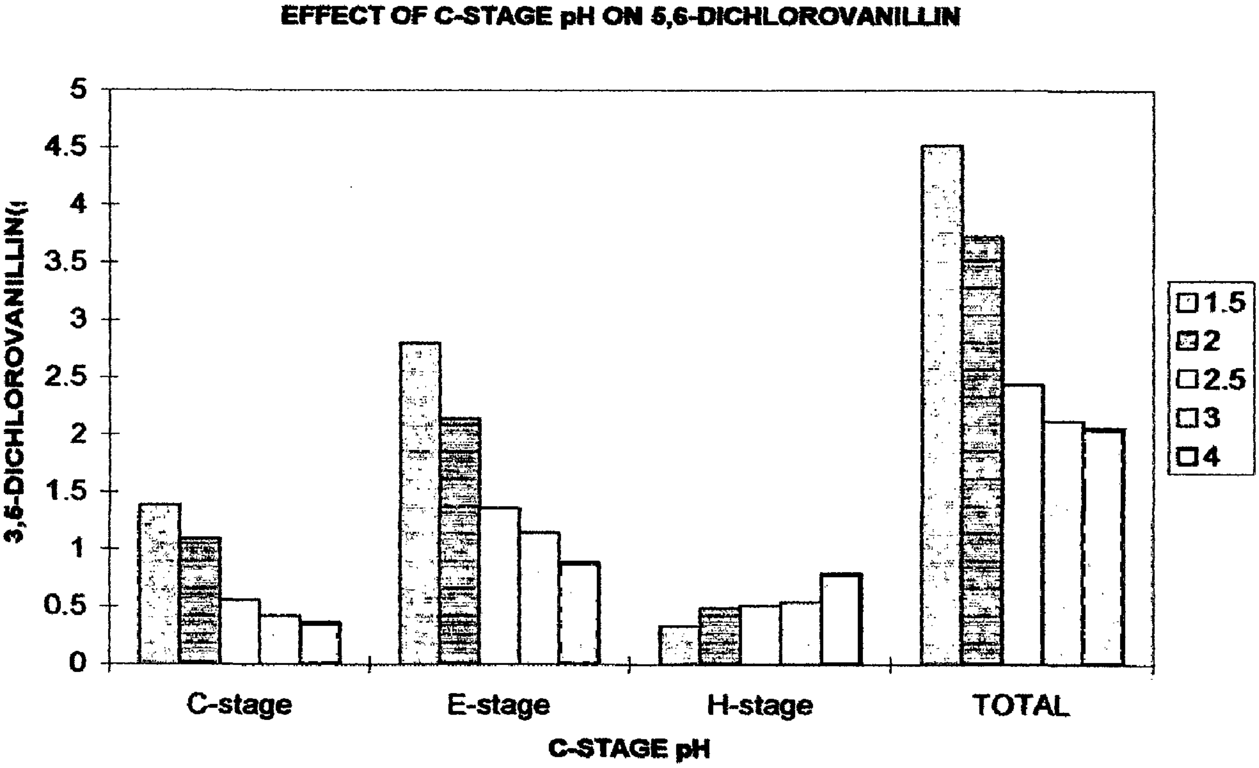


Table 3.116

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Temperature of 15^{0}C

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	2.10	0.04	0.75	0.03	-	-	2.85
2	3-chlorophenol	0.15	0.003	1.44	0.06	0.08	0.003	1.67
3	4-chloroguaiacol	-	-	-	-	0.02	0.001	0.02
4	5-chloroguaiacol	-	-	-	-	0.009	0.0004	0.009
5	2,3,5-trichlorophenol	0.03	0.001	0.25	0.01	-	-	0.28
6	2,4,6-trichlorophenol	8.10	0.16	3.82	0.15	0.36	0.01	12.28
7	3,6-dichloroguaiacol	0.04	0.001	0.3	0.01	-	-	0.34
8	3,4-dichlorocatechol	1.34	0.03	0.18	0.01	-	-	1.52
9	4,5-dichloroguaiacol	0.11	0.002	0.07	0.003	0.07	0.003	0.25
10	5,6-dichloroguaiacol	0.86	0.02	0.04	0.002	0.09	0.004	0.99
11	2,3,4,6-tetrachlorophenol	0.76	0.02	-	-	-	-	0.76
12	3,4,5-trichloroguaiacol	0.08	0.002	0.90	0.04	-	-	0.98
13	3,4,6-trichloroguaiacol	0.60	0.01	-	-	-	-	0.6
14	3,5-dichlorosyringol	0.90	0.02	0.25	0.01	0.11	0.004	1.26
15	3,6-dichlorocatechol	0.69	0.01	-	-	-	-	0.69
16	4,5,6-trichloroguaiacol	0.31	0.01	0.54	0.02	-	-	0.85
17	tetrachloroguaiacol	0.12	0.002	0.23	0.01	0.12	0.005	0.47
18	3,4,6-trichlorocatechol	0.55	0.01	0.75	0.03	0.04	0.002	1.34
19	2,6-dichlorosyringaldehyde	1.16	0.02	1.27	0.05	-	-	2.43
20	5,6-dichlorovanillin	0.31	0.01	1.44	0.06	0.28	0.01	2.03
21	tetrachlorocatechol	3.57	0.07	1.7	0.07	0.32	0.01	5.59
22	2,3,4-trichlorophenol	-	-	-	-	0.04	0.002	0.04
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	21.78	0.43	13.93	0.56	1.54	0.05	37.25

C Stage bleaching conditions: Charge 5.1%, pH 2, Consistency 3%

Table 3.117

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Temperature of 20^{0}C

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	3.87	0.08	1.63	0.07	-	-	5.50
2	3-chlorophenol	1.48	0.03	1.97	0.08	0.09	0.004	3.54
3	4-chloroguaiacol	-	-	-	-	0.04	0.001	0.04
4	5-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01
5	2,3,5-trichlorophenol	0.05	0.001	0.44	0.02	-	-	0.49
6	2,4,6-trichlorophenol	8.95	0.18	4.54	0.18	0.79	0.03	14.28
7	3,6-dichloroguaiacol	0.09	0.002	0.25	0.01	-	-	0.34
8	3,4-dichlorocatechol	1.52	0.03	0.56	0.02	-	-	2.08
9	4,5-dichloroguaiacol	0.21	0.004	0.24	0.01	0.23	0.01	0.68
10	5,6-dichloroguaiacol	0.89	0.02	0.29	0.01	0.1	0.004	1.28
11	2,3,4,6-tetrachlorophenol	0.81	0.02	0.04	0.002	-	-	0.85
12	3,4,5-trichloroguaiacol	0.09	0.02	0.93	0.04	-	-	1.02
13	3,4,6-trichloroguaiacol	0.87	0.02	0.24	0.01	-	-	1.11
14	3,5-dichlorosyringol	1.53	0.03	0.87	0.03	0.17	0.01	2.57
15	3,6-dichlorocatechol	0.92	0.02	0.30	0.01	-	-	1.22
16	4,5,6-trichloroguaiacol	0.82	0.02	1.44	0.06	-	-	2.26
17	tetrachloroguaiacol	0.88	0.02	0.57	0.02	0.2	0.01	1.65
18	3,4,6-trichlorocatechol	0.81	0.02	0.92	0.04	0.09	0.003	1.82
19	2,6-dichlorosyringaldehyde	1.95	0.04	1.54	0.06	-	-	3.49
20	5,6-dichlorovanillin	0.61	0.01	1.73	0.07	0.38	0.02	2.72
21	tetrachlorocatechol	4.64	0.09	2.69	0.11	0.50	0.02	7.83
22	2,3,4-trichlorophenol	-	-	-	-	0.09	0.004	0.09
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	30.99	0.62	21.19	0.85	2.69	0.12	54.87

C Stage bleaching conditions: Charge 5.1%, pH 2, Consistency 3%

Table 3.118

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Temperature of 25^{0}C

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	3.98	0.08	2.49	0.10	-	-	6.47
2	3-chlorophenol	1.79	0.03	2.09	0.08	0.10	0.004	3.98
3	4-chloroguaiacol	-	-	-	-	0.07	0.003	0.07
4	5-chloroguaiacol	-	-	-	-	0.02	0.001	0.02
5	2,3,5-trichlorophenol	0.09	0.002	0.62	0.02	-	-	0.71
6	2,4,6-trichlorophenol	9.25	0.19	4.87	0.19	0.84	0.03	14.96
7	3,6-dichloroguaiacol	0.13	0.003	0.2	0.01	-	-	0.33
8	3,4-dichlorocatechol	1.87	0.04	0.98	0.04	-	-	2.85
9	4,5-dichloroguaiacol	0.28	0.01	0.77	0.03	0.31	0.01	1.36
10	5,6-dichloroguaiacol	1.43	0.03	0.35	0.01	0.11	0.004	1.89
11	2,3,4,6-tetrachlorophenol	0.87	0.02	0.06	0.002	-	-	0.93
12	3,4,5-trichloroguaiacol	0.98	0.02	0.95	0.04	-	-	1.93
13	3,4,6-trichloroguaiacol	1.42	0.03	0.27	0.01	-	-	1.69
14	3,5-dichlorosyringol	1.89	0.04	1.15	0.05	0.2	0.01	3.24
15	3,6-dichlorocatechol	-	-	0.46	0.02	-	-	0.46
16	4,5,6-trichloroguaiacol	1.37	0.03	1.94	0.08	-	-	3.31
17	tetrachloroguaiacol	0.98	0.02	0.67	0.03	0.27	0.01	1.92
18	3,4,6-trichlorocatechol	1.18	0.02	1.27	0.05	0.11	0.004	2.56
19	2,6-dichlorosyringaldehyde	2.98	0.06	1.60	0.06	-	-	4.58
20	5,6-dichlorovanillin	0.85	0.02	2.09	0.08	0.45	0.02	3.39
21	tetrachlorocatechol	6.47	0.13	3.04	0.12	0.63	0.03	10.14
22	2,3,4-trichlorophenol	-	-	-	-	0.13	0.001	0.13
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	37.81	0.76	25.87	1.02	3.24	0.13	66.92

C Stage bleaching conditions: Charge 5.1%, pH 2, Consistency 3%

Table 3.119

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Temperature of 30^{0}C

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	4.17	0.08	2.77	0.11	-	-	6.94
2	3-chlorophenol	2.39	0.05	2.37	0.09	0.12	0.004	4.88
3	4-chloroguaiacol	-	-	-	-	0.09	0.003	0.09
4	5-chloroguaiacol	-	-	-	-	0.02	0.008	0.02
5	2,3,5-trichlorophenol	0.14	0.003	0.87	0.03	-	-	1.01
6	2,4,6-trichlorophenol	10.82	0.22	5.23	0.21	0.91	0.04	16.96
7	3,6-dichloroguaiacol	0.17	0.003	0.16	0.01	-	-	0.33
8	3,4-dichlorocatechol	2.98	0.06	1.18	0.05	-	-	4.16
9	4,5-dichloroguaiacol	0.31	0.01	0.89	0.04	0.37	0.01	1.57
10	5,6-dichloroguaiacol	1.48	0.03	-	-	0.11	0.004	1.59
11	2,3,4,6-tetrachlorophenol	0.96	0.02	0.07	0.003	-	-	1.03
12	3,4,5-trichloroguaiacol	1.19	0.02	0.95	0.04	-	-	2.14
13	3,4,6-trichloroguaiacol	3.66	0.07	0.28	0.01	0.04	0.001	3.98
14	3,5-dichlorosyringol	2.69	0.05	1.42	0.06	0.25	0.01	4.36
15	3,6-dichlorocatechol	-	-	0.96	0.04	-	-	0.96
16	4,5,6-trichloroguaiacol	2.20	0.04	2.36	0.09	-	-	4.56
17	tetrachloroguaiacol	3.19	0.06	0.82	0.03	0.32	0.01	4.33
18	3,4,6-trichlorocatechol	2.47	0.05	1.82	0.07	0.13	0.005	4.42
19	2,6-dichlorosyringaldehyde	4.86	0.10	1.62	0.06	-	-	6.48
20	5,6-dichlorovanillin	1.09	0.02	2.14	0.09	0.49	0.02	3.72
21	tetrachlorocatechol	8.42	0.17	3.65	0.15	0.68	0.03	12.75
22	2,3,4-trichlorophenol	-	-	-	-	0.15	0.01	0.15
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	53.19	1.06	29.56	1.18	3.68	0.15	86.43

C Stage bleaching conditions: Charge 5.1%, pH 2, Consistency 3%

Table 3.120

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Temperature of 35°C								
S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	4.54	0.09	3.12	0.12	-	-	7.66
2	3-chlorophenol	2.95	0.06	2.93	0.12	0.33	0.01	6.21
3	4-chloroguaiacol	-	-	-	-	0.10	.004	0.10
4	5-chloroguaiacol	-	-	-	-	0.05	0.002	0.05
5	2,3,5-trichlorophenol	1.16	0.02	0.98	0.04	-	-	2.14
6	2,4,6-trichlorophenol	11.23	0.22	6.03	0.24	0.99	0.04	18.25
7	3,6-dichloroguaiacol	0.47	0.01	0.11	0.004	-	-	0.58
8	3,4-dichlorocatechol	3.10	0.06	1.67	0.07	-	-	4.77
9	4,5-dichloroguaiacol	0.35	0.01	1.04	0.04	0.39	0.02	1.78
10	5,6-dichloroguaiacol	1.54	0.03	0.77	0.03	0.17	0.01	2.48
11	2,3,4,6-tetrachlorophenol	1.09	0.02	0.36	0.01	-	-	1.45
12	3,4,5-trichloroguaiacol	1.82	0.04	1.40	0.06	-	-	3.22
13	3,4,6-trichloroguaiacol	3.78	0.07	0.70	0.03	-	-	4.48
14	3,5-dichlorosyringol	3.42	0.07	1.71	0.07	0.32	0.01	5.45
15	3,6-dichlorocatechol	-	-	2.50	0.10	-	-	2.5
16	4,5,6-trichloroguaiacol	2.72	0.05	2.45	0.10	-	-	5.17
17	tetrachloroguaiacol	3.23	0.06	2.23	0.09	0.43	0.02	5.89
18	3,4,6-trichlorocatechol	2.53	0.05	1.93	0.08	0.15	0.01	4.61
19	2,6-dichlorosyringaldehyde	5.44	0.11	1.66	0.07	-	-	7.10
20	5,6-dichlorovanillin	1.76	0.04	2.22	0.09	0.69	0.03	4.67
21	tetrachlorocatechol	8.88	0.18	5.6	0.22	0.83	0.03	15.31
22	2,3,4-trichlorophenol	-	-	-	-	0.19	0.01	0.19
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	60.01	1.20	39.41	1.58	4.64	0.20	104.06

C Stage bleaching conditions: Charge 5.1%, pH 2, Consistency 3%

Table 3.223

Effect of change in C Stage temperature on the generation of Chlorophenolic compounds

	Chlorophenolic compounds (kg/t)			
Temperature^{0}C	C-stage	E-stage	H-stage	TOTAL
15	21.78	13.93	1.54	37.25
20	30.99	21.19	2.69	54.87
25	37.81	25.87	3.24	66.92
30	53.19	29.56	3.68	86.43
35	60.01	39.41	4.64	104.06

Table 3.224

Effect of change in C Stage temperature on the generation of effluent COD

	COD (kg/t)			
Temperature^{0}C	C-stage	E-stage	H-stage	TOTAL
15	32.5	25.3	17.3	75.1
20	38.7	28.6	18.9	86.2
25	39	30.9	19.8	89.7
30	39.9	35.8	21.8	97.5
35	40.2	36.1	22.5	98.8

Table 3.225

Effect of change in C Stage temperature on the generation of effluent Colour

	Colour (kg/t)			
Temperature^{0}C	C-stage	E-stage	H-stage	TOTAL
15	21.5	74.3	0.6	96.4
20	37.5	77.5	1.2	116.2
25	39.5	79.6	1.6	120.7
30	42.5	81.2	1.9	125.6
35	43.5	82.3	2.1	127.9

Table 3.226

Effect of change in C Stage temperature on Brightness and Viscosity of bleached pulps obtained by CEH bleaching

Temperature^{0}C	Brightness (%)	Viscosity (cp)
15	79.1	10.1
20	79.9	9.8
25	80.2	9.6
30	80.1	9.4
35	80.5	8.5

Table 3.227

Monochlorophenolic compounds present in different effluents formed by bleaching at various C Stage temperature

Monochlorophenolic compounds (g/t)				
Temperature(⁰C)	C-stage	E-stage	H-stage	TOTAL
15	0.15	1.44	0.11	1.70
20	1.48	1.97	0.14	3.59
25	1.79	2.09	0.19	4.07
30	2.39	2.37	0.23	4.99
35	2.95	2.93	0.48	6.36

Table 3.228

Dichlorophenolic compounds present in different effluents formed by bleaching at various C Stage temperature

Dichlorophenolic compounds (g/t)				
Temperature(⁰C)	C-stage	E-stage	H-stage	TOTAL
15	7.51	4.30	0.55	12.36
20	11.59	7.41	0.88	19.88
25	13.41	10.09	1.07	24.57
30	16.27	11.14	1.22	28.63
35	20.62	14.80	1.57	36.99

Table 3.229

Trichlorophenolic compounds present in different effluents formed by bleaching at various C Stage temperature

Trichlorophenolic compounds (g/t)				
Temperature(⁰C)	C-stage	E-stage	H-stage	TOTAL
15	9.67	6.26	0.44	16.37
20	11.59	8.51	0.97	21.07
25	14.29	9.92	1.08	25.29
30	20.48	11.51	1.23	33.22
35	23.24	13.49	1.33	38.06

Table 3.330

Tetrachlorophenolic compounds present in different effluents formed by bleaching at various C Stage temperature

Tetrachlorophenolic compounds (g/t)				
Temperature(⁰C)	C-stage	E-stage	H-stage	TOTAL
15	4.45	1.93	0.44	6.82
20	6.33	3.30	0.70	10.33
25	8.32	3.77	0.9	12.99
30	11.70	4.54	1.00	17.24
35	13.20	8.19	1.26	22.65

Table 3.331

Category wise load of chlorophenols in different effluents formed by bleaching at various C Stage temperature

Chlorophenols (g/t)				
Temperature(^{0}C)	**C-stage**	**E-stage**	**H-stage**	**TOTAL**
15	11.14	6.26	0.48	17.88
20	15.16	8.62	0.97	24.75
25	15.98	10.13	1.07	27.18
30	17.61	11.31	1.18	30.10
35	20.97	13.42	1.51	35.9

Table 3.330

Category wise load of chloroguaiacols in different effluents formed by bleaching at various C Stage temperature

Chloroguaiacols (g/t)				
Temperature(^{0}C)	**C-stage**	**E-stage**	**H-stage**	**TOTAL**
15	2.12	2.08	0.31	4.51
20	3.85	3.96	0.58	8.39
25	6.59	5.15	0.78	12.52
30	10.72	5.46	0.95	17.13
35	13.91	8.70	1.14	23.75

Table 3.331

Category wise load of chlorocatechols in different effluents formed by bleaching at various C Stage temperature

Chlorocatechols (g/t)				
Temperature(^{0}C)	**C-stage**	**E-stage**	**H-stage**	**TOTAL**
15	6.15	2.63	0.36	9.14
20	7.89	4.47	0.59	12.95
25	9.52	5.75	0.74	16.01
30	13.87	7.61	0.81	22.29
35	14.51	11.70	0.98	27.19

Table 3.334

Category wise load of other chlorophenolic compounds in different effluents formed by bleaching at various C Stage temperature

Other Chlorophenolic compounds (g/t)				
Temperature(^{0}C)	C-stage	E-stage	H-stage	TOTAL
15	2.37	2.96	0.39	5.72
20	4.09	4.14	0.55	8.78
25	5.72	4.84	0.65	11.21
30	8.64	5.18	0.74	14.56
35	10.62	5.59	1.01	17.22

Table 3.315 dfferent chlorophenolic compounds formed in C stage at various temperature

		C stage Temperature(^{0}C)				
S.No.	Chlorophenolic compounds(g/T)	15	20	25	30	35
1	2,4-dichlorophenol	2.10	3.87	3.98	4.17	4.54
2	3-chlorophenol	0.15	1.48	1.79	2.39	2.95
3	4-chloroguaiacol	-	-	-	-	-
4	5-chloroguaiacol	-	-	-	-	-
5	2,3,5-trichlorophenol	0.03	0.05	0.09	0.14	1.16
6	2,4,6-trichlorophenol	8.10	8.95	9.25	10.82	11.23
7	3,6-dichloroguaiacol	0.04	0.09	0.13	0.17	0.47
8	3,4dichlorocatechol	1.34	1.52	1.87	2.98	3.10
9	4,5-dichloroguaiacol	0.11	0.21	0.28	0.31	0.35
10	5,6-dichloroguaiacol	0.86	0.89	1.43	1.48	1.54
11	2,3,4,6-tetrachlorophenol	0.76	0.81	0.87	0.96	1.09
12	3,4,5-trichloroguaiacol	0.08	0.09	0.98	1.19	1.82
13	3,4,6-trichloroguaiacol	0.60	0.87	1.42	3.66	3.78
14	3,5-dichlorosyringol	0.90	1.53	1.89	2.69	3.42
15	3,6-dichlorocatechol	0.69	0.92	-	-	-
16	4,5,6-trichloroguaiacol	0.31	0.82	1.37	2.20	2.72
17	tetrachloroguaiacol	0.12	0.88	0.98	3.19	3.23
18	3,4,6-trichlorocatechol	0.55	0.81	1.18	2.47	2.53
19	2,6-dichlorosyringaldehyde	1.16	1.95	2.98	4.86	5.44
20	5,6-dichlorovanillin	0.31	0.61	0.85	1.09	1.76
21	tetrachlorocatechol	3.57	4.64	6.47	8.42	8.88
22	2,3,4-trichlorophenol	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	21.78	30.99	37.81	53.19	60.01

C Stage bleaching conditions: Charge 5.1%, pH 2, Consistency 3%

Table 3.316 Different chlorophenolic compounds formed in E stage at various temperature

		C stage Temperature(^{0}C)				
S.No.	Chlorophenolic compounds(g/T)	**15**	**20**	**25**	**30**	**35**
1	2,4-dichlorophenol	0.75	1.63	2.49	2.77	3.12
2	3-chlorophenol	1.44	1.97	2.09	2.37	2.93
3	4-chloroguaiacol	-	-	-	-	-
4	5-chloroguaiacol	-	-	-	-	-
5	2,3,5-trichlorophenol	0.25	0.44	0.62	0.87	0.98
6	2,4,6-trichlorophenol	3.82	4.54	4.87	5.23	6.03
7	3,6-dichloroguaiacol	0.30	0.25	0.20	0.16	0.11
8	3,4dichlorocatechol	0.18	0.56	0.98	1.18	1.67
9	4,5-dichloroguaiacol	0.07	0.24	0.77	0.89	1.04
10	5,6-dichloroguaiacol	0.04	0.29	0.35	-	0.77
11	2,3,4,6-tetrachlorophenol	-	0.04	0.06	0.07	0.36
12	3,4,5-trichloroguaiacol	0.90	0.93	0.95	0.95	1.40
13	3,4,6-trichloroguaiacol	-	0.24	0.27	0.28	0.70
14	3,5-dichlorosyringol	0.25	0.87	1.15	1.42	1.71
15	3,6-dichlorocatechol	-	0.30	0.46	0.96	2.50
16	4,5,6-trichloroguaiacol	0.54	1.44	1.94	2.36	2.45
17	tetrachloroguaiacol	0.23	0.57	0.67	0.82	2.23
18	3,4,6-trichlorocatechol	0.75	0.92	1.27	1.82	1.93
19	2,6-dichlorosyringaldehyde	1.27	1.54	1.60	1.62	1.66
20	5,6-dichlorovanillin	1.44	1.73	2.09	2.14	2.22
21	tetrachlorocatechol	1.70	2.69	3.04	3.65	5.60
22	2,3,4-trichlorophenol	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	13.93	21.19	25.87	29.56	39.41

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.317 Different chlorophenolic compounds formed in H stage at various temperature

		C stage Temperature(⁰C)				
S.No.	Chlorophenolic compounds(g/T)	15	20	25	30	35
1	2,4-dichlorophenol	-	-	-	-	-
2	3-chlorophenol	0.08	0.09	0.10	0.12	0.33
3	4-chloroguaiacol	0.02	0.04	0.07	0.09	0.1
4	5-chloroguaiacol	0.009	0.01	0.02	0.02	0.05
5	2,3,5-trichlorophenol	-	-	-	-	-
6	2,4,6-trichlorophenol	0.36	0.79	0.84	0.91	0.99
7	3,6-dichloroguaiacol	-	-	-	-	-
8	3,4dichlorocatechol	-	-	-	-	-
9	4,5-dichloroguaiacol	0.07	0.23	0.31	0.37	0.39
10	5,6-dichloroguaiacol	0.09	0.10	0.11	0.11	0.17
11	2,3,4,6-tetrachlorophenol	-	-	-	-	-
12	3,4,5-trichloroguaiacol	-	-	-	-	-
13	3,4,6-trichloroguaiacol	-	-	-	0.04	-
14	3,5-dichlorosyringol	0.11	0.17	0.2	0.25	0.32
15	3,6-dichlorocatechol	-	-	-	-	-
16	4,5,6-trichloroguaiacol	-	-	-	-	-
17	tetrachloroguaiacol	0.12	0.2	0.27	0.32	0.43
18	3,4,6-trichlorocatechol	0.04	0.09	0.11	0.13	0.15
19	2,6-dichlorosyringaldehyde	-	-	-	-	-
20	5,6-dichlorovanillin	0.28	0.38	0.45	0.49	0.69
21	tetrachlorocatechol	0.32	0.5	0.63	0.68	0.83
22	2,3,4-trichlorophenol	0.04	0.09	0.13	0.15	0.19
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	1.54	2.69	3.24	3.68	4.64

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30⁰C, Consistency 3%

Table 3.318 Total chlorophenolic compounds formed in CEH bleaching at various temperature

C stage Temperature(^{0}C)						
S.No.	Chlorophenolic compounds(g/T)	**15**	**20**	**25**	**30**	**35**
1	2,4-dichlorophenol	2.85	5.50	6.47	6.94	7.66
2	3-chlorophenol	1.67	3.54	3.98	4.88	6.21
3	4-chloroguaiacol	0.02	0.04	0.07	0.09	0.10
4	5-chloroguaiacol	0.009	0.01	0.02	0.02	0.05
5	2,3,5-trichlorophenol	0.28	0.49	0.71	1.01	2.14
6	2,4,6-trichlorophenol	12.28	14.28	14.96	16.96	18.25
7	3,6-dichloroguaiacol	0.34	0.34	0.33	0.33	0.58
8	3,4dichlorocatechol	1.52	2.08	2.85	4.16	4.77
9	4,5-dichloroguaiacol	0.25	0.68	1.36	1.57	1.78
10	5,6-dichloroguaiacol	0.99	1.28	1.89	1.59	2.48
11	2,3,4,6-tetrachlorophenol	0.76	0.85	0.93	1.03	1.45
12	3,4,5-trichloroguaiacol	0.98	1.02	1.93	2.14	3.22
13	3,4,6-trichloroguaiacol	0.60	1.11	1.69	3.98	4.48
14	3,5-dichlorosyringol	1.26	2.57	3.24	4.36	5.45
15	3,6-dichlorocatechol	0.69	1.22	0.46	0.96	2.50
16	4,5,6-trichloroguaiacol	0.85	2.26	3.31	4.56	5.17
17	tetrachloroguaiacol	0.47	1.65	1.92	4.33	5.89
18	3,4,6-trichlorocatechol	1.34	1.82	2.56	4.42	4.61
19	2,6-dichlorosyringaldehyde	2.43	3.49	4.58	6.48	7.10
20	5,6-dichlorovanillin	2.03	2.72	3.39	3.72	4.67
21	tetrachlorocatechol	5.59	7.83	10.14	12.75	15.31
22	2,3,4-trichlorophenol	0.04	0.09	0.13	0.15	0.19
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	37.25	54.87	66.92	86.43	104.06

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Fig.3.223

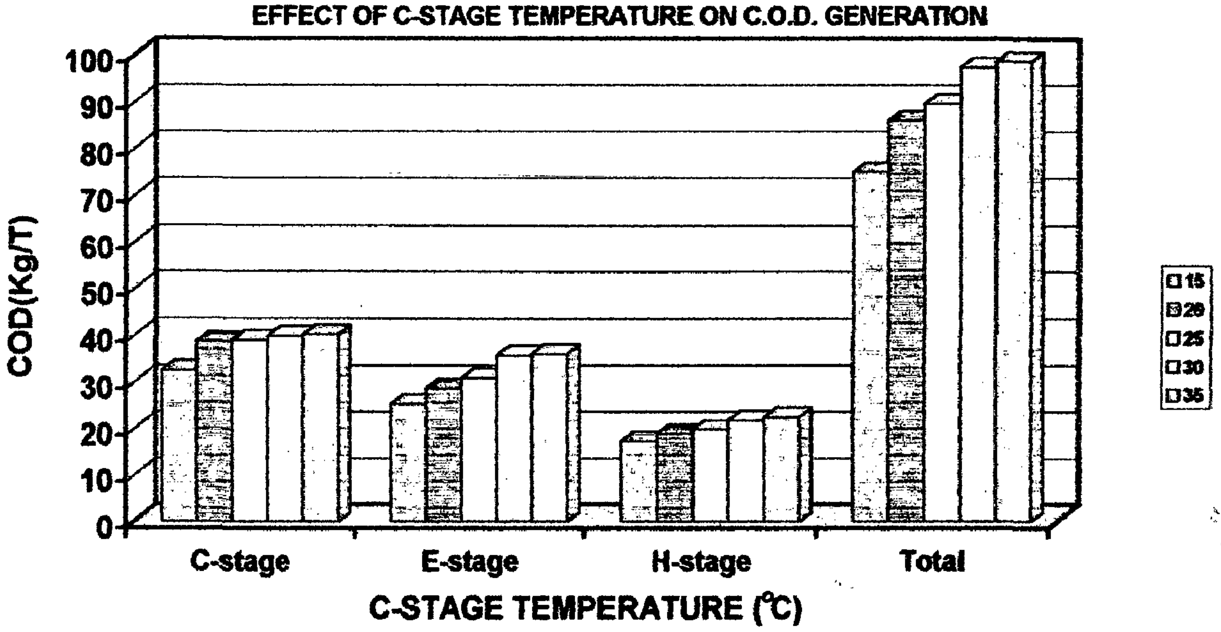


Fig.3.224

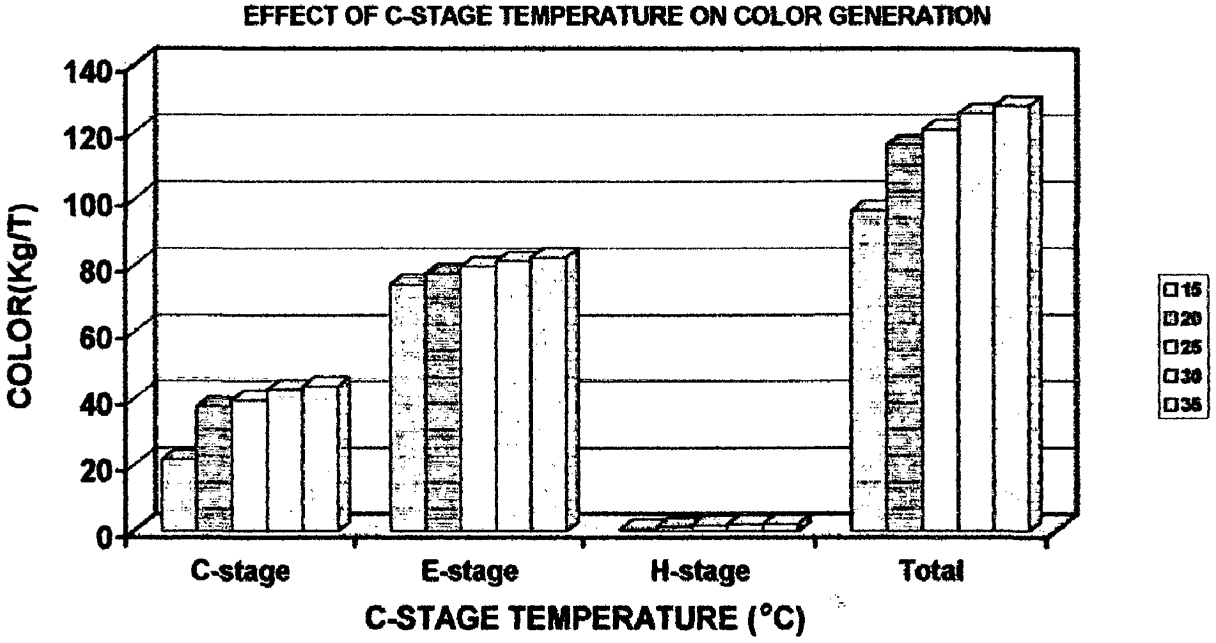


Fig.3.225

EFFECT OF C-STAGE TEMPERATURE ON CHLOROPHENOL GENERATION

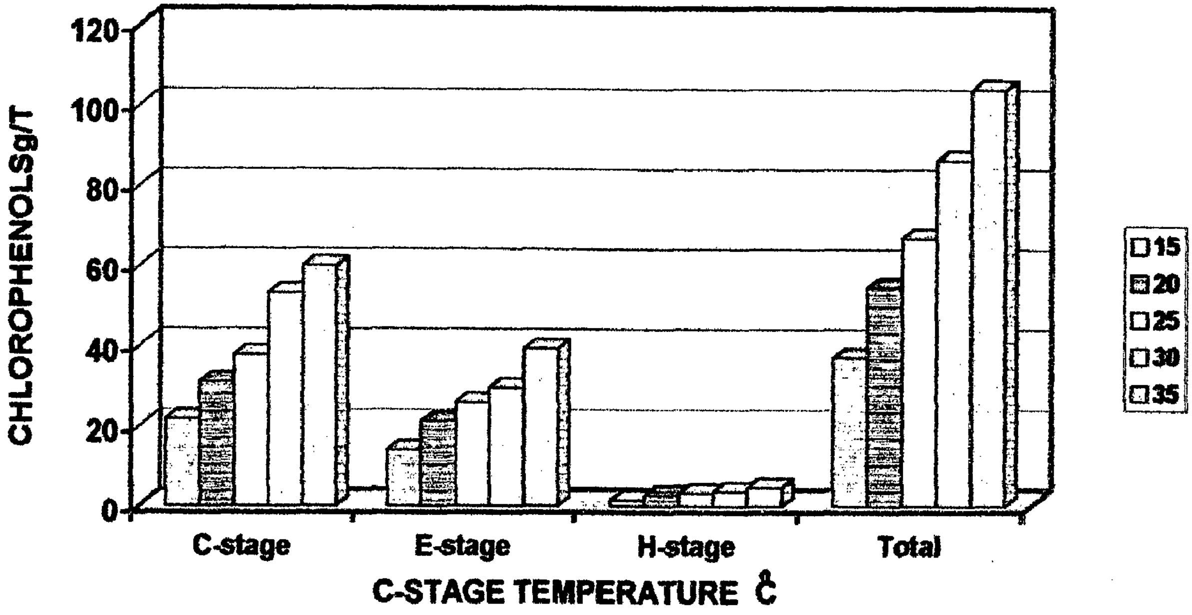


Fig.3.226

EFFECT OF C-STAGE TEMPERATURE ON BRIGHTNESS & VISCOSITY

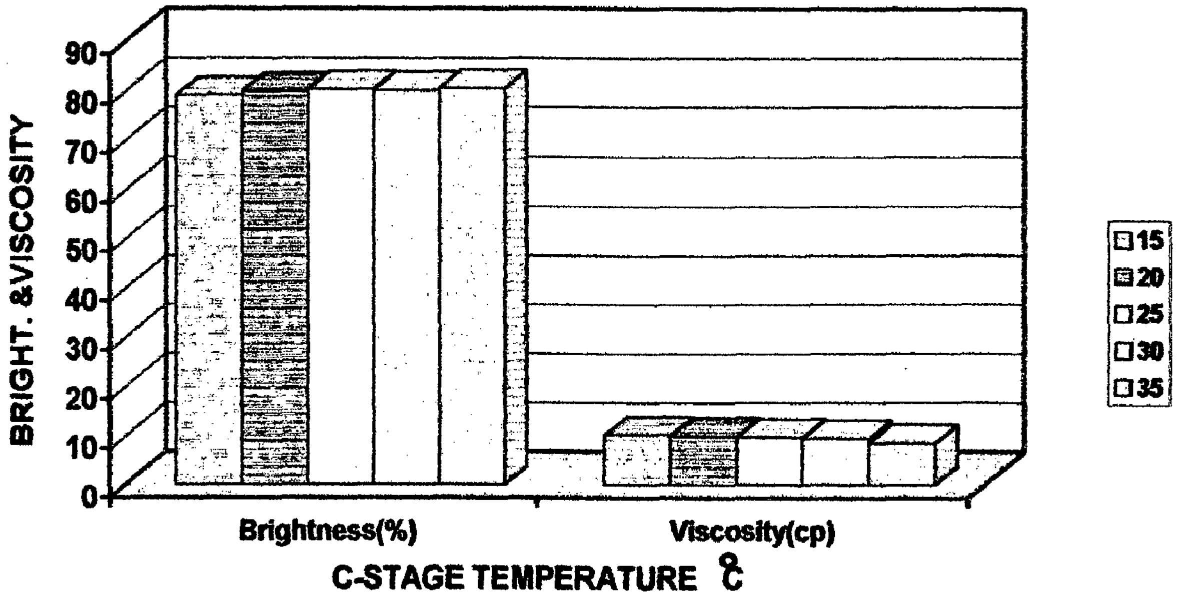


Fig.3.227

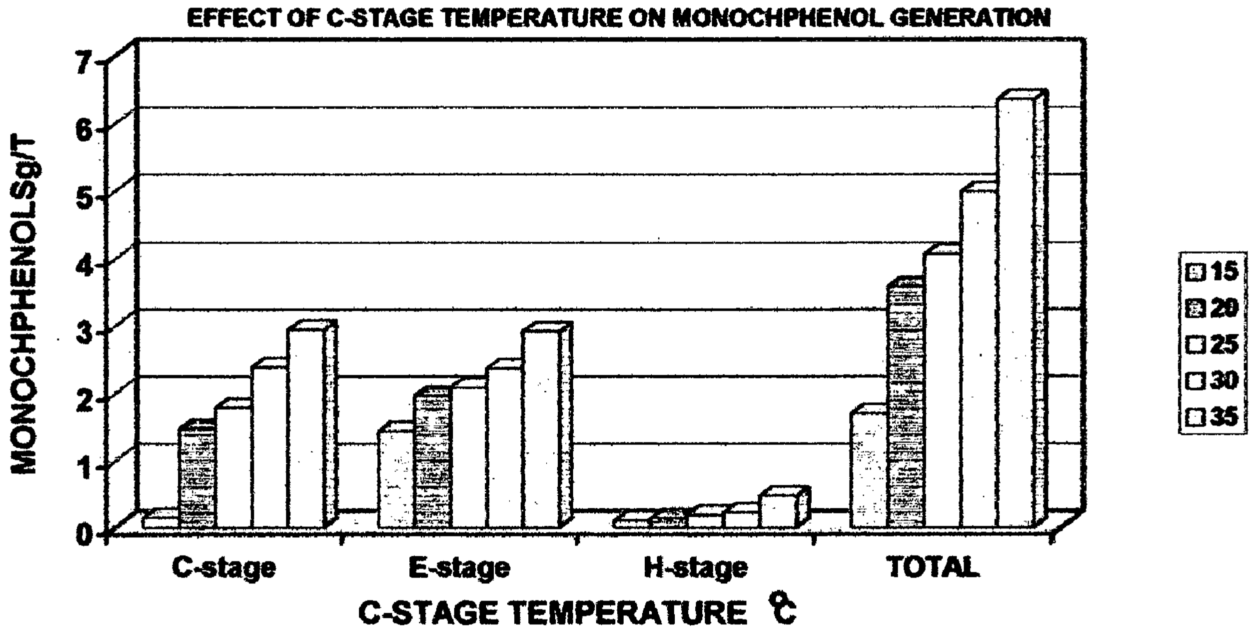


Fig.3.228

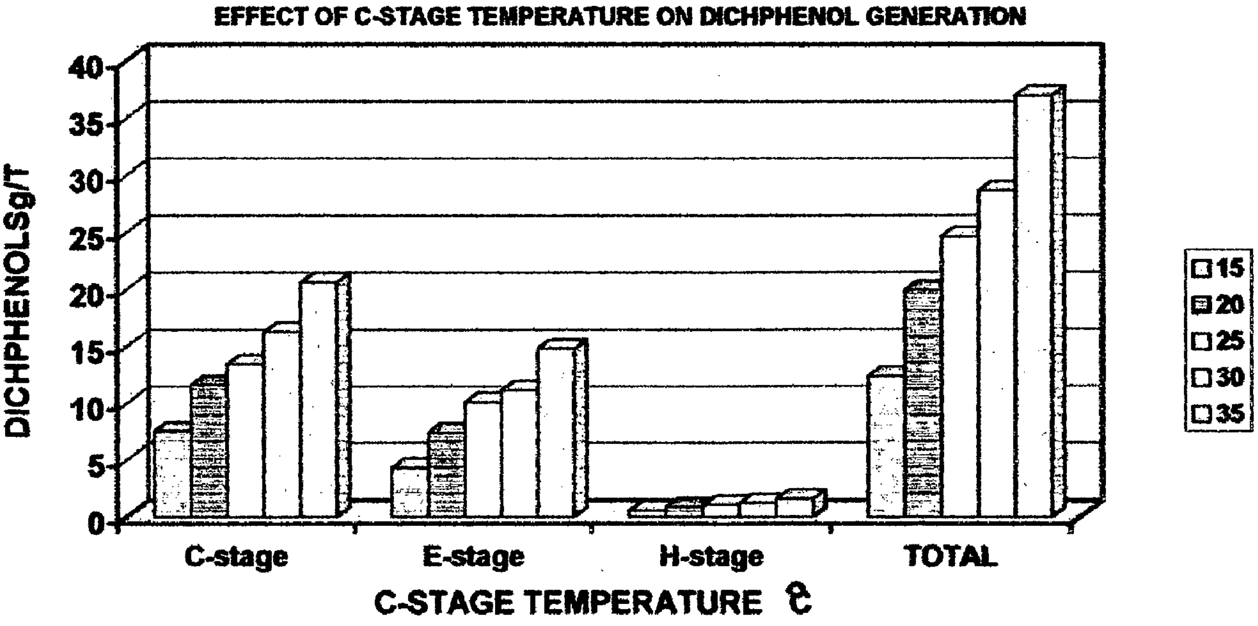


Fig.3.229

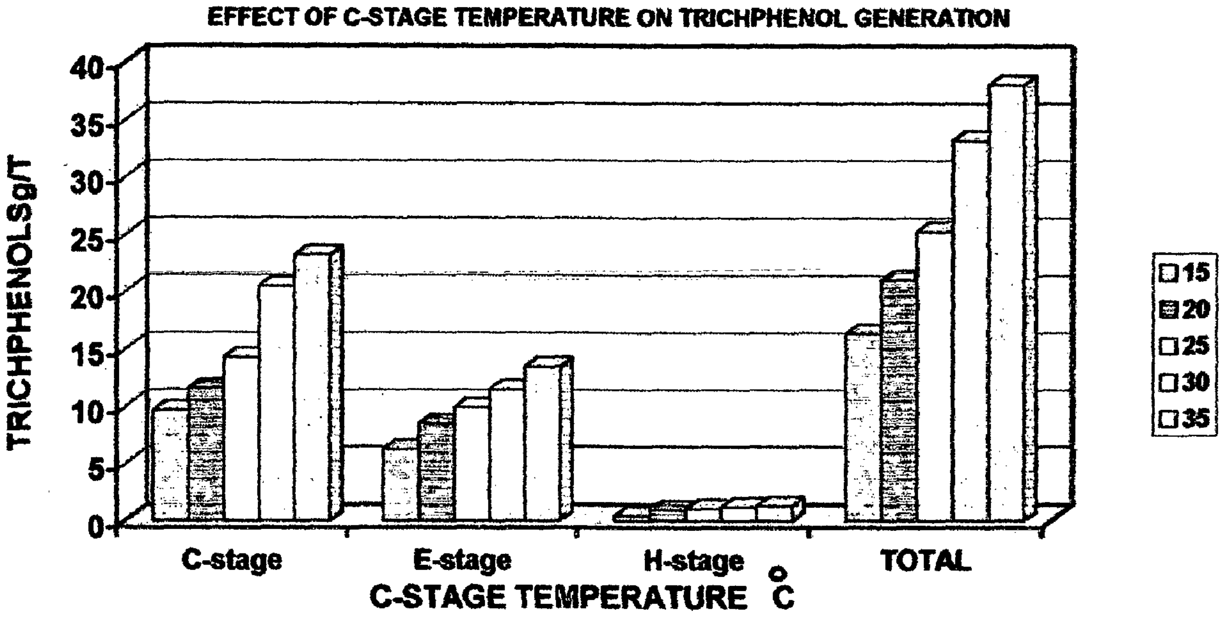


Fig.3.230

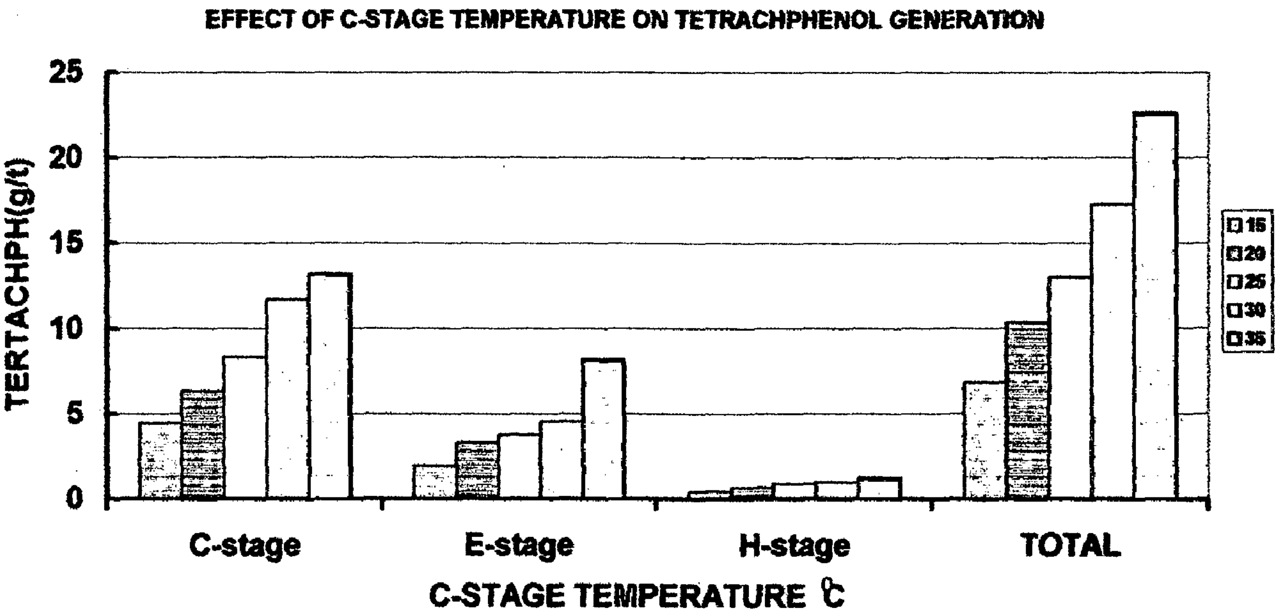


Fig.3.231

EFFECT OF C-STAGE TEMPERATURE ON PHENOL GENERATION

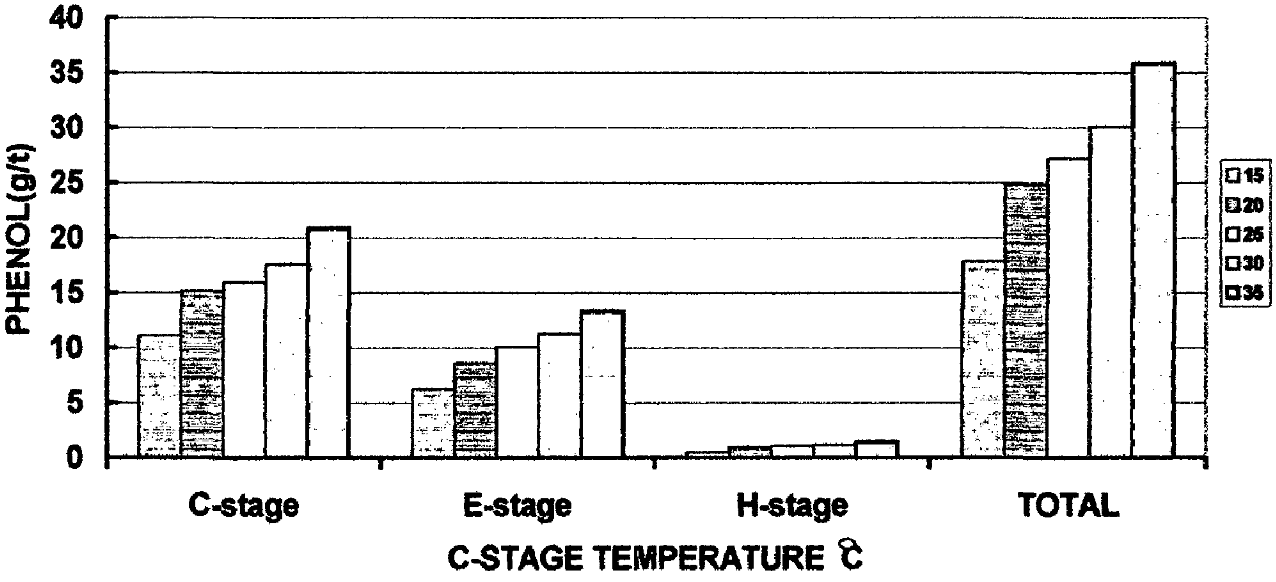


Fig.3.232

EFFECT OF C-STAGE TEMPERATURE ON GUAIACOL GENERATION

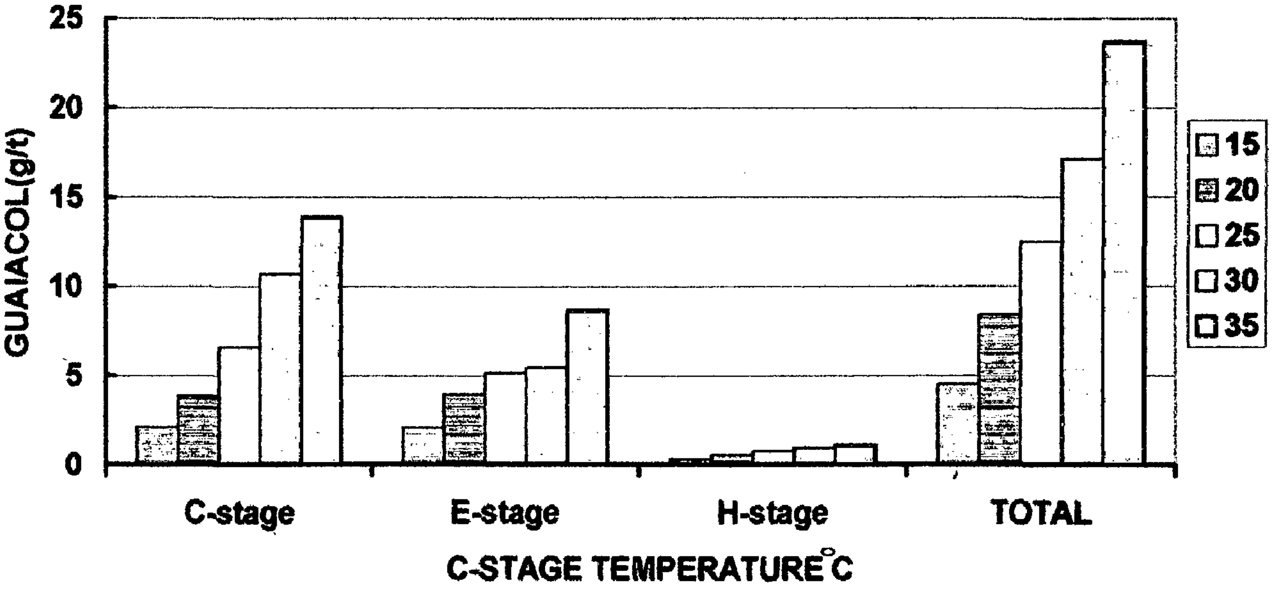


Fig.3.233

EFFECT OF C-STAGE TEMPERATURE ON CATECHOL GENERATION

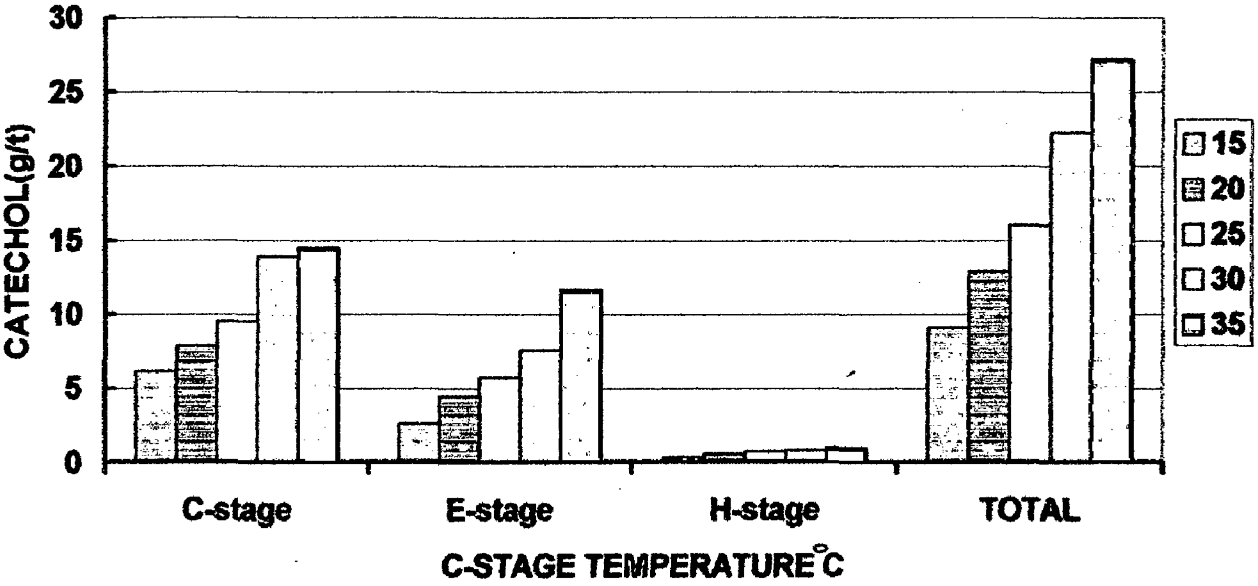


Fig.3.234

EFFECT OF C-STAGE TEMPERATURE ON VANILLIN,SYRINGOL,SYRINGALDEHYDE GENERATION

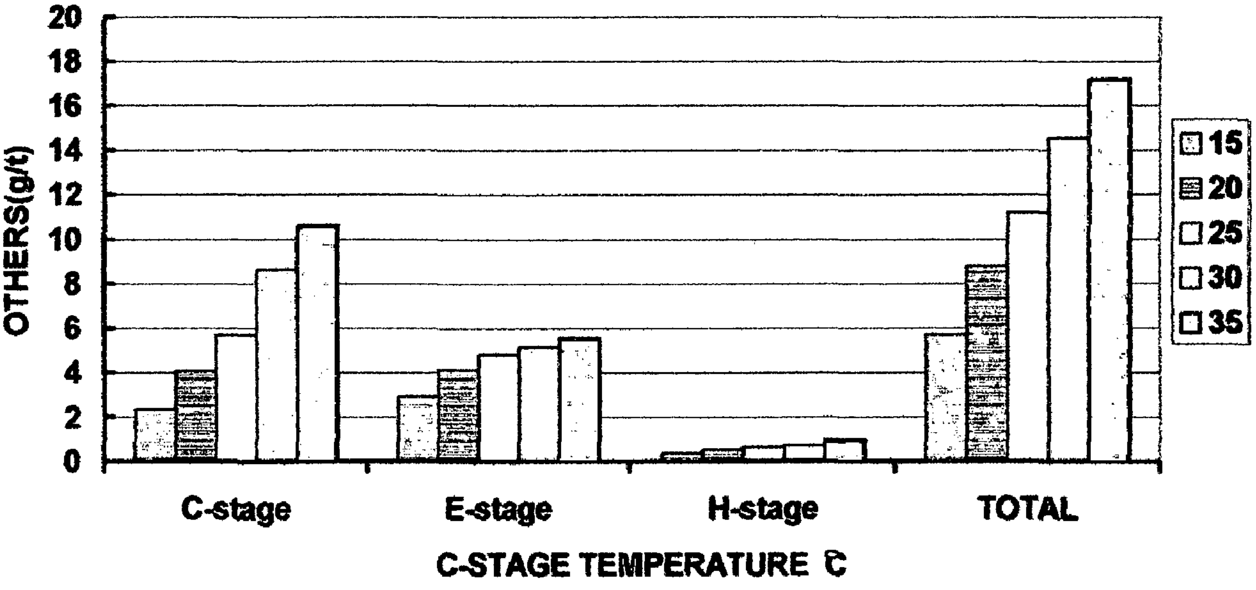


Fig.3.315

EFFECT OF C-STAGE TEMPERATURE ON 2,4-DCP GENERATION

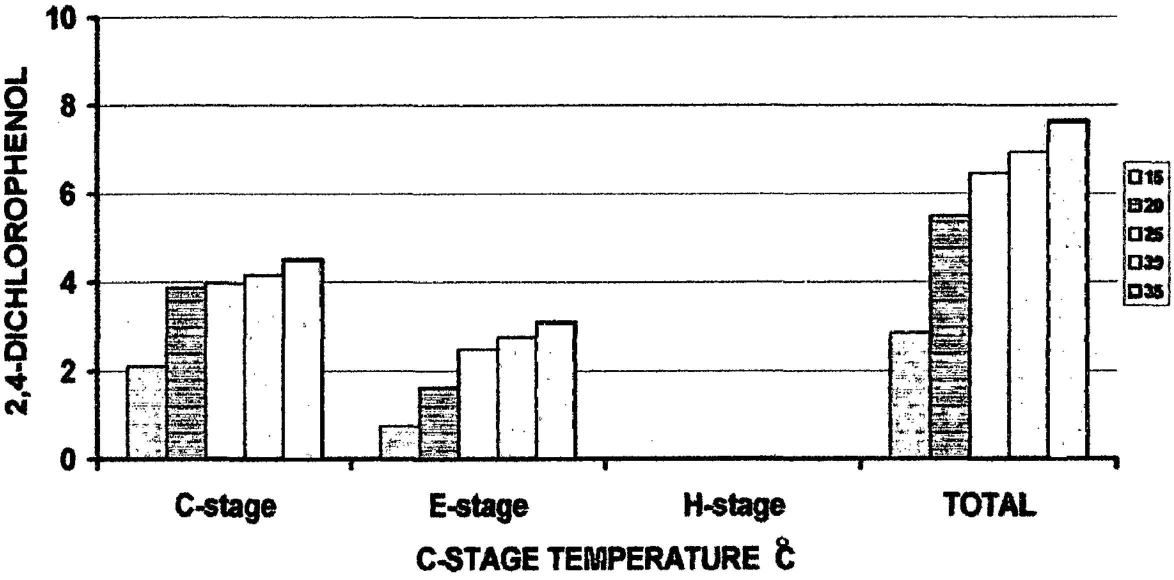


Fig.3.316

EFFECT OF C-STAGE TEMPERATURE ON 3,4,5-TCG GENERATION

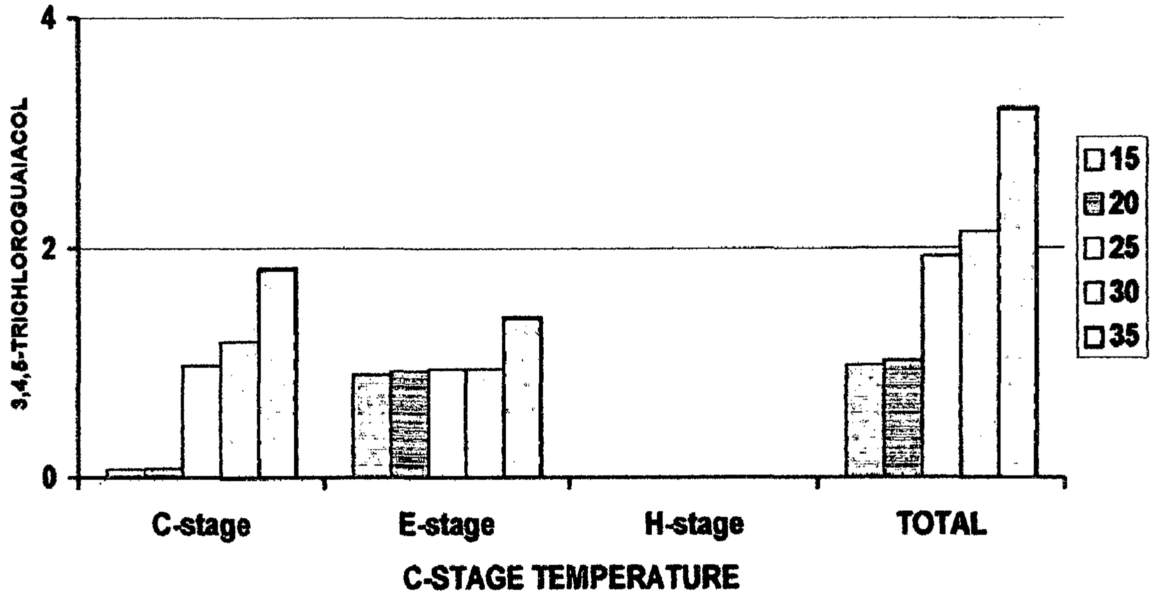


Fig.3.317

EFFECT OF C-STAGE TEMPERATURE ON 3,4,6-TCC GENERATION

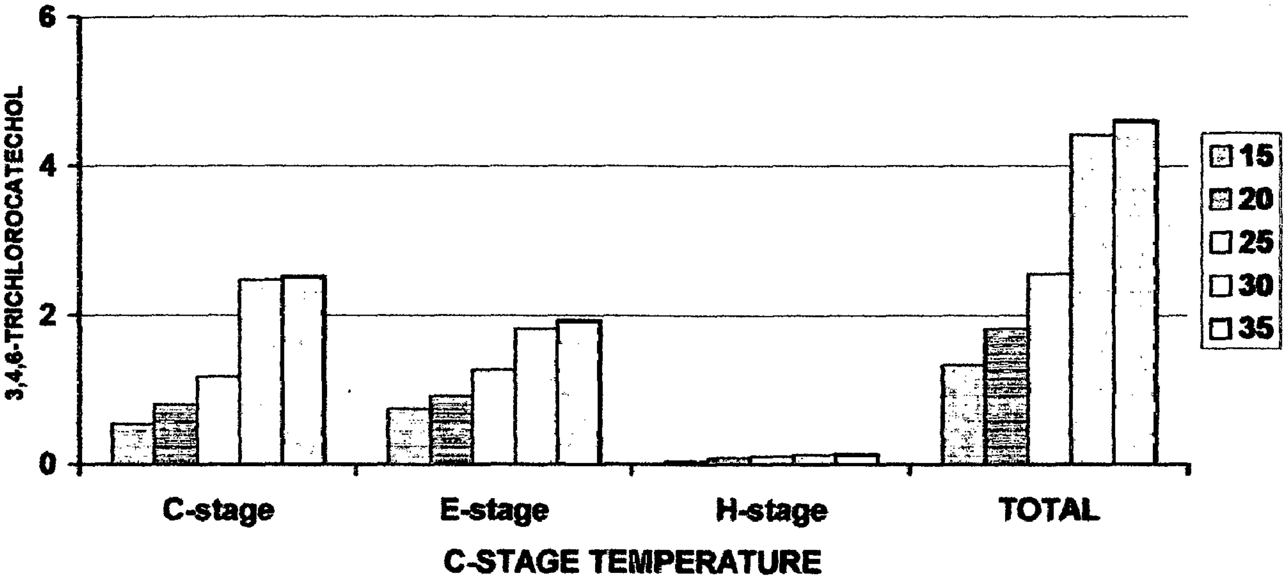


Fig.3.318

EFFECT OF C-STAGE TEMPERATURE ON 2,6-DICHLOROSYRINGALDEHYDE

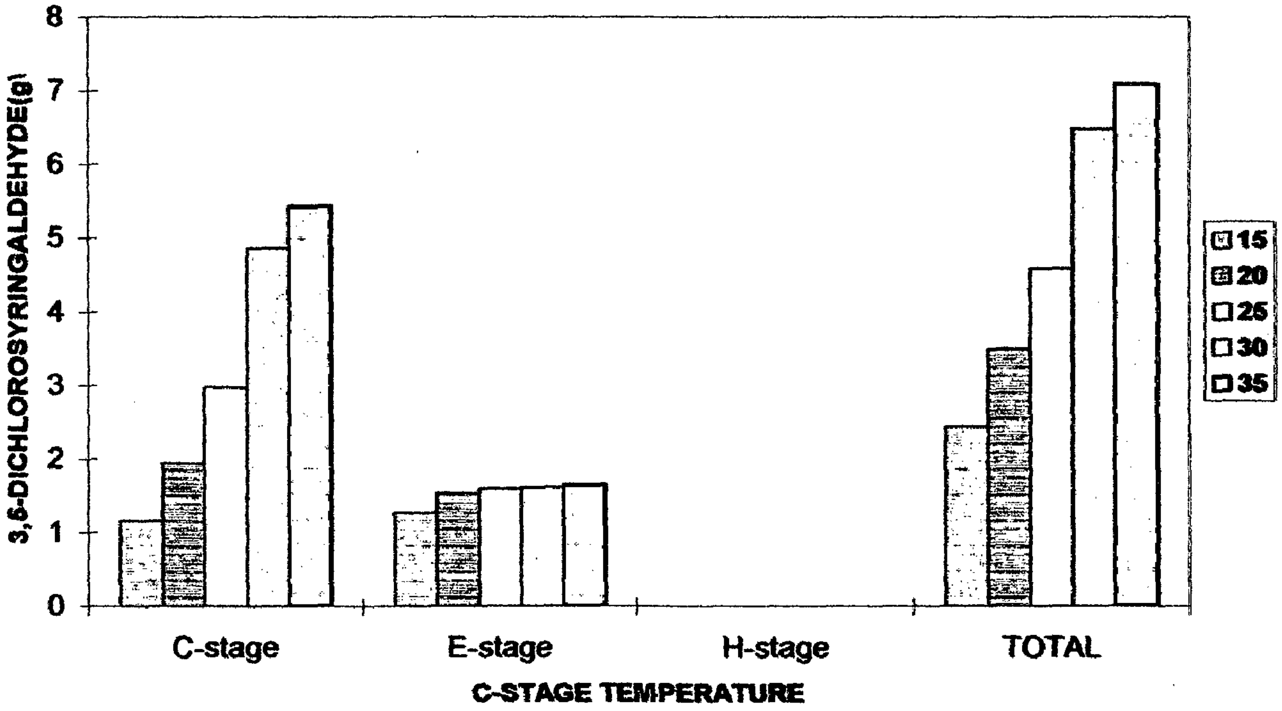


Table 3.121

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Consistency of 2.5%

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	2.58	0.05	1.72	0.07	-	-	4.30
2	3-chlorophenol	0.72	0.01	1.48	0.06	0.04	0.002	2.24
3	4-chloroguaiacol	-	-	-	-	0.03	0.001	0.03
4	5-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01
5	2,3,5-trichlorophenol	0.07	0.001	0.02	0.001	-	-	0.09
6	2,4,6-trichlorophenol	2.22	0.04	3.37	0.13	0.26	0.01	5.85
7	3,6-dichloroguaiacol	0.11	0.002	0.12	0.005	-	-	0.23
8	3,4-dichlorocatechol	3.10	0.06	0.48	0.02	-	-	3.58
9	4,5-dichloroguaiacol	0.24	0.005	0.2	0.01	0.04	0.002	0.48
10	5,6-dichloroguaiacol	0.84	0.02	0.24	0.01	0.10	0.004	1.18
11	2,3,4,6-tetrachlorophenol	0.66	0.01	0.05	0.002	-	-	0.71
12	3,4,5-trichloroguaiacol	0.72	0.01	0.88	0.02	-	-	1.6
13	3,4,6-trichloroguaiacol	-	-	0.07	0.003	-	-	3.79
14	3,5-dichlorosyringol	2.74	0.05	0.23	0.01	0.06	0.002	3.03
15	3,6-dichlorocatechol	3.72	0.07	0.59	0.02	-	-	0.59
16	4,5,6-trichloroguaiacol	0.34	0.01	0.04	0.002	-	-	0.38
17	tetrachloroguaiacol	1.65	0.03	0.26	0.01	0.07	0.003	1.98
18	3,4,6-trichlorocatechol	1.02	0.02	0.26	0.01	-	-	1.28
19	2,6-dichlorosyringaldehyde	1.15	0.02	1.29	0.05	-	-	2.44
20	5,6-dichlorovanillin	0.84	0.02	0.26	0.01	-	-	1.10
21	tetrachlorocatechol	4.16	0.08	2.87	0.11	0.33	0.01	7.36
22	2,3,4-trichlorophenol	-	-	-	-	0.10	0.004	0.10
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	26.88	0.54	14.43	0.55	1.04	0.04	42.35

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C

Table 3.122

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Consistency of 3%

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	4.17	0.08	2.77	0.11	-	-	6.94
2	3-chlorophenol	2.39	0.05	2.37	0.09	0.12	0.004	4.88
3	4-chloroguaiacol	-	-	-	-	0.09	0.003	0.09
4	5-chloroguaiacol	-	-	-	-	0.02	0.008	0.02
5	2,3,5-trichlorophenol	0.14	0.003	0.87	0.03	-	-	1.01
6	2,4,6-trichlorophenol	10.82	0.22	5.23	0.21	0.91	0.04	16.96
7	3,6-dichloroguaiacol	0.17	0.003	0.16	0.01	-	-	0.33
8	3,4-dichlorocatechol	2.98	0.06	1.18	0.05	-	-	4.16
9	4,5-dichloroguaiacol	0.31	0.01	0.89	0.04	0.37	0.01	1.57
10	5,6-dichloroguaiacol	1.48	0.03	-	-	0.11	0.004	1.59
11	2,3,4,6-tetrachlorophenol	0.96	0.02	0.07	0.003	-	-	1.03
12	3,4,5-trichloroguaiacol	1.19	0.02	0.95	0.04	-	-	2.14
13	3,4,6-trichloroguaiacol	3.66	0.07	0.28	0.01	0.04	0.001	3.98
14	3,5-dichlorosyringol	2.69	0.05	1.42	0.06	0.25	0.01	4.36
15	3,6-dichlorocatechol	-	-	0.96	0.04	-	-	0.96
16	4,5,6-trichloroguaiacol	2.20	0.04	2.36	0.09	-	-	4.56
17	tetrachloroguaiacol	3.19	0.06	0.82	0.03	0.32	0.01	4.33
18	3,4,6-trichlorocatechol	2.47	0.05	1.82	0.07	0.13	0.005	4.42
19	2,6-dichlorosyringaldehyde	4.86	0.10	1.62	0.06	-	-	6.48
20	5,6-dichlorovanillin	1.09	0.02	2.14	0.09	0.49	0.02	3.72
21	tetrachlorocatechol	8.42	0.17	3.65	0.15	0.68	0.03	12.75
22	2,3,4-trichlorophenol	-	-	-	-	0.15	0.01	0.15
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	53.19	1.06	29.56	1.18	3.68	0.15	86.43

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C

Table 3.123

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Consistency of 3.5%

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	5.86	0.12	3.33	0.13	-	-	9.19
2	3-chlorophenol	3.08	0.06	2.50	0.10	0.52	0.02	6.10
3	4-chloroguaiacol	-	-	-	-	0.10	0.004	0.10
4	5-chloroguaiacol	-	-	-	-	0.03	0.001	0.03
5	2,3,5-trichlorophenol	0.15	0.003	0.92	0.04	-	-	1.07
6	2,4,6-trichlorophenol	11.23	0.22	5.56	0.22	0.94	0.04	17.73
7	3,6-dichloroguaiacol	0.33	0.01	0.32	0.01	-	-	0.65
8	3,4-dichlorocatechol	0.77	0.01	1.80	0.07	-	-	2.57
9	4,5-dichloroguaiacol	1.59	0.03	1.20	0.05	0.44	0.02	3.23
10	5,6-dichloroguaiacol	1.58	0.03	0.10	0.004	0.22	0.01	1.90
11	2,3,4,6-tetrachlorophenol	1.04	0.02	0.25	0.01	-	-	1.29
12	3,4,5-trichloroguaiacol	1.73	0.03	1.12	0.04	-	-	2.85
13	3,4,6-trichloroguaiacol	1.51	0.03	0.62	0.02	-	-	2.13
14	3,5-dichlorosyringol	1.22	0.02	1.72	0.07	0.34	0.01	3.28
15	3,6-dichlorocatechol	-	-	0.99	0.04	-	-	0.99
16	4,5,6-trichloroguaiacol	2.63	0.05	2.68	0.11	-	-	5.31
17	tetrachloroguaiacol	3.74	0.07	1.48	0.06	0.35	0.01	5.57
18	3,4,6-trichlorocatechol	2.57	0.05	2.06	0.08	0.26	0.01	4.89
19	2,6-dichlorosyringaldehyde	4.95	0.10	1.76	0.07	-	-	6.71
20	5,6-dichlorovanillin	1.13	0.02	2.78	0.11	0.88	0.04	4.79
21	tetrachlorocatechol	10.02	0.20	4.45	0.18	0.89	0.04	15.36
22	2,3,4-trichlorophenol	-	-	-	-	0.17	0.01	0.17
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	55.13	1.10	35.64	1.41	5.14	0.22	95.91

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C

Table 3.124

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Consistency of 4%

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	6.49	0.13	3.53	0.14	-	-	10.02
2	3-chlorophenol	4.03	0.08	4.16	0.17	0.98	0.04	9.17
3	4-chloroguaiacol	-	-	-	-	0.12	0.005	0.12
4	5-chloroguaiacol	-	-	-	-	0.54	0.02	0.54
5	2,3,5-trichlorophenol	0.19	0.004	0.98	0.04	-	-	1.17
6	2,4,6-trichlorophenol	13.12	0.26	6.5	0.26	0.95	0.04	20.57
7	3,6-dichloroguaiacol	0.37	0.01	0.41	0.01	-	-	0.78
8	3,4-dichlorocatechol	0.44	0.01	2.39	0.10	-	-	2.83
9	4,5-dichloroguaiacol	1.8	0.04	2.36	0.09	0.65	0.03	4.81
10	5,6-dichloroguaiacol	1.67	0.03	0.04	0.002	0.27	0.01	1.98
11	2,3,4,6-tetrachlorophenol	1.17	0.02	0.46	0.02	-	-	1.63
12	3,4,5-trichloroguaiacol	2.54	0.05	2.28	0.09	-	-	4.82
13	3,4,6-trichloroguaiacol	1.15	0.02	0.98	0.04	-	-	2.13
14	3,5-dichlorosyringol	0.81	0.02	2.46	0.10	0.35	0.01	3.62
15	3,6-dichlorocatechol	-	-	1.74	0.07	-	-	1.74
16	4,5,6-trichloroguaiacol	2.82	0.06	3.20	0.13	-	-	6.02
17	tetrachloroguaiacol	3.95	0.08	2.82	0.11	0.56	0.02	7.33
18	3,4,6-trichlorocatechol	2.71	0.05	3.41	0.14	0.3	0.01	6.42
19	2,6-dichlorosyringaldehyde	5.37	0.11	1.95	0.08	-	-	7.32
20	5,6-dichlorovanillin	1.24	0.02	3.13	0.13	0.94	0.04	5.31
21	tetrachlorocatechol	14.65	0.29	5.29	0.21	0.93	0.04	20.87
22	2,3,4-trichlorophenol	-	-	-	-	0.19	0.01	0.19
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	64.52	1.29	48.09	1.93	6.78	0.27	119.39

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C

Table 3.335 Effect of change in C Stage consistency on the generation of Chlorophenolic compounds

	Chlorophenolic compounds (kg/t)			
Consistency (%)	C-stage	E-stage	H-stage	TOTAL
2.5	26.88	14.43	1.04	42.35
3.0	53.19	29.56	3.68	86.43
3.5	55.13	35.64	5.14	95.91
4.0	64.52	48.09	6.78	119.39

Table 3.336 Effect of change in C Stage consistency on the generation of effluent COD

	COD (kg/t)			
Consistency (%)	C-stage	E-stage	H-stage	TOTAL
2.5	39.3	24.4	18.6	82.3
3.0	39.9	35.8	21.8	97.5
3.5	40.2	36.9	22.2	99.3
4.0	41.5	38.4	23.5	103.4

Table 3.337 Effect of change in C Stage consistency on the generation of effluent Colour

	Colour (kg/t)			
Consistency (%)	C-stage	E-stage	H-stage	TOTAL
2.5	30	73.7	1.2	105
3.0	42.5	81.2	1.9	125.6
3.5	44	83.6	1.9	129.5
4.0	47.5	85	2.2	134.7

Table 3.338 Effect of change in C Stage consistency on Brightness and Viscosity of bleached pulps obtained by CEH bleaching

Consistency (%)	Brightness (%)	Viscosity (cp)
2.5	79.9	9.7
3.0	80.1	9.4
3.5	80.4	8.6
4.0	80.6	8.4

Table 3.339 Monochlorophenolic compounds present in different effluents formed by bleaching at various C Stage consistency

Monochlorophenolic compounds (g/t)				
Consistency (%)	C-stage	E-stage	H-stage	TOTAL
15	0.72	1.48	0.08	2.28
20	2.39	2.37	0.23	4.99
25	3.08	2.5	0.65	6.23
30	4.03	4.16	1.64	9.83
35	0.72	1.48	0.08	2.28

Table 3.340 Dichlorophenolic compounds present in different effluents formed by bleaching at various C Stage consistency

Dichlorophenolic compounds (g/t)				
Consistency (%))	C-stage	E-stage	H-stage	TOTAL
2.5	11.60	5.13	0.20	16.93
3.0	16.27	11.14	1.22	28.63
3.5	17.43	14.00	1.88	33.31
4.0	18.19	18.01	2.21	38.41

Table 3.341 Trichlorophenolic compounds present in different effluents formed by bleaching at various C Stage consistency

Trichlorophenolic compounds (g/t)				
Consistency (%)	C-stage	E-stage	H-stage	TOTAL
2.5	8.09	4.64	0.36	13.09
3.0	20.48	11.51	1.23	33.22
3.5	19.82	12.96	1.37	34.15
4.0	22.53	17.35	1.44	41.32

Table 3.342 Tetrachlorophenolic compounds present in different effluents formed by bleaching at various C Stage consistency

Tetrachlorophenolic compounds (g/t)				
Consistency (%)	C-stage	E-stage	H-stage	TOTAL
2.5	6.47	3.18	0.4	10.05
3.0	11.70	4.54	1.00	17.24
3.5	14.80	6.18	1.24	22.22
4.0	19.77	8.57	1.49	29.83

Table 3.343 Category wise load of chlorophenols in different effluents formed by bleaching at various C Stage consistency

Chlorophenols (g/t)				
Consistency (%)	**C-stage**	**E-stage**	**H-stage**	**TOTAL**
2.5	6.25	6.64	0.40	13.29
3.0	17.61	11.31	1.18	30.10
3.5	21.36	12.56	1.63	35.55
4.0	25.00	15.63	2.12	42.75

Table 3.344 Category wise load of chloroguaiacols in different effluents formed by bleaching at various C Stage consistency

Chloroguaiacols (g/t)				
Consistency (%)	**C-stage**	**E-stage**	**H-stage**	**TOTAL**
2.5	7.62	1.81	0.25	9.68
3.0	10.72	5.46	0.95	17.13
3.5	13.11	7.52	1.14	21.77
4.0	14.30	12.09	2.14	28.53

Table 3.345 Category wise load of chlorocatechols in different effluents formed by bleaching at various C Stage consistency

Chlorocatechols (g/t)				
Consistency (%)	**C-stage**	**E-stage**	**H-stage**	**TOTAL**
2.5	8.28	4.20	0.33	12.81
3.0	13.87	7.61	0.81	22.29
3.5	13.36	9.30	1.15	23.81
4.0	17.80	12.83	1.23	31.86

Table 3.346 Category wise load of other chlorophenolic compounds in different effluents formed by bleaching at various C Stage consistency

Other Chlorophenolic compounds (g/t)				
Consistency (%)	**C-stage**	**E-stage**	**H-stage**	**TOTAL**
2.5	4.73	1.78	0.06	6.57
3.0	8.64	5.18	0.74	14.56
3.5	7.30	6.26	1.22	14.78
4.0	7.42	7.54	1.29	16.25

Table 3.319 Different chlorophenolic compounds formed in C stage at various consistency

C stage Consistency(%)					
S.No.	Chlorophenolic compounds(g/T)	**2.5**	**3.0**	**3.5**	**4.0**
1	2,4-dichlorophenol	2.58	4.17	5.86	6.49
2	3-chlorophenol	0.72	2.39	3.08	4.03
3	4-chloroguaiacol	-	-	-	-
4	5-chloroguaiacol	-	-	-	-
5	2,3,5-trichlorophenol	0.07	0.14	0.15	0.19
6	2,4,6-trichlorophenol	2.22	10.82	11.23	13.12
7	3,6-dichloroguaiacol	0.11	0.17	0.33	0.37
8	3,4dichlorocatechol	3.1	2.98	0.77	0.44
9	4,5-dichloroguaiacol	0.24	0.31	1.59	1.80
10	5,6-dichloroguaiacol	0.84	1.48	1.58	1.67
11	2,3,4,6-tetrachlorophenol	0.66	0.96	1.04	1.17
12	3,4,5-trichloroguaiacol	0.72	1.19	1.73	2.54
13	3,4,6-trichloroguaiacol	3.72	3.66	1.51	1.15
14	3,5-dichlorosyringol	2.74	2.69	1.22	0.81
15	3,6-dichlorocatechol	-	-	-	-
16	4,5,6-trichloroguaiacol	0.34	2.20	2.63	2.82
17	tetrachloroguaiacol	1.65	3.19	3.74	3.95
18	3,4,6-trichlorocatechol	1.02	2.47	2.57	2.71
19	2,6-dichlorosyringaldehyde	1.15	4.86	4.95	5.37
20	5,6-dichlorovanillin	0.84	1.09	1.13	1.24
21	tetrachlorocatechol	4.16	8.42	10.02	14.65
22	2,3,4-trichlorophenol	-	-	-	-
23	4,5-dichlorocatechol	-	-		-
	TOTAL	26.88	53.19	55.13	64.52

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C

Table 3.320 Different chlorophenolic compounds formed in E stage at various consistency

		C stage Consistency(%)			
S.No.	Chlorophenolic compounds(g/T)	**2.5**	**3.0**	**3.5**	**4.0**
1	2,4-dichlorophenol	1.72	2.77	3.33	3.53
2	3-chlorophenol	1.48	2.37	2.50	4.16
3	4-chloroguaiacol	-	-	-	-
4	5-chloroguaiacol	-	-	-	-
5	2,3,5-trichlorophenol	0.02	0.87	0.92	0.98
6	2,4,6-trichlorophenol	3.37	5.23	5.56	6.50
7	3,6-dichloroguaiacol	0.12	0.16	0.32	0.41
8	3,4dichlorocatechol	0.48	1.18	1.80	2.39
9	4,5-dichloroguaiacol	0.20	0.89	1.20	2.36
10	5,6-dichloroguaiacol	0.24	-	0.10	0.04
11	2,3,4,6-tetrachlorophenol	0.05	0.07	0.25	0.46
12	3,4,5-trichloroguaiacol	0.88	0.95	1.12	2.28
13	3,4,6-trichloroguaiacol	0.07	0.28	0.62	0.98
14	3,5-dichlorosyringol	0.23	1.42	1.72	2.46
15	3,6-dichlorocatechol	0.59	0.96	0.99	1.74
16	4,5,6-trichloroguaiacol	0.04	2.36	2.68	3.20
17	tetrachloroguaiacol	0.26	0.82	1.48	2.82
18	3,4,6-trichlorocatechol	0.26	1.82	2.06	3.41
19	2,6-dichlorosyringaldehyde	1.29	1.62	1.76	1.95
20	5,6-dichlorovanillin	0.26	2.14	2.78	3.13
21	tetrachlorocatechol	2.87	3.65	4.45	5.29
22	2,3,4-trichlorophenol	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-
	TOTAL	14.43	29.56	35.64	48.09

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.321 Different chlorophenolic compounds formed in H stage at various consistency

		C stage Consistency(%)			
S.No.	Chlorophenolic compounds(g/T)	**2.5**	**3.0**	**3.5**	**4.0**
1	2,4-dichlorophenol	-	-	-	-
2	3-chlorophenol	0.04	0.12	0.52	0.98
3	4-chloroguaiacol	0.03	0.09	0.10	0.12
4	5-chloroguaiacol	0.01	0.02	0.03	0.54
5	2,3,5-trichlorophenol	-	-	-	-
6	2,4,6-trichlorophenol	0.26	0.91	0.94	0.95
7	3,6-dichloroguaiacol	-	-	-	-
8	3,4dichlorocatechol	-	-	-	-
9	4,5-dichloroguaiacol	0.04	0.37	0.44	0.65
10	5,6-dichloroguaiacol	0.10	0.11	0.22	0.27
11	2,3,4,6-tetrachlorophenol	-	-	-	-
12	3,4,5-trichloroguaiacol	-	-	-	-
13	3,4,6-trichloroguaiacol	-	0.04	-	-
14	3,5-dichlorosyringol	0.06	0.25	0.34	0.35
15	3,6-dichlorocatechol	-	-	-	-
16	4,5,6-trichloroguaiacol	-	-	-	-
17	tetrachloroguaiacol	0.07	0.32	0.35	0.56
18	3,4,6-trichlorocatechol	-	0.13	0.26	0.3
19	2,6-dichlorosyringaldehyde	-	-	-	-
20	5,6-dichlorovanillin	-	0.49	0.88	0.94
21	tetrachlorocatechol	0.33	0.68	0.89	0.93
22	2,3,4-trichlorophenol	0.10	0.15	0.17	0.19
23	4,5-dichlorocatechol	-	-	-	-
	TOTAL	1.04	3.68	5.14	6.78

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C, Consistency 3%

Table 3.322 Total chlorophenolic compounds formed in CEH bleaching at various consistency

C stage Consistency(%)					
S.No.	Chlorophenolic compounds(g/T)	2.5	3.0	3.5	4.0
1	2,4-dichlorophenol	4.30	6.94	9.19	10.02
2	3-chlorophenol	2.24	4.88	6.10	9.17
3	4-chloroguaiacol	0.03	0.09	0.10	0.12
4	5-chloroguaiacol	0.01	0.02	0.03	0.54
5	2,3,5-trichlorophenol	0.09	1.01	1.07	1.17
6	2,4,6-trichlorophenol	5.85	16.96	17.73	20.57
7	3,6-dichloroguaiacol	0.23	0.33	0.65	0.78
8	3,4dichlorocatechol	3.58	4.16	2.57	2.83
9	4,5-dichloroguaiacol	0.48	1.57	3.23	4.81
10	5,6-dichloroguaiacol	1.18	1.59	1.90	1.98
11	2,3,4,6-tetrachlorophenol	0.71	1.03	1.29	1.63
12	3,4,5-trichloroguaiacol	1.60	2.14	2.85	4.82
13	3,4,6-trichloroguaiacol	3.79	3.98	2.13	2.13
14	3,5-dichlorosyringol	3.03	4.36	3.28	3.62
15	3,6-dichlorocatechol	0.59	0.96	0.99	1.74
16	4,5,6-trichloroguaiacol	0.38	4.56	5.31	6.02
17	tetrachloroguaiacol	1.98	4.33	5.57	7.33
18	3,4,6-trichlorocatechol	1.28	4.42	4.89	6.42
19	2,6-dichlorosyringaldehyde	2.44	6.48	6.71	7.32
20	5,6-dichlorovanillin	1.10	3.72	4.79	5.31
21	tetrachlorocatechol	7.36	12.75	15.36	20.87
22	2,3,4-trichlorophenol	0.10	0.15	0.17	0.19
23	4,5-dichlorocatechol	-	-	-	-
	TOTAL	42.35	86.43	95.91	119.39

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Fig.3.235

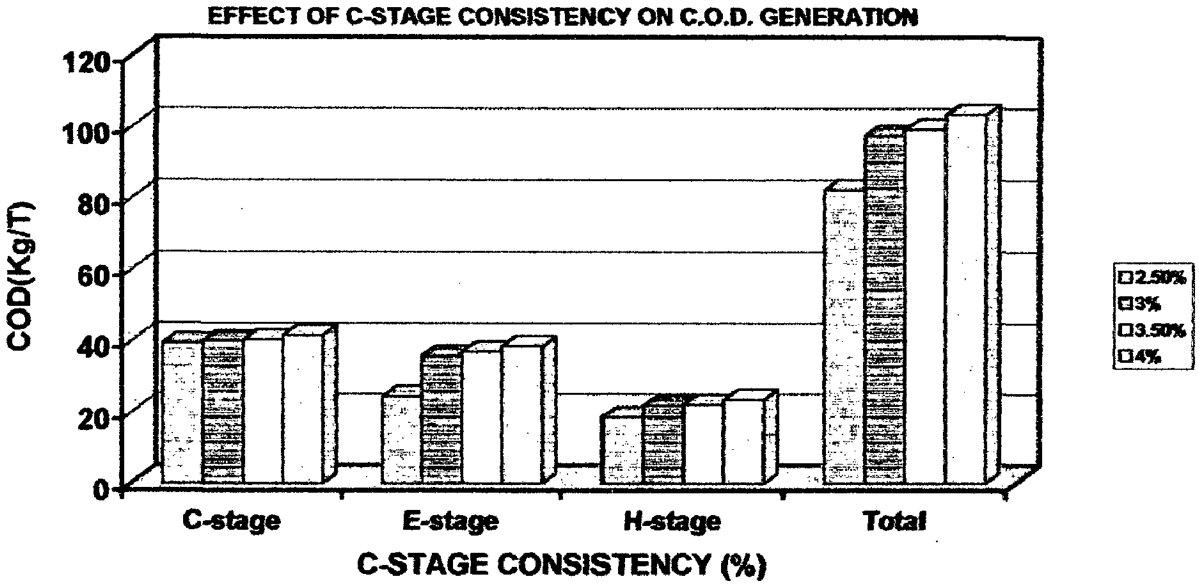


Fig.3.236

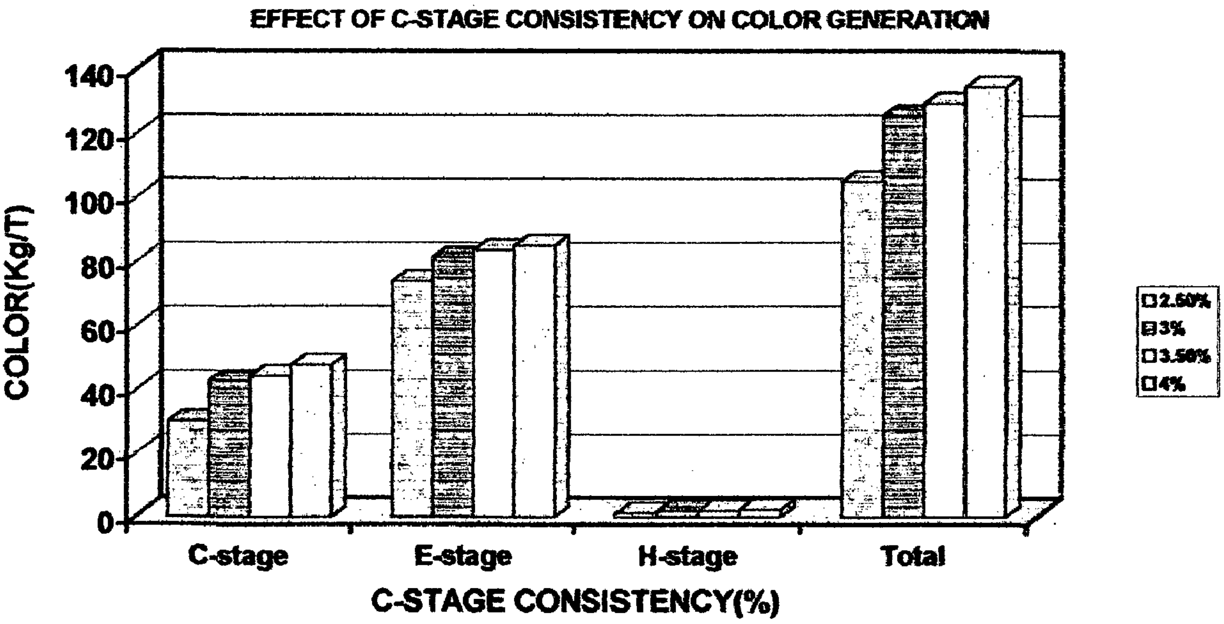


Fig.3.237

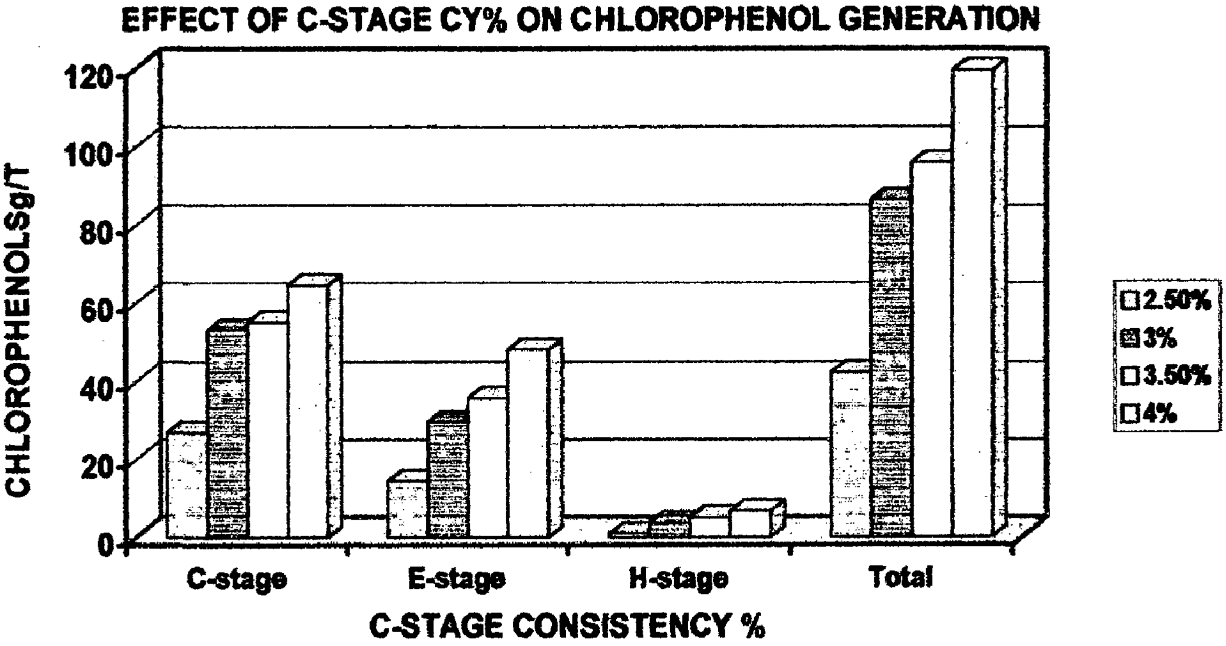


Fig.3.238

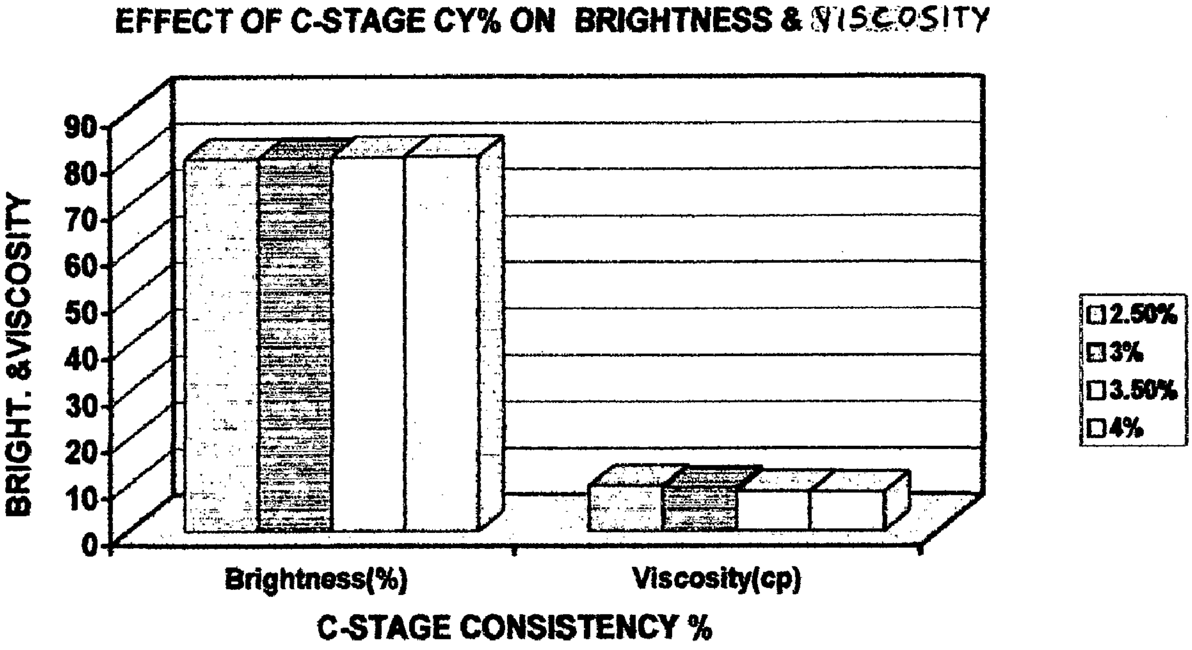


Fig.3.239

EFFECT OF C-STAGE CY% ON MONOCHPH GENERATION

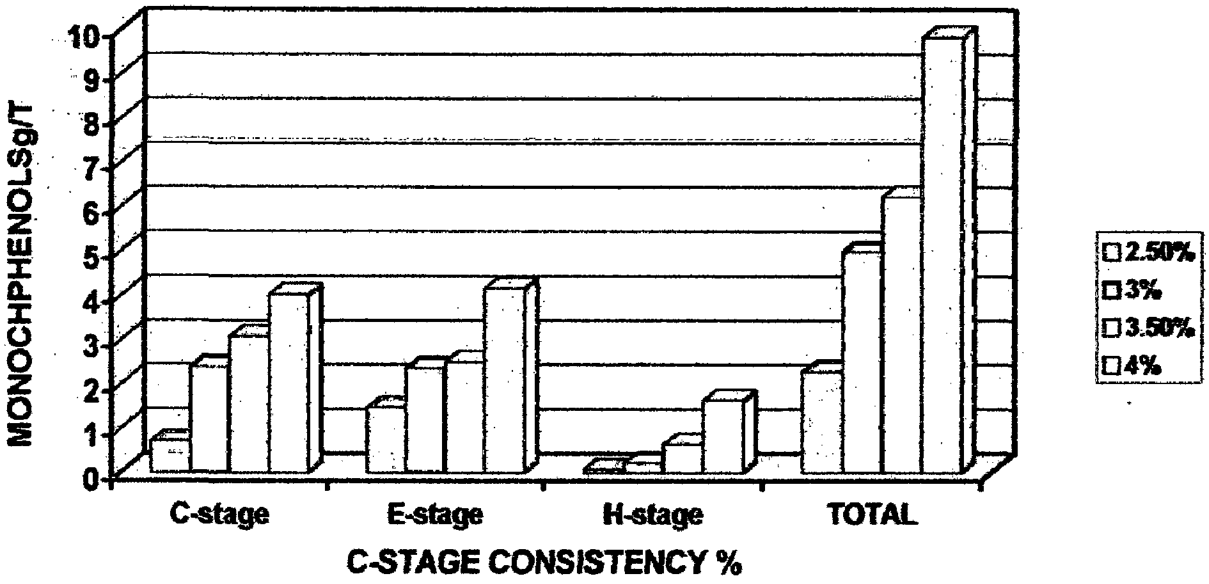


Fig.3.240

EFFECT OF C-STAGE CY% ON DICHPHENOL GENERATION

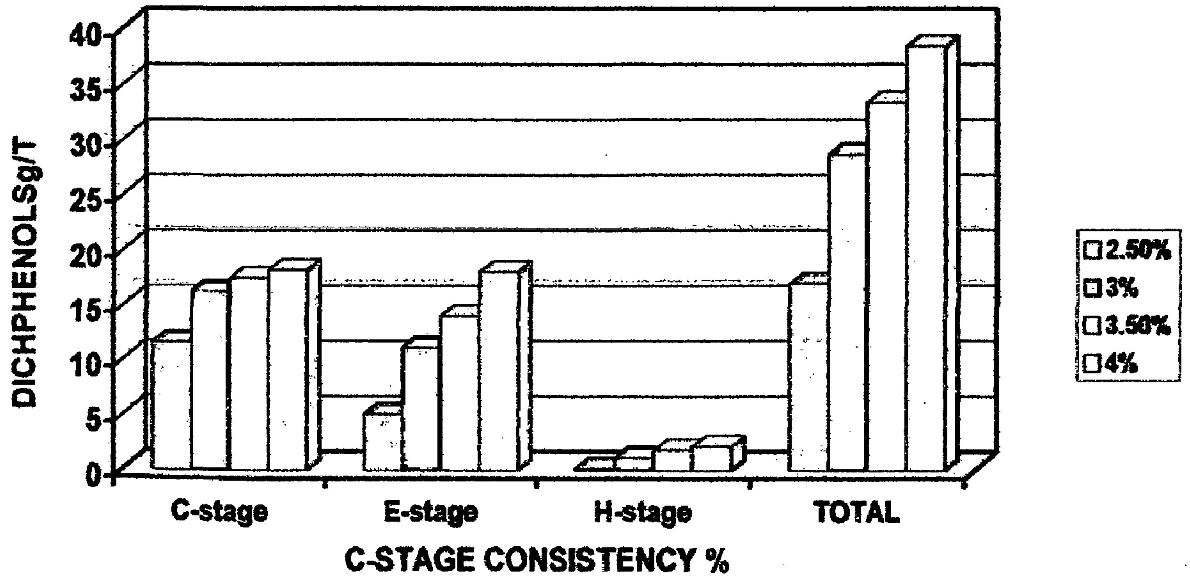


Fig.3.241

EFFECT OF C-STAGE CY% ON TRICHPHENOL GENERATION

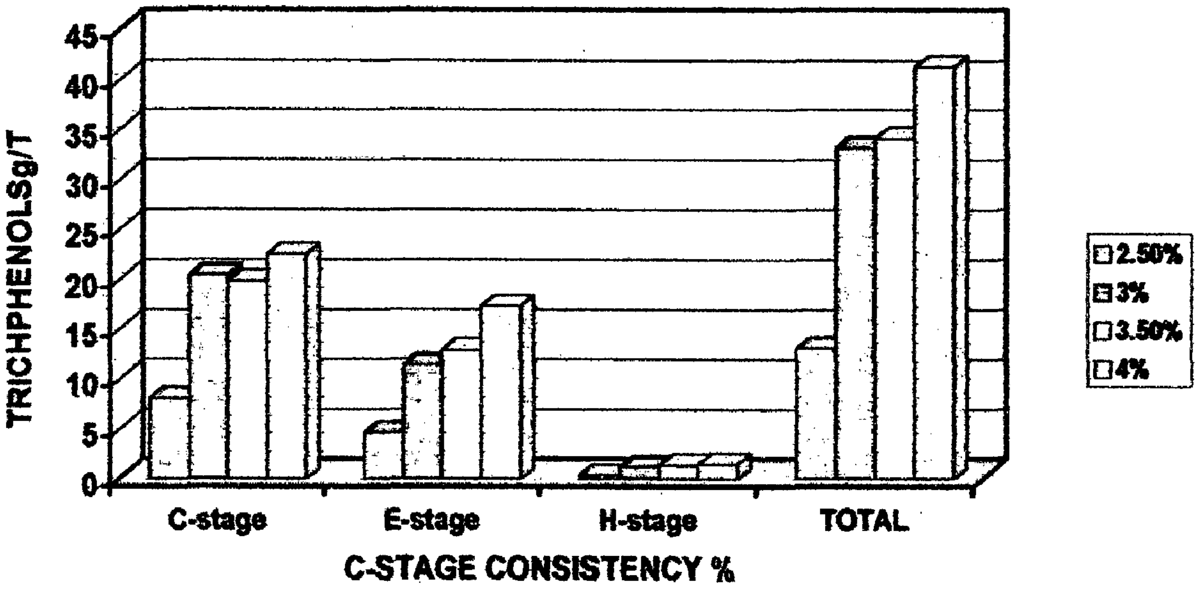


Fig.3.242

EFFECT OF C-STAGE CONSISTENCY ON TETRACHPHENOL GENERATION

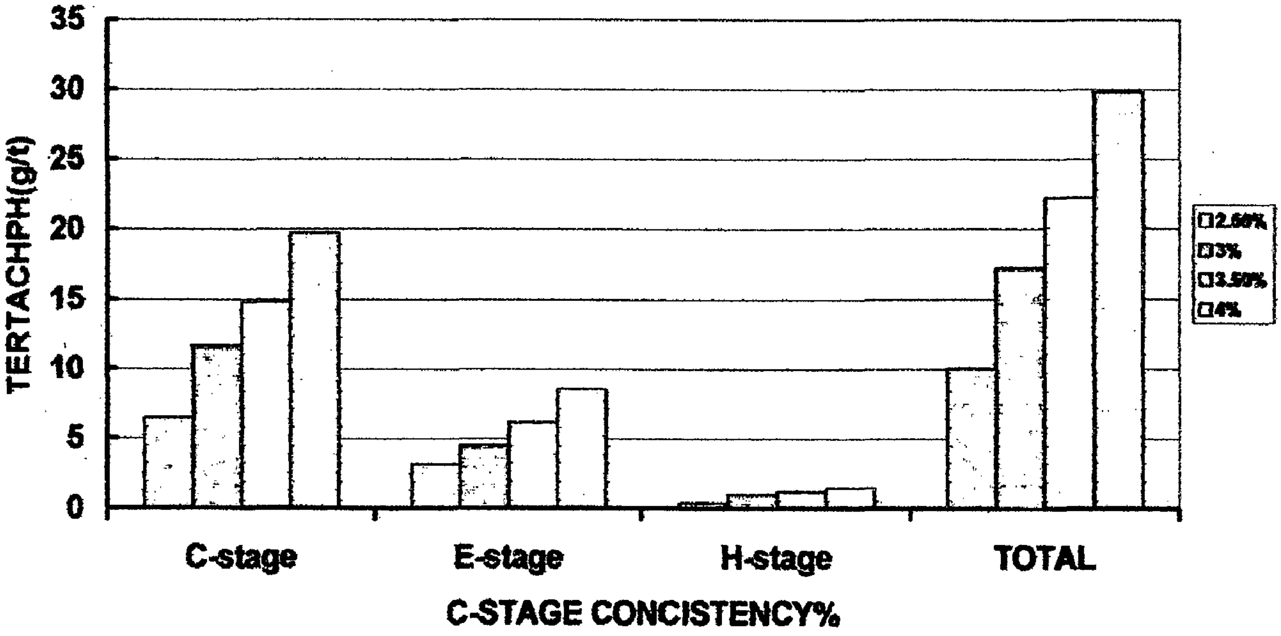


Fig.3.243

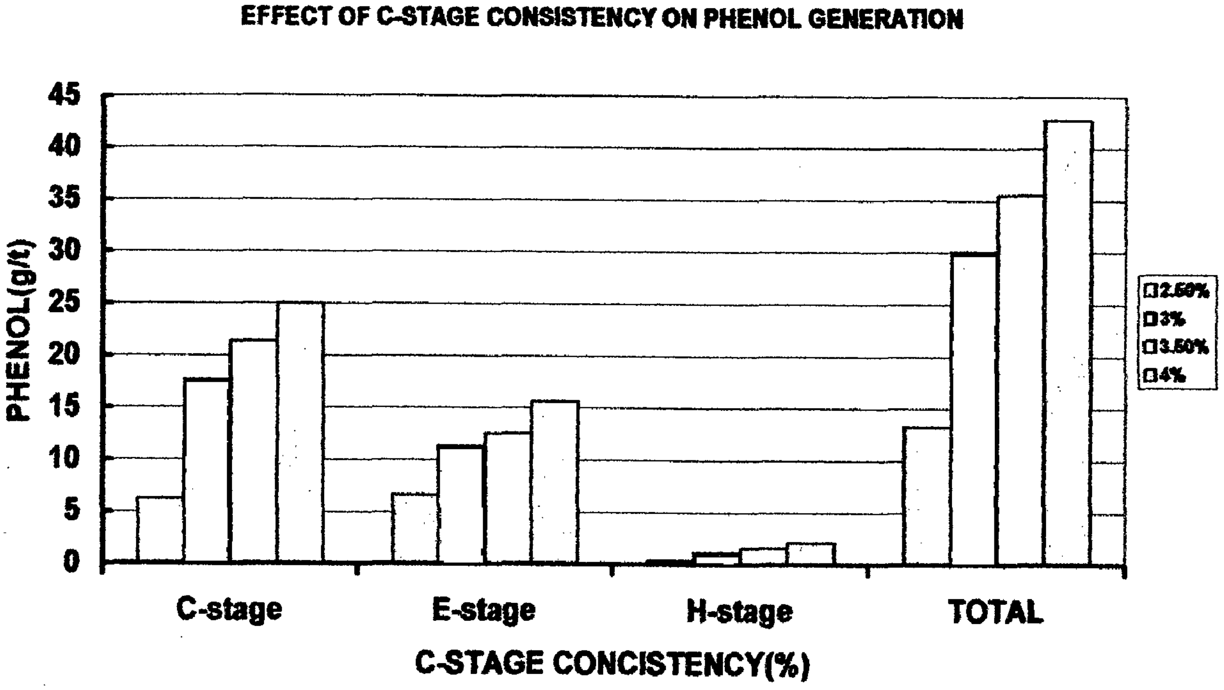


Fig.3.244

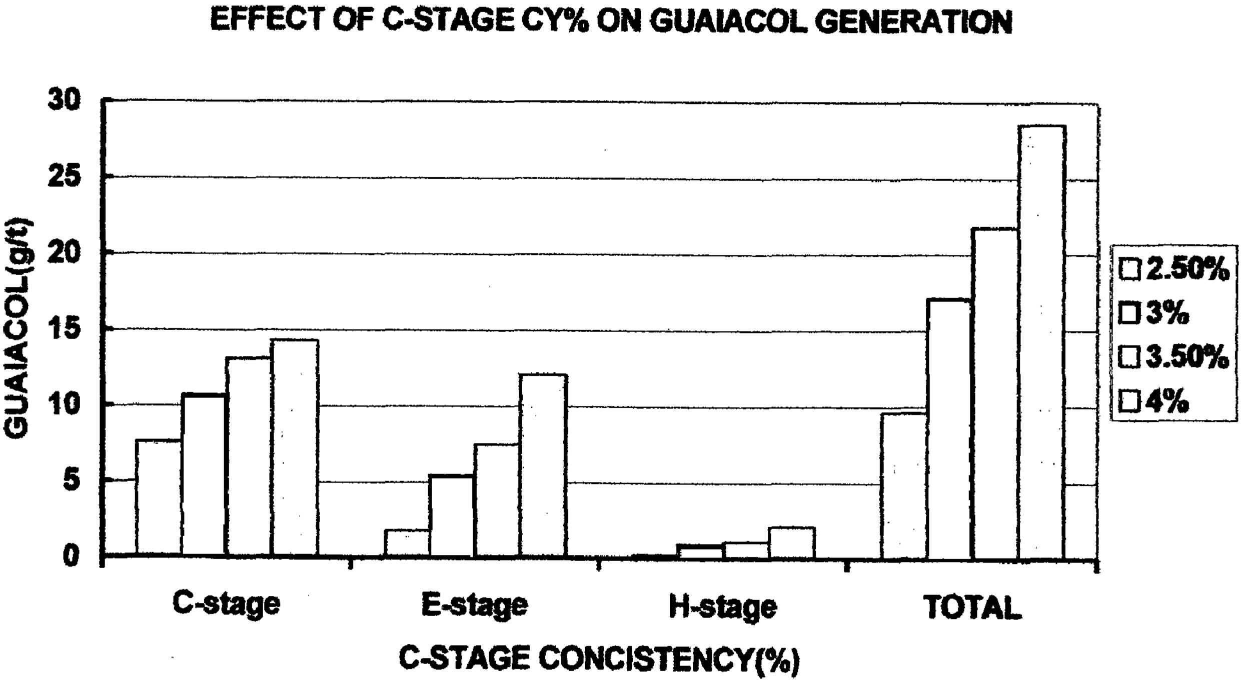


Fig.3.245

EFFECT OF C-STAGE CY% ON CATECHOL GENERATION

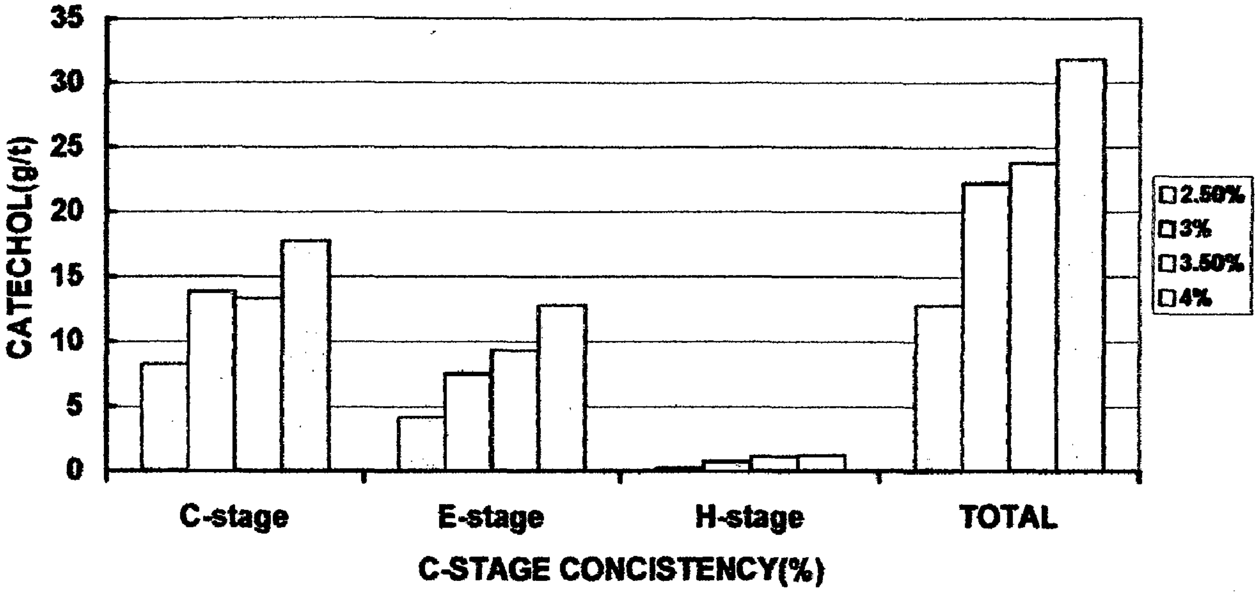


Fig.3.246

EFFECT OF C-STAGE CY% ON VANILLIN,SYRINGOL,SYRINGALDEHYDE GENERATION

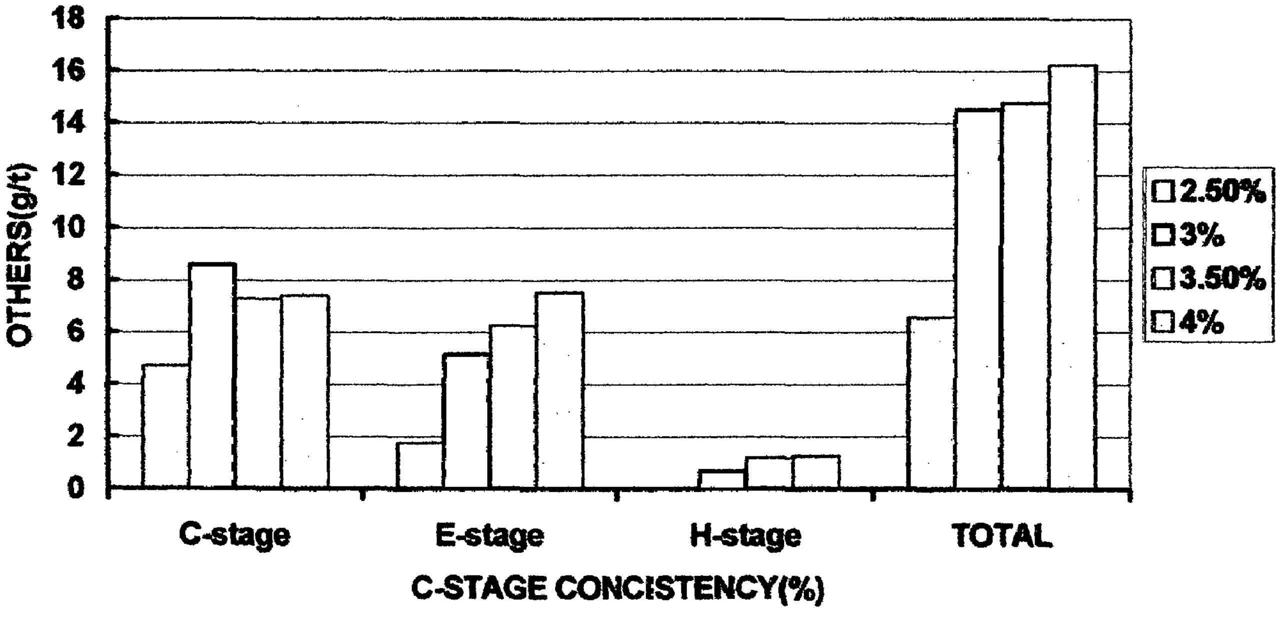


Fig.3.319

EFFECT OF C-STAGE CONSISTENCY ON 2,4,6-TCP GENERATION

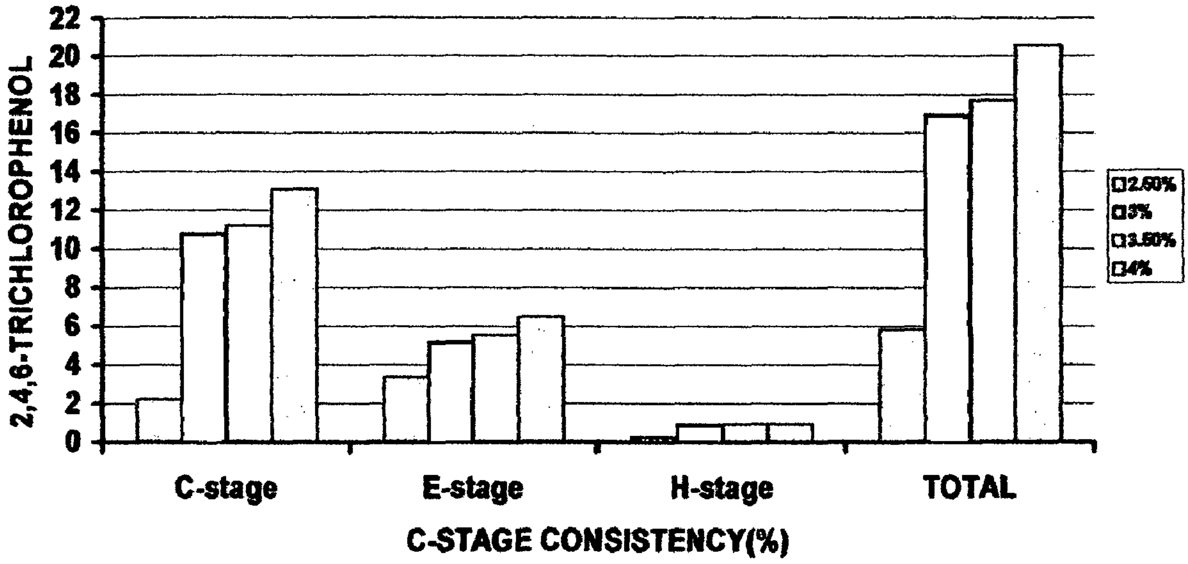


Fig.3.320

EFFECT OF C-STAGE CONSISTENCY ON 5,6-DICHLOROVANILLIN

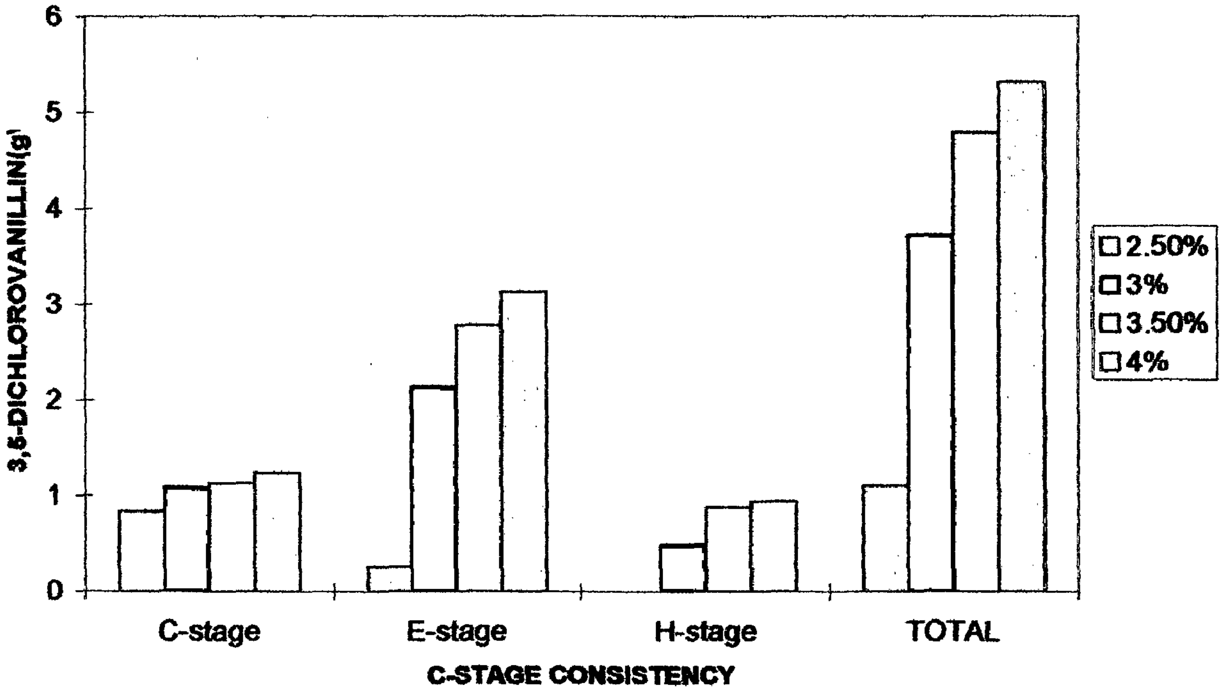


Table 3.125

Formation of different chlorophenolic compounds in various effluents by bleaching at 10% replacement of Chlorine by Chlorine dioxide

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	5.17	0.10	2.60	0.10	0.002	0.0001	7.77
2	3-chlorophenol	3.25	0.13	2.33	0.09	-	-	5.58
3	4-chloroguaiacol	-	-	-	-	0.07	0.003	0.07
4	5-chloroguaiacol	-	-	-	-	0.02	0.001	0.02
5	2,3,5-trichlorophenol	0.17	0.003	0.55	0.02	-	-	0.72
6	2,4,6-trichlorophenol	11.02	0.22	2.56	0.10	0.44	0.02	14.02
7	3,6-dichloroguaiacol	0.14	0.003	0.09	0.004	-	-	0.23
8	3,4-dichlorocatechol	2.22	0.04	1.12	0.04	-	-	3.34
9	4,5-dichloroguaiacol	0.28	0.006	0.48	0.02	0.31	0.01	1.07
10	5,6-dichloroguaiacol	1.52	0.03	-	-	0.12	0.005	1.64
11	2,3,4,6-tetrachlorophenol	0.12	0.002	0.06	0.002	-	-	0.18
12	3,4,5-trichloroguaiacol	1.22	0.02	0.56	0.02	-	-	1.78
13	3,4,6-trichloroguaiacol	3.74	0.07	0.24	0.01	0.02	0.001	4.00
14	3,5-dichlorosyringol	0.32	0.01	0.08	0.003	0.20	0.01	0.60
15	3,6-dichlorocatechol	-	-	-	-	-	-	-
16	4,5,6-trichloroguaiacol	2.66	0.05	0.6	0.02	-	-	3.26
17	tetrachloroguaiacol	1.94	0.04	0.54	0.02	0.24	0.01	2.72
18	3,4,6-trichlorocatechol	1.87	0.04	0.97	0.04	0.13	0.01	2.97
19	2,6-dichlorosyringaldehyde	3.74	0.07	0.54	0.02	-	-	4.28
20	5,6-dichlorovanillin	0.94	0.02	1.66	0.07	0.34	0.01	2.94
21	tetrachlorocatechol	5.21	0.10	1.22	0.05	0.48	0.02	6.91
22	2,3,4-trichlorophenol	-	-	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	2.23	0.09	-	-	2.23
	TOTAL	45.53	0.91	18.43	0.72	2.37	0.09	66.33

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.126

Formation of different chlorophenolic compounds in various effluents by bleaching at 30% replacement of Chlorine by Chlorine dioxide

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	6.54	0.13	2.12	0.08	0.02	0.001	8.68
2	3-chlorophenol	3.63	0.07	-	-	-	-	3.63
3	4-chloroguaiacol	-	-	-	-	0.05	0.002	0.05
4	5-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01
5	2,3,5-trichlorophenol	0.25	0.01	0.53	0.02	-	-	0.78
6	2,4,6-trichlorophenol	11.99	0.24	0.94	0.04	0.37	0.01	13.3
7	3,6-dichloroguaiacol	0.07	0.001	0.03	0.001	-	-	0.1
8	3,4-dichlorocatechol	1.72	0.03	1.04	0.04	-	-	2.76
9	4,5-dichloroguaiacol	0.18	0.004	0.41	0.02	0.29	0.01	0.88
10	5,6-dichloroguaiacol	1.65	0.03	-	-	0.15	0.006	0.18
11	2,3,4,6-tetrachlorophenol	0.19	0.004	0.04	0.002	-	-	0.23
12	3,4,5-trichloroguaiacol	1.29	0.02	0.43	0.02	-	-	1.72
13	3,4,6-trichloroguaiacol	3.79	0.07	0.18	0.01	0.03	0.001	4.00
14	3,5-dichlorosyringol	0.14	0.003	-	-	0.14	0.01	0.28
15	3,6-dichlorocatechol	-	-	-	-	-	-	-
16	4,5,6-trichloroguaiacol	2.73	0.05	0.50	0.02	-	-	3.23
17	tetrachloroguaiacol	1.34	0.03	0.46	0.02	0.17	0.01	1.97
18	3,4,6-trichlorocatechol	1.05	0.22	0.62	0.02	0.11	0.004	1.78
19	2,6-dichlorosyringaldehyde	2.44	0.05	0.23	0.01			2.67
20	5,6-dichlorovanillin	0.78	0.02	1.46	0.06	0.20	0.01	2.44
21	tetrachlorocatechol	4.76	0.10	0.9	0.04	0.31	0.01	5.97
22	2,3,4-trichlorophenol	-	-	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	1.96	0.08	-	-	1.96
	TOTAL	44.54	0.89	11.85	0.48	1.85	0.07	58.24

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.127

Formation of different chlorophenolic compounds in various effluents by bleaching at 50% replacement of Chlorine by Chlorine dioxide

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	7.11	0.14	0.24	0.01	0.05	0.002	7.40
2	3-chlorophenol	3.82	0.08	1.57	0.06	-	-	5.39
3	4-chloroguaiacol	-	-	-	-	0.05	0.002	0.05
4	5-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01
5	2,3,5-trichlorophenol	0.36	0.01	0.10	0.004	-	-	0.46
6	2,4,6-trichlorophenol	12.24	0.24	0.49	0.02	0.28	0.01	13.01
7	3,6-dichloroguaiacol	-	-	0.02	0.001	-	-	0.02
8	3,4-dichlorocatechol	0.77	0.02	0.33	0.01	-	-	1.10
9	4,5-dichloroguaiacol	0.12	0.002	0.24	0.01	0.16	0.01	0.52
10	5,6-dichloroguaiacol	1.72	0.08	-	-	0.17	0.01	1.89
11	2,3,4,6-tetrachlorophenol	0.27	0.01	0.03	0.001	-	-	0.35
12	3,4,5-trichloroguaiacol	1.34	0.03	2.35	0.09	-	-	3.69
13	3,4,6-trichloroguaiacol	3.85	0.08	0.14	0.01	0.05	0.002	4.04
14	3,5-dichlorosyringol	0.13	0.003	-	-	0.07	0.003	0.20
15	3,6-dichlorocatechol	-	-	-	-	-	-	-
16	4,5,6-trichloroguaiacol	2.79	0.05	0.25	0.01	-	-	3.04
17	tetrachloroguaiacol	1.27	0.03	0.37	0.01	0.13	0.005	1.77
18	3,4,6-trichlorocatechol	0.53	0.01	0.45	0.02	0.09	0.004	1.07
19	2,6-dichlorosyringaldehyde	1.07	0.02	0.18	0.01	-	-	1.25
20	5,6-dichlorovanillin	0.74	0.01	0.41	0.02	0.19	0.008	1.34
21	tetrachlorocatechol	3.8	0.08	0.45	0.02	0.27	0.01	4.52
22	2,3,4-trichlorophenol	-	-	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	1.89	0.08	-	-	1.89
	TOTAL	41.93	0.83	9.51	0.39	1.52	0.06	52.96

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.128

Formation of different chlorophenolic compounds in various effluents by bleaching at 75% replacement of Chlorine by Chlorine dioxide

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	0.35	0.01	0.20	0.01	0.07	0.003	0.62
2	3-chlorophenol	0.55	0.01	-	-	-	-	0.55
3	4-chloroguaiacol	-	-	-	-	0.04	0.002	0.04
4	5-chloroguaiacol	-	-	-	-	0.05	0.002	0.05
5	2,3,5-trichlorophenol	-	-	-	-	-	-	-
6	2,4,6-trichlorophenol	1.75	0.04	0.34	0.01	0.20	0.008	2.29
7	3,6-dichloroguaiacol	-	-	0.01	0.0004	-	-	0.01
8	3,4-dichlorocatechol	0.58	0.01	0.12	0.005	-	-	0.70
9	4,5-dichloroguaiacol	0.09	0.002	0.1	0.004	0.12	0.005	0.31
10	5,6-dichloroguaiacol	0.08	0.002	-	-	0.11	0.004	0.19
11	2,3,4,6-tetrachlorophenol	-	-	0.01	0.0004	-	-	0.01
12	3,4,5-trichloroguaiacol	0.49	0.01	0.21	0.01	-	-	0.70
13	3,4,6-trichloroguaiacol	0.24	0.005	0.05	0.002	0.01	0.0004	0.30
14	3,5-dichlorosyringol	0.08	0.002	-	-	0.03	0.001	0.11
15	3,6-dichlorocatechol	-	-	-	-	-	-	-
16	4,5,6-trichloroguaiacol	0.18	0.004	0.19	0.01	-	-	0.37
17	tetrachloroguaiacol	0.46	0.01	0.22	0.01	0.12	0.005	0.8
18	3,4,6-trichlorocatechol	0.48	0.01	0.11	0.004	0.06	0.002	0.65
19	2,6-dichlorosyringaldehyde	0.67	0.01	0.04	0.002	-	-	0.71
20	5,6-dichlorovanillin	0.29	0.006	0.05	0.002	0.17	0.007	0.51
21	tetrachlorocatechol	2.90	0.06	0.20	0.008	0.12	0.005	3.22
22	2,3,4-trichlorophenol	-	-	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	1.79	0.07	-	-	1.79
	TOTAL	9.19	0.18	3.64	0.14	1.10	0.04	13.93

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C, Consistency 3%

Table 3.347 Effect of partial substitution of chlorine by chlorine dioxide in C stage on the generation of Chlorophenolic compounds

Chlorophenolic compounds (kg/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0%	53.19	29.56	3.68	86.43
10%	45.53	18.43	2.37	66.33
30%	44.54	11.85	1.85	58.24
50%	41.93	9.51	1.52	52.96
75%	9.19	3.64	1.10	13.93

Table 3.348 Effect of partial substitution of chlorine by chlorine dioxide in C stage on the generation of effluent COD

COD (kg/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0%	39.9	35.8	21.8	97.5
10%	31.1	29.4	19.8	80.3
30%	29.8	27.7	17.8	75.3
50%	26.1	24.3	15.7	66.1
75%	22.2	20.9	14.2	57.3

Table 3.349 Effect of partial substitution of chlorine by chlorine dioxide in C stage on the generation of effluent Colour

Colour (kg/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0%	42.5	81.2	1.9	125.6
10%	33.7	79.2	1.2	114.2
30%	31.7	74.4	1.2	107.3
50%	28.7	43.7	0.6	73.1
75%	12.5	13.7	0.3	26.5

Table 3.350 Effect of partial substitution of chlorine by chlorine dioxide in C stage on Brightness and Viscosity of bleached pulps obtained by CEH bleaching

Substitution by D	Brightness (%)	Viscosity (cp)
0%	80.1	9.4
10%	80.7	11.9
30%	81.2	13.1
50%	81.7	14.7
75%	82	16.4

Table 3.351 Monochlorophenolic compounds present in different effluents formed by partial substitution of chlorine by chlorine dioxide in C stage

Monochlorophenolic compounds (g/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0% D	2.39	2.37	0.23	4.99
10% D	3.25	2.33	0.09	5.67
30% D	3.63	-	0.06	3.69
50% D	3.82	1.57	0.06	5.45
75% D	0.55	-	0.09	0.64

Table 3.352 Dichlorophenolic compounds present in different effluents formed by partial substitution of chlorine by chlorine dioxide in C stage

Dichlorophenolic compounds (g/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0% D	16.27	11.14	1.22	28.63
10% D	14.33	8.80	0.97	24.10
30% D	13.52	7.25	0.87	21.64
50% D	11.66	3.31	0.87	15.84
75% D	2.14	2.31	0.79	5.24

Table 3.353 Trichlorophenolic compounds present in different effluents formed by partial substitution of chlorine by chlorine dioxide in C stage

Trichlorophenolic compounds (g/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0% D	20.48	11.51	1.23	33.22
10% D	20.68	5.48	0.59	26.75
30% D	21.10	3.20	0.88	25.18
50% D	21.11	3.78	0.60	25.49
75% D	3.14	0.90	0.41	4.45

Table 3.354 Tetrachlorophenolic compounds present in different effluents formed by partial substitution of chlorine by chlorine dioxide in C stage

Tetrachlorophenolic compounds (g/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0% D	11.70	4.54	1.00	17.24
10% D	7.27	1.82	0.72	9.81
30% D	6.29	1.40	0.68	8.37
50% D	5.34	0.85	0.75	6.94
75% D	3.36	0.43	0.79	4.58

Table 3.355 Category wise load of chlorophenols in different effluents formed by partial substitution of chlorine by chlorine dioxide in C stage

Chlorophenols (g/t)				
Substitution by D	**C-stage**	**E-stage**	**H-stage**	**TOTAL**
0% D	17.61	11.31	1.18	30.10
10% D	19.73	8.10	0.44	28.27
30% D	22.60	3.63	0.39	26.62
50% D	23.8	2.43	0.33	26.56
75% D	2.65	0.55	0.27	3.47

Table 3.356 Category wise load of chloroguaiacols in different effluents formed by partial substitution of chlorine by chlorine dioxide in C stage

Chloroguaiacols (g/t)				
Substitution by D	**C-stage**	**E-stage**	**H-stage**	**TOTAL**
0% D	10.72	5.46	0.95	17.13
10% D	11.50	2.51	0.78	14.79
30% D	11.05	2.01	0.70	13.76
50% D	11.09	3.37	0.57	15.03
75% D	1.54	0.78	0.45	2.77

Table 3.357 Category wise load of chlorocatechols in different effluents formed by partial substitution of chlorine by chlorine dioxide in C stage

Chlorocatechols (g/t)				
Substitution by D	**C-stage**	**E-stage**	**H-stage**	**TOTAL**
0% D	13.87	7.61	0.81	22.29
10% D	9.30	5.54	0.61	15.45
30% D	7.53	4.52	0.42	12.47
50% D	5.10	3.12	0.36	8.58
75% D	3.96	2.22	0.18	6.36

Table 3.358 Category wise load of other chlorophenolic compounds in different effluents formed by partial substitution of chlorine by chlorine dioxide in C stage

Other Chlorophenolic compounds (g/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0% D	8.64	5.18	0.74	14.56
10% D	5.00	2.28	0.54	7.82
30% D	3.36	1.69	0.34	5.39
50% D	1.94	0.59	0.26	2.79
75% D	1.04	0.09	0.20	1.33

Table 3.323 Different chlorophenolic compounds formed in C stage by partial substitution of chlorine by chlorine dioxide

Partial substitution of chlorine by chlorine dioxide						
S.No.	Chlorophenolic compounds(g/T)	**0% D**	**10% D**	**30% D**	**50% D**	**75% D**
1	2,4-dichlorophenol	4.17	5.17	6.54	7.11	0.35
2	3-chlorophenol	2.39	3.25	3.63	3.82	0.55
3	4-chloroguaiacol	-	-	-	-	-
4	5-chloroguaiacol	-	-	-	-	-
5	2,3,5-trichlorophenol	0.14	0.17	0.25	0.36	-
6	2,4,6-trichlorophenol	10.82	11.02	11.99	12.24	1.75
7	3,6-dichloroguaiacol	0.17	0.14	0.07	-	-
8	3,4dichlorocatechol	2.98	2.22	1.72	0.77	0.58
9	4,5-dichloroguaiacol	0.31	0.28	0.18	0.12	0.09
10	5,6-dichloroguaiacol	1.48	1.52	1.65	1.72	0.08
11	2,3,4,6-tetrachlorophenol	0.96	0.12	0.19	0.27	-
12	3,4,5-trichloroguaiacol	1.19	1.22	1.29	1.34	0.49
13	3,4,6-trichloroguaiacol	3.66	3.74	3.79	3.85	0.24
14	3,5-dichlorosyringol	2.69	0.32	0.14	0.13	0.08
15	3,6-dichlorocatechol	-	-	-	-	-
16	4,5,6-trichloroguaiacol	2.20	2.66	2.73	2.79	0.18
17	tetrachloroguaiacol	3.19	1.94	1.34	1.27	0.46
18	3,4,6-trichlorocatechol	2.47	1.87	1.05	0.53	0.48
19	2,6-dichlorosyringaldehyde	4.86	3.74	2.44	1.07	0.67
20	5,6-dichlorovanillin	1.09	0.94	0.78	0.74	0.29
21	tetrachlorocatechol	8.42	5.21	4.76	3.80	2.90
22	2,3,4-trichlorophenol	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	53.19	45.53	44.54	41.93	9.19

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C, Consistency 3%

Table 3.324 Different chlorophenolic compounds formed in E stage by partial substitution of chlorine by chlorine dioxide

Partial substitution of chlorine by chlorine dioxide						
S.No.	Chlorophenolic compounds(g/T)	0% D	10% D	30% D	50% D	75% D
1	2,4-dichlorophenol	2.77	2.60	2.12	0.24	0.20
2	3-chlorophenol	2.37	2.33	-	1.57	-
3	4-chloroguaiacol	-	-	-	-	-
4	5-chloroguaiacol	-	-	-	-	-
5	2,3,5-trichlorophenol	0.87	0.55	0.53	0.10	-
6	2,4,6-trichlorophenol	5.23	2.56	0.94	0.49	0.34
7	3,6-dichloroguaiacol	0.16	0.09	0.03	0.02	0.01
8	3,4dichlorocatechol	1.18	1.12	1.04	0.33	0.12
9	4,5-dichloroguaiacol	0.89	0.48	0.41	0.24	0.10
10	5,6-dichloroguaiacol	-	-	-	-	-
11	2,3,4,6-tetrachlorophenol	0.07	0.06	0.04	0.03	0.01
12	3,4,5-trichloroguaiacol	0.95	0.56	0.43	2.35	0.21
13	3,4,6-trichloroguaiacol	0.28	0.24	0.18	0.14	0.05
14	3,5-dichlorosyringol	1.42	0.08	-	-	
15	3,6-dichlorocatechol	0.96	-	-	-	-
16	4,5,6-trichloroguaiacol	2.36	0.60	0.50	0.25	0.19
17	tetrachloroguaiacol	0.82	0.54	0.46	0.37	0.22
18	3,4,6-trichlorocatechol	1.82	0.97	0.62	0.45	0.11
19	2,6-dichlorosyringaldehyde	1.62	0.54	0.23	0.18	0.04
20	5,6-dichlorovanillin	2.14	1.66	1.46	0.41	0.05
21	tetrachlorocatechol	3.65	1.22	0.90	0.45	0.20
22	2,3,4-trichlorophenol	-	-	-	-	-
23	4,5-dichlorocatechol	-	2.23	1.96	1.89	1.79
	TOTAL	29.56	18.43	11.85	9.51	3.64

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.325 Different chlorophenolic compounds formed in H stage by partial substitution of chlorine by chlorine dioxide

Partial substitution of chlorine by chlorine dioxide						
S.No.	Chlorophenolic compounds(g/T)	**0% D**	**10% D**	**30% D**	**50% D**	**75% D**
1	2,4-dichlorophenol	-	0.002	0.02	0.05	0.07
2	3-chlorophenol	0.12	-	-	-	-
3	4-chloroguaiacol	0.09	0.07	0.05	0.05	0.04
4	5-chloroguaiacol	0.02	0.02	0.01	0.01	0.05
5	2,3,5-trichlorophenol	-	-	-	-	-
6	2,4,6-trichlorophenol	0.91	0.44	0.37	0.28	0.2
7	3,6-dichloroguaiacol	-	-	-	-	-
8	3,4dichlorocatechol	-	-	-	-	-
9	4,5-dichloroguaiacol	0.37	0.31	0.29	0.16	0.12
10	5,6-dichloroguaiacol	0.11	0.12	0.15	0.17	0.11
11	2,3,4,6-tetrachlorophenol	-	-	-	-	-
12	3,4,5-trichloroguaiacol	-	-	-	-	-
13	3,4,6-trichloroguaiacol	0.04	0.02	0.03	0.05	0.01
14	3,5-dichlorosyringol	0.25	0.20	0.14	0.07	0.03
15	3,6-dichlorocatechol	-	-	-	-	-
16	4,5,6-trichloroguaiacol	-	-	-	-	-
17	tetrachloroguaiacol	0.32	0.24	0.17	0.13	0.12
18	3,4,6-trichlorocatechol	0.13	0.13	0.11	0.09	0.06
19	2,6-dichlorosyringaldehyde	-	-	-	-	-
20	5,6-dichlorovanillin	0.49	0.34	0.20	0.19	0.17
21	tetrachlorocatechol	0.68	0.48	0.31	0.27	0.12
22	2,3,4-trichlorophenol	0.15	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	3.68	2.37	1.85	1.52	1.10

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C, Consistency 3%

Table 3.326 Total chlorophenolic compounds formed in CEH bleaching by partial substitution of chlorine by chlorine dioxide

Partial substitution of chlorine by chlorine dioxide						
S.No.	Chlorophenolic compounds(g/T)	0% D	10% D	30% D	50% D	75% D
1	2,4-dichlorophenol	6.94	7.772	8.68	7.40	0.62
2	3-chlorophenol	4.88	5.58	3.63	5.39	0.55
3	4-chloroguaiacol	0.09	0.07	0.05	0.05	0.04
4	5-chloroguaiacol	0.02	0.02	0.01	0.01	0.05
5	2,3,5-trichlorophenol	1.01	0.72	0.78	0.46	-
6	2,4,6-trichlorophenol	16.96	14.02	13.3	13.01	2.29
7	3,6-dichloroguaiacol	0.33	0.23	0.10	0.02	0.01
8	3,4dichlorocatechol	4.16	3.34	2.76	1.10	0.70
9	4,5-dichloroguaiacol	1.57	1.07	0.88	0.52	0.31
10	5,6-dichloroguaiacol	1.59	1.64	1.80	1.89	0.19
11	2,3,4,6-tetrachlorophenol	1.03	0.18	0.23	0.30	0.01
12	3,4,5-trichloroguaiacol	2.14	1.78	1.72	3.69	0.7
13	3,4,6-trichloroguaiacol	3.98	4.00	4.00	4.04	0.30
14	3,5-dichlorosyringol	4.36	0.60	0.28	0.20	0.11
15	3,6-dichlorocatechol	0.96	-	-	-	-
16	4,5,6-trichloroguaiacol	4.56	3.26	3.23	3.04	0.37
17	tetrachloroguaiacol	4.33	2.72	1.97	1.77	0.80
18	3,4,6-trichlorocatechol	4.42	2.97	1.78	1.07	0.65
19	2,6-dichlorosyringaldehyde	6.48	4.28	2.67	1.25	0.71
20	5,6-dichlorovanillin	3.72	2.94	2.44	1.34	0.51
21	tetrachlorocatechol	12.75	6.91	5.97	4.52	3.22
22	2,3,4-trichlorophenol	0.15	-	-	-	-
23	4,5-dichlorocatechol	-	2.23	1.96	1.89	1.79
	TOTAL	86.43	66.332	58.24	52.96	13.93

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Fig. 3.247

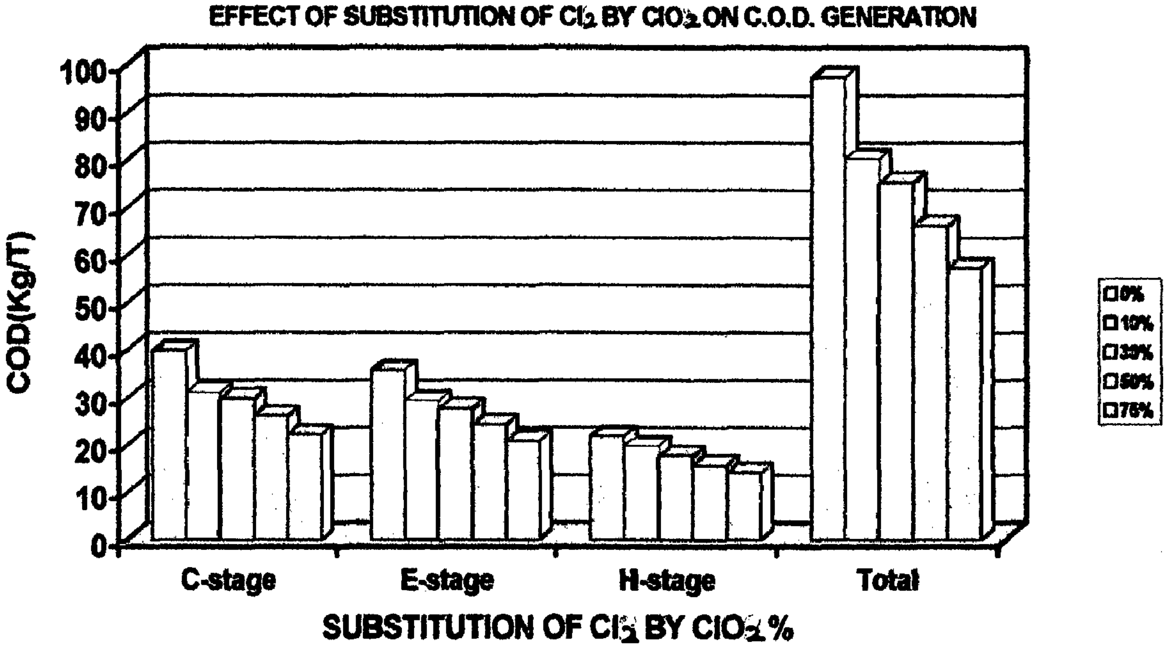

EFFECT OF SUBSTITUTION OF Cl_2 BY ClO_2 ON C.O.D. GENERATION

Fig. 3.248

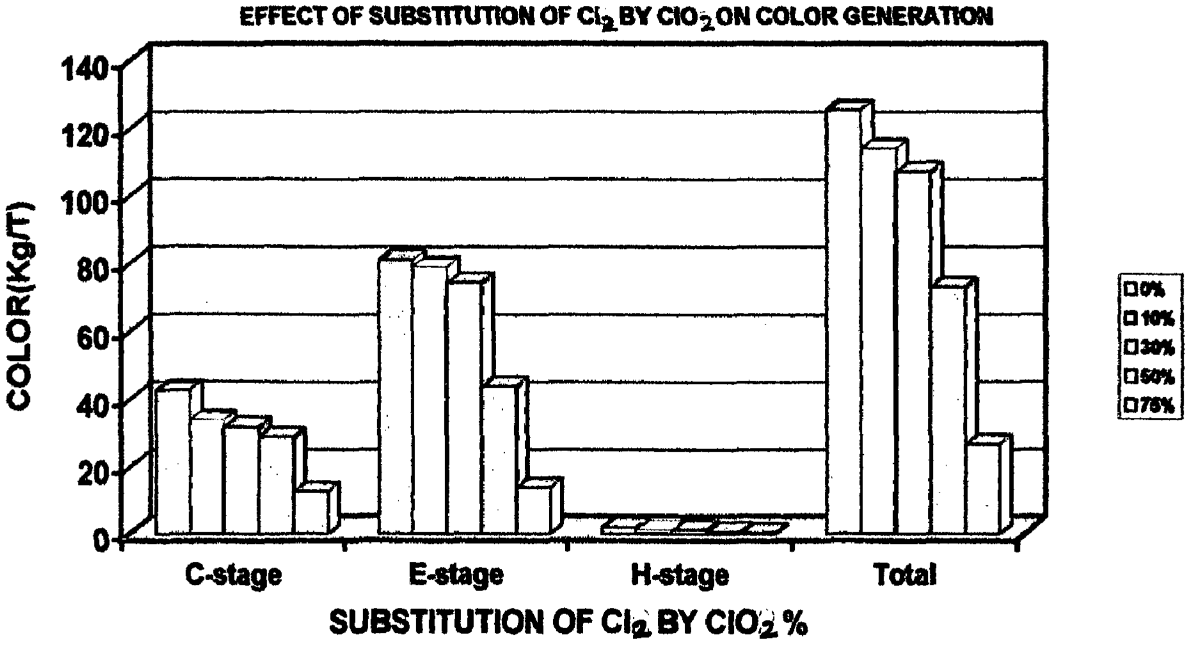

EFFECT OF SUBSTITUTION OF Cl_2 BY ClO_2 ON COLOR GENERATION

Fig. 3.249

EFFECT OF SUBSTITUTION OF Cl_2 BY ClO_2 ON CHLOROPHENOL GENERATION

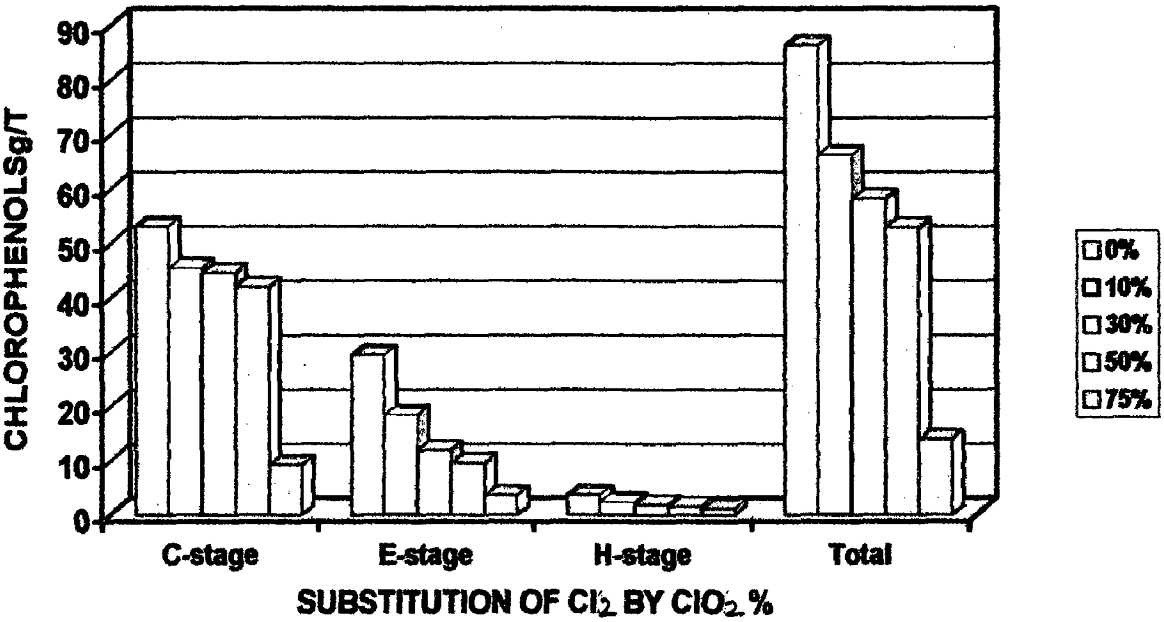


Fig. 3.250

EFFECT OF SUBSTITUTION OF Cl_2 BY ClO_2 ON BRIGHTNESS & VISCOSITY

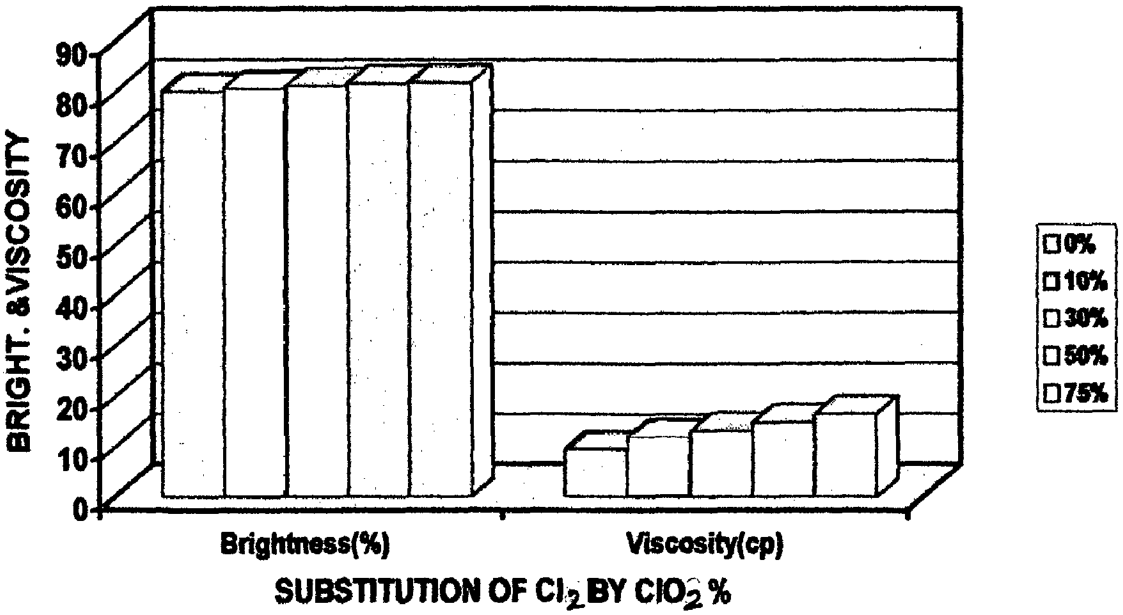


Fig. 3.251

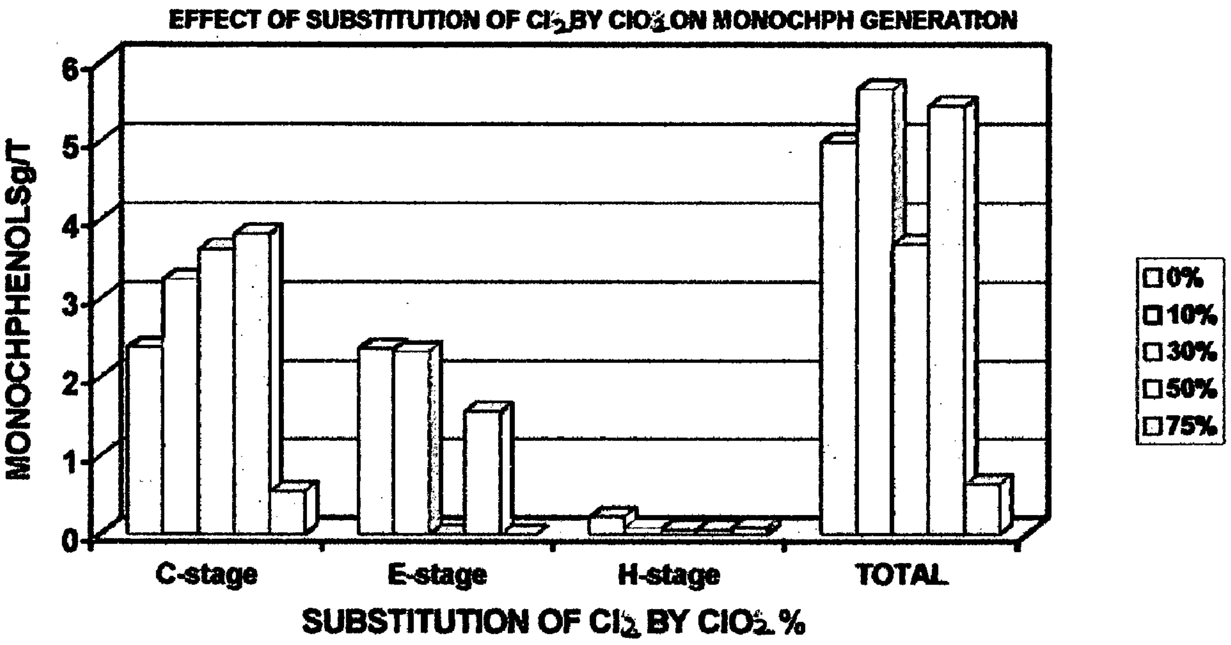


Fig. 3.252

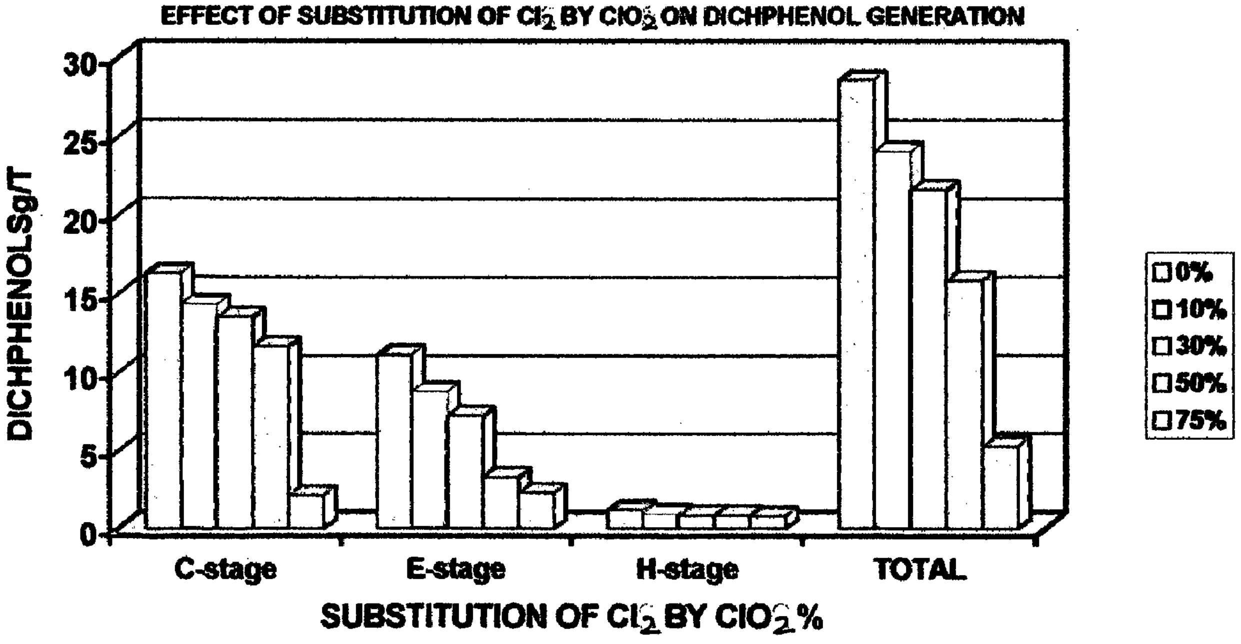


Fig. 3.253

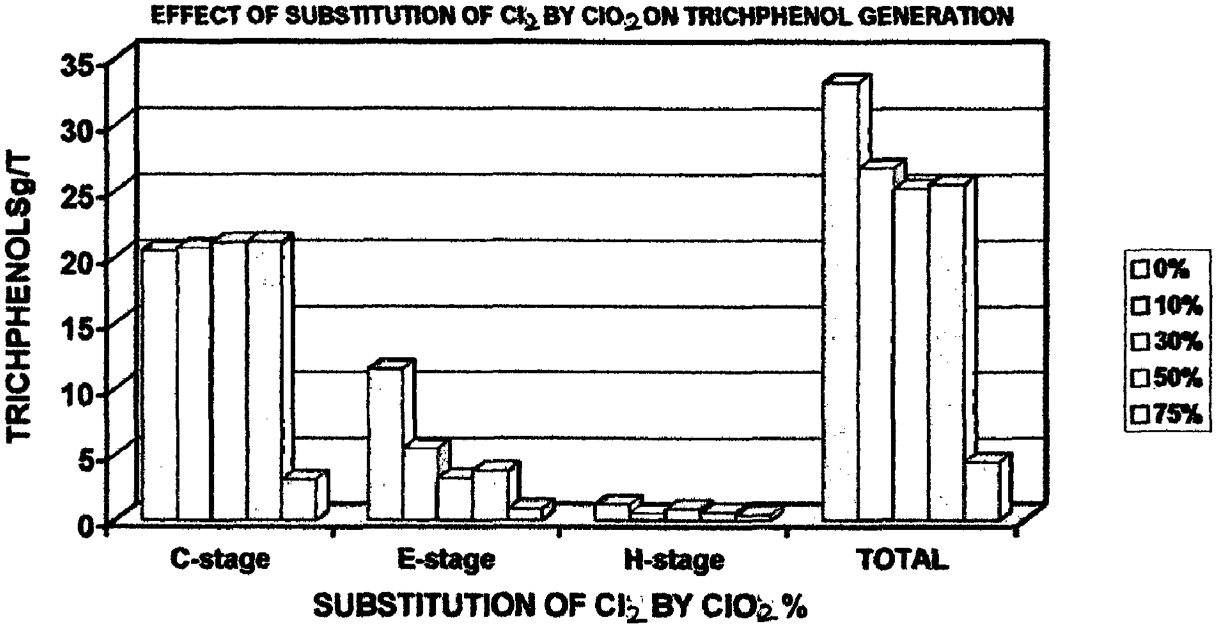


Fig. 3.254

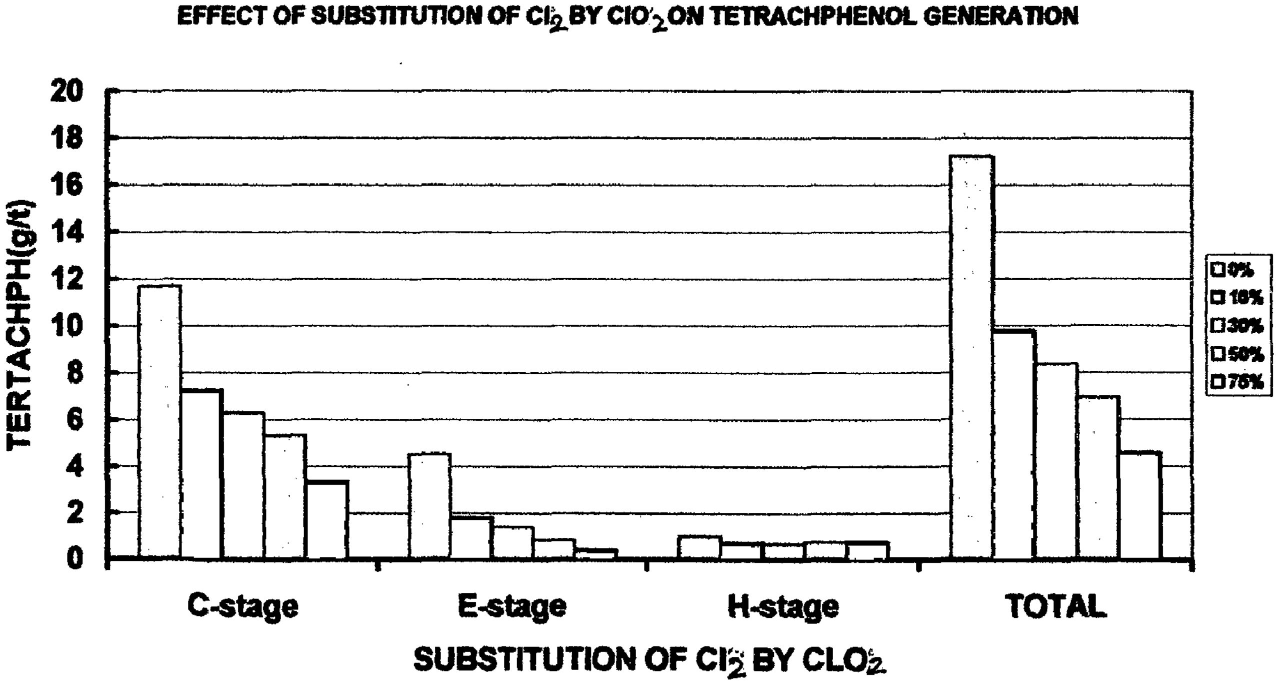


Fig. 3.255

EFFECT OF SUBSTITUTION OF Cl_2 BY ClO_2 ON PHENOL GENERATION

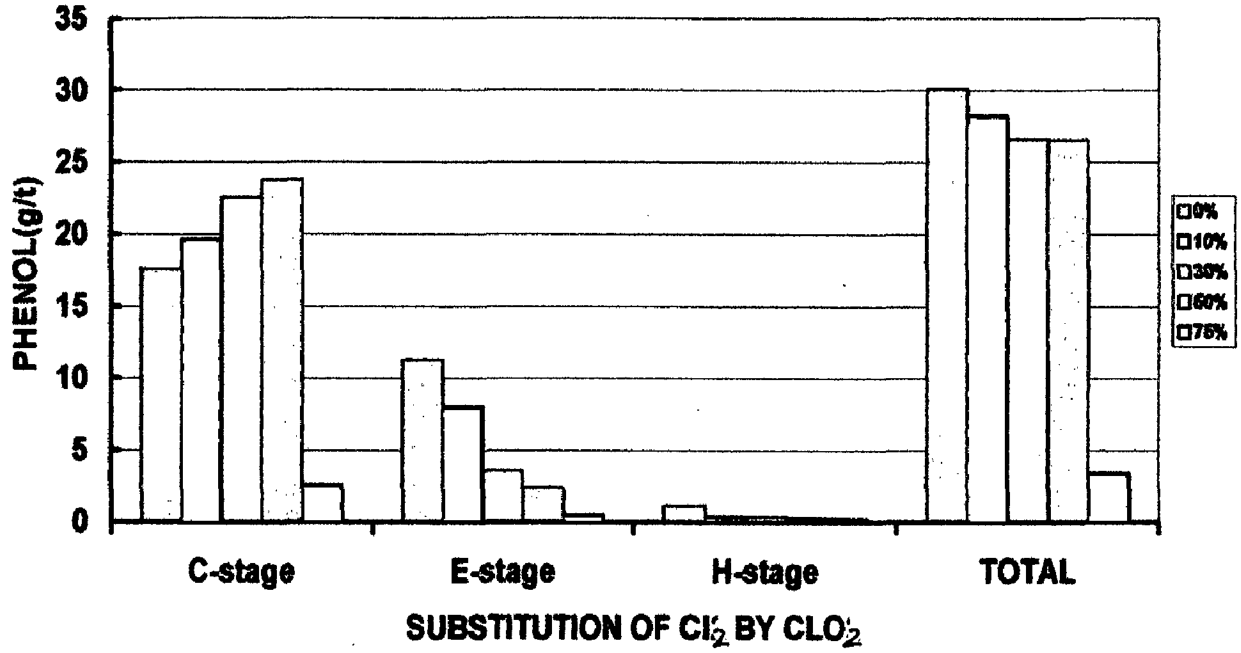


Fig. 3.256

EFFECT OF SUBSTITUTION OF Cl_2 BY ClO_2 ON GUAIACOL GENERATION

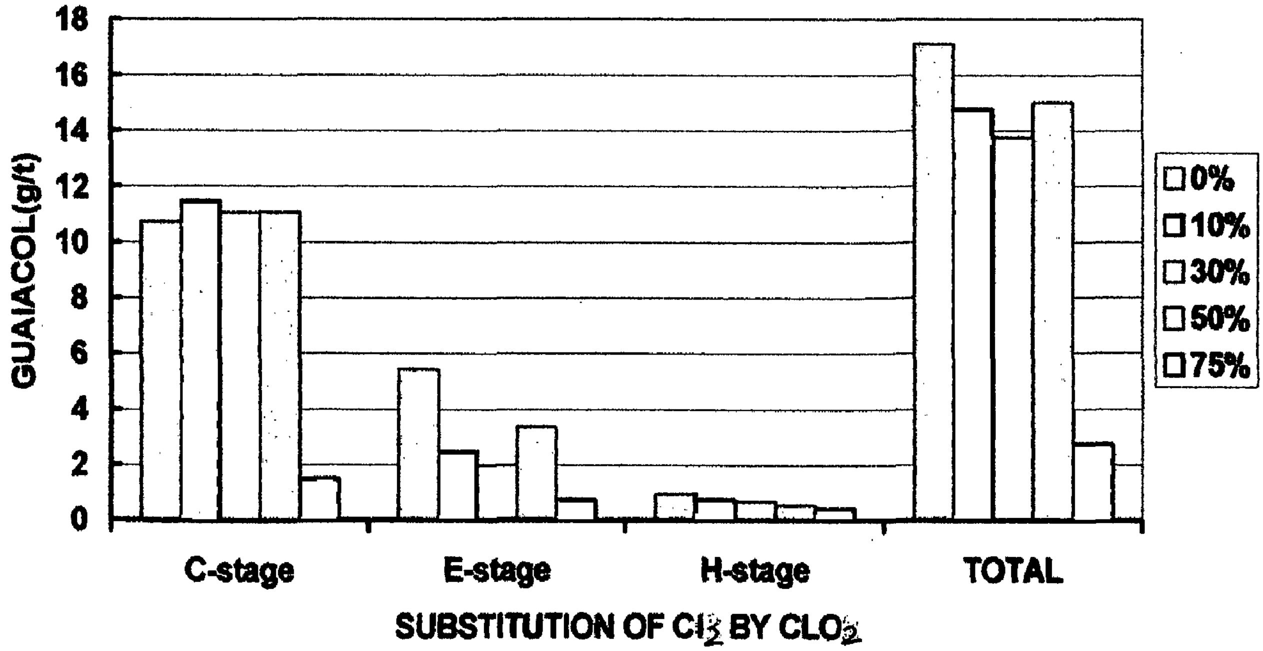


Fig. 3.257

EFFECT OF SUBSTITUTION OF Cl_2 BY ClO_2 ON CATECHOL GENERATION

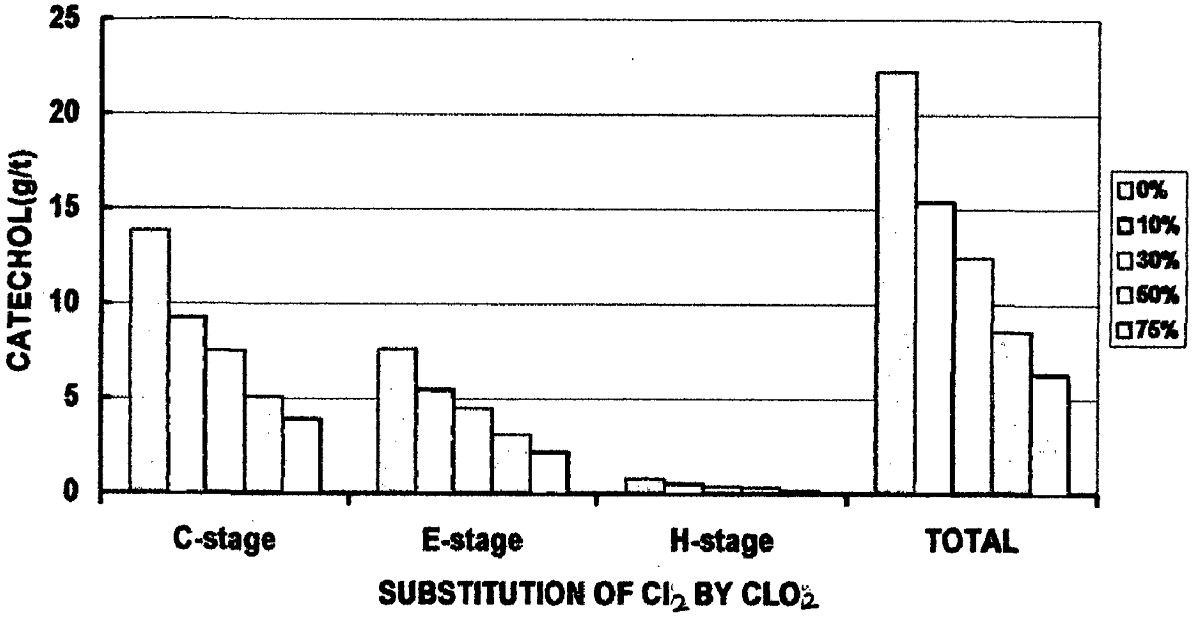


Fig. 3.258

EFFECT OF SUBSTITUTION OF Cl_2 BY ClO_2 ON VANILLIN,SYRINGOL,SYRINGALDEHYDE GENERATION

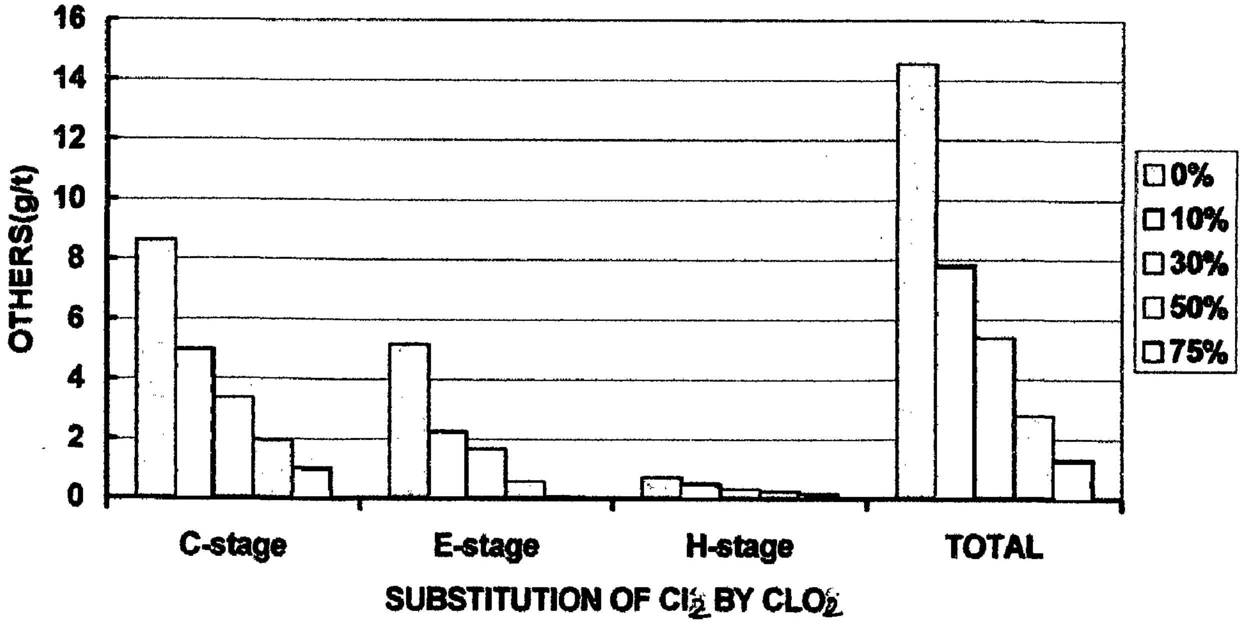


Fig. 3.321

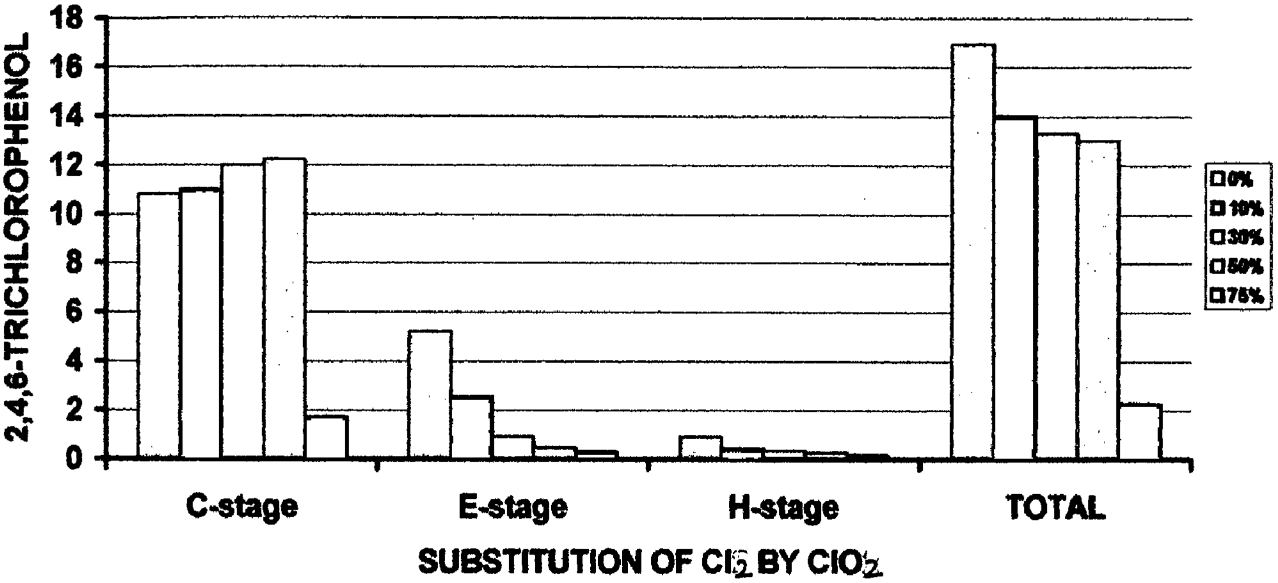

EFFECT OF SUBSTITUTION OF Cl_2 BY ClO_2 ON 2,4,6-TCP GENERATION

Fig. 3.322

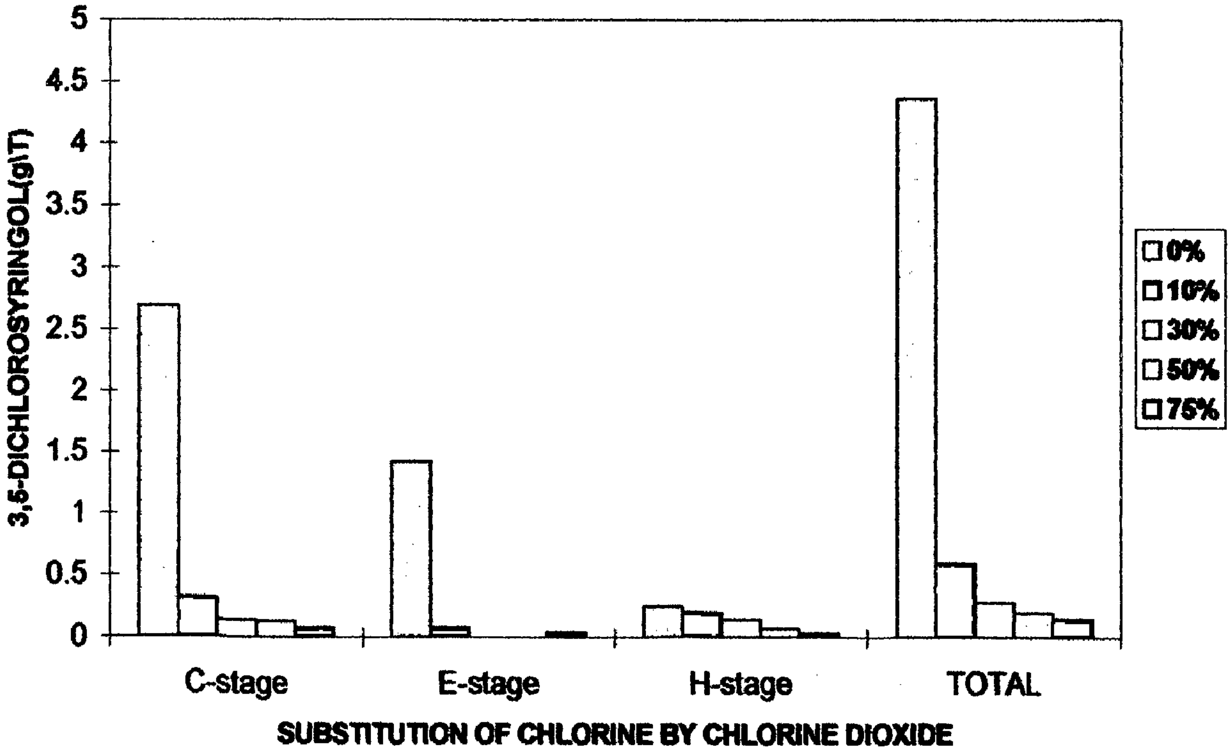

EFFECT OF SUBSTITUTION OF CHLORINE BY CHLORINE DIOXIDE ON 3,5-DICHLOROSYRINGOL

Fig. 3.323

EFFECT OF SUBSTITUTION OF CHLORINE BY CHLORINE DIOXIDE ON 5,6-DICHLOROVANILLIN

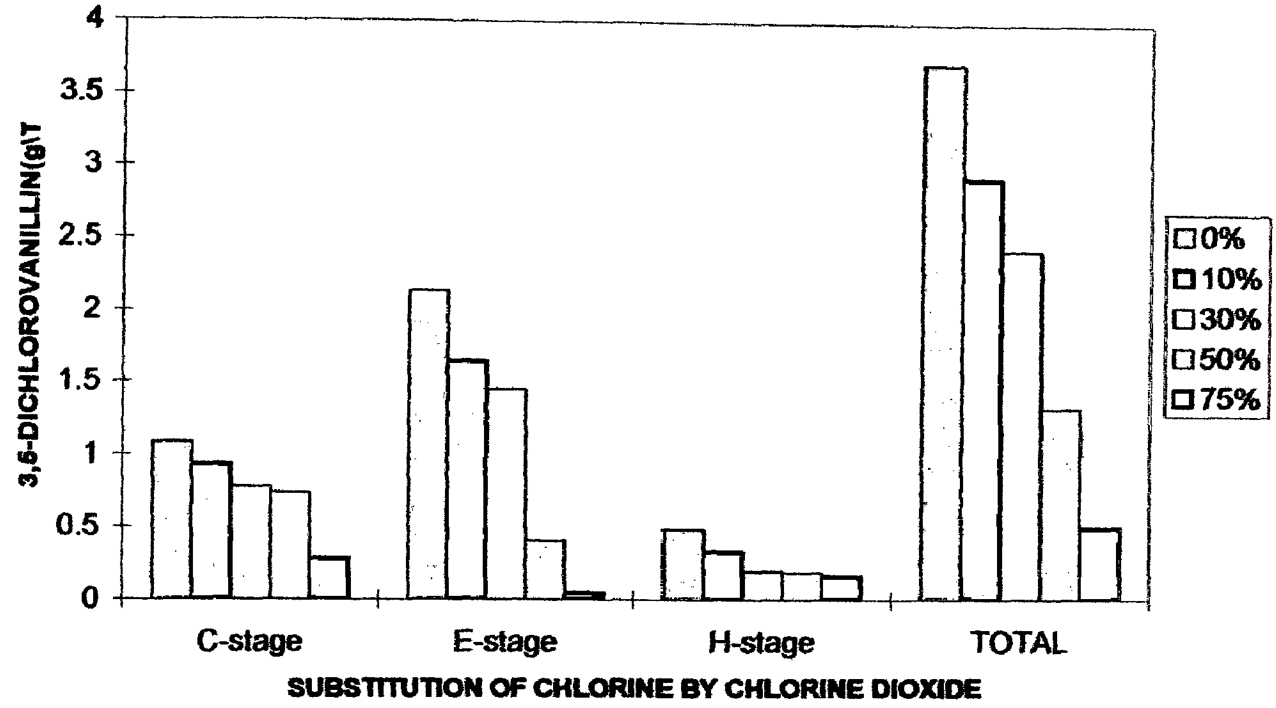


Fig. 3.324

EFFECT OF SUBSTITUTION OF Cl_2 BY ClO_2 ON TeCC GENERATION

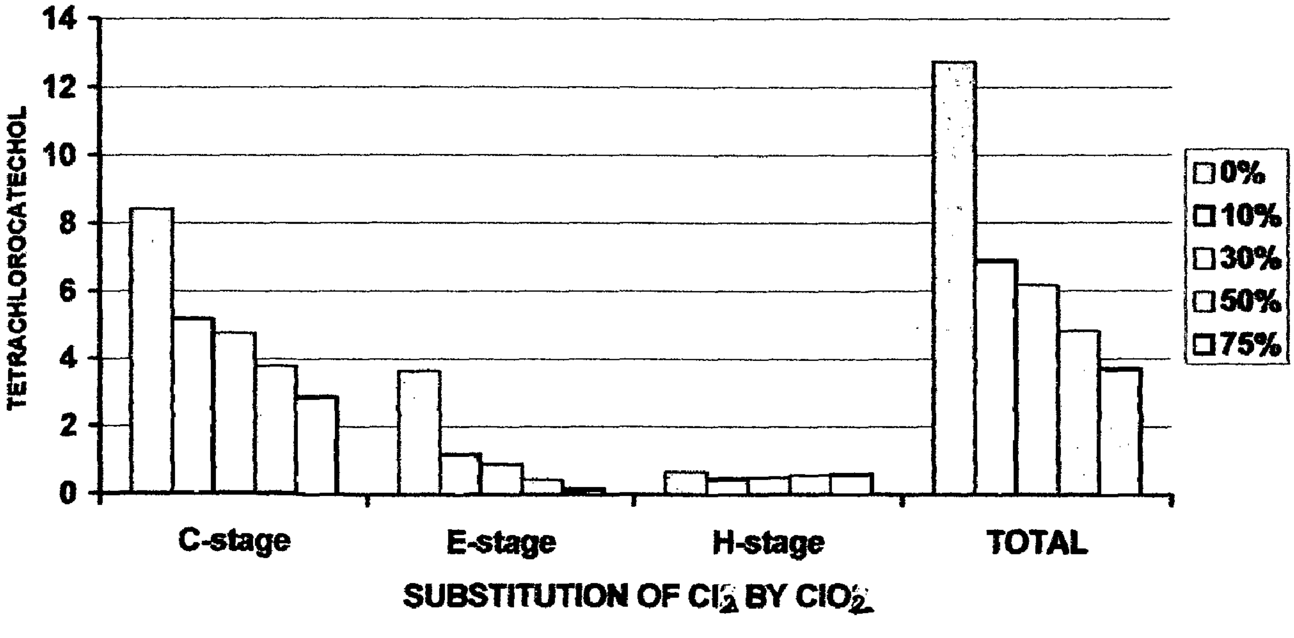


Table 3.129

Formation of different chlorophenolic compounds in various effluents by bleaching at 40:60 Chlorine charge distribution

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	1.83	0.04	-	-	-	-	1.83
2	3-chlorophenol	0.97	0.02	0.09	0.003	0.20	0.01	1.26
3	4-chloroguaiacol	-	-	-	-	0.12	0.005	0.12
4	5-chloroguaiacol	-	-	-	-	0.10	0.004	0.10
5	2,3,5-trichlorophenol	0.06	0.001	0.11	0.004	-	-	0.17
6	2,4,6-trichlorophenol	7.54	0.15	1.81	0.07	0.99	0.04	10.34
7	3,6-dichloroguaiacol	0.04	0.001	0.01	0.0004	-	-	0.05
8	3,4-dichlorocatechol	0.83	0.02	0.42	0.02	-	-	1.25
9	4,5-dichloroguaiacol	0.12	0.002	0.18	0.01	0.18	0.01	0.48
10	5,6-dichloroguaiacol	0.64	0.01	-	0.001	0.19	0.01	0.83
11	2,3,4,6-tetrachlorophenol	0.18	0.003	0.02	0.02	-	-	0.20
12	3,4,5-trichloroguaiacol	0.16	0.003	0.51	0.002	-	-	0.67
13	3,4,6-trichloroguaiacol	1.44	0.03	0.04	0.001	-	-	1.48
14	3,5-dichlorosyringol	1.02	0.02	0.03	0.01	0.10	0.004	1.15
15	3,6-dichlorocatechol	-	-	0.20	0.02	-	-	0.20
16	4,5,6-trichloroguaiacol	0.73	0.01	0.45	0.02	-	-	1.18
17	tetrachloroguaiacol	1.58	0.03	0.47	0.02	0.57	0.02	2.62
18	3,4,6-trichlorocatechol	1.52	0.03	1.52	0.06	0.43	0.02	3.47
19	2,6-dichlorosyringaldehyde	2.30	0.05	0.59	0.02	-	-	2.89
20	5,6-dichlorovanillin	1.22	0.02	2.33	0.09	0.25	0.01	3.80
21	tetrachlorocatechol	4.90	0.10	1.40	0.06	0.89	0.04	7.19
22	2,3,4-trichlorophenol	-	-	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-		-	-
	TOTAL	27.08	0.54	10.18	0.41	4.02	0.17	41.28

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.130

Formation of different chlorophenolic compounds in various effluents by bleaching at 50:50 Chlorine charge distribution

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	2.56	0.05	-	-	-	-	2.56
2	3-chlorophenol	1.27	0.03	1.76	0.07	0.18	0.01	3.21
3	4-chloroguaiacol	-	-	-	-	0.11	0.004	0.11
4	5-chloroguaiacol	-	-	-	-	0.08	0.003	0.08
5	2,3,5-trichlorophenol	0.09	0.002	0.42	0.02	-	-	0.51
6	2,4,6-trichlorophenol	8.01	0.16	3.56	0.14	0.94	0.04	12.51
7	3,6-dichloroguaiacol	0.06	0.001	0.06	0.002	-	-	0.12
8	3,4-dichlorocatechol	1.37	0.03	0.61	0.02	-	-	1.98
9	4,5-dichloroguaiacol	0.18	0.004	0.25	0.01	0.28	0.01	0.71
10	5,6-dichloroguaiacol	0.78	0.01	-	-	0.15	0.01	0.93
11	2,3,4,6-tetrachlorophenol	0.27	0.005	0.04	0.001	-	-	0.31
12	3,4,5-trichloroguaiacol	0.28	0.01	0.88	0.03	-	-	1.16
13	3,4,6-trichloroguaiacol	2.22	0.04	0.15	0.01	-	-	2.37
14	3,5-dichlorosyringol	2.05	0.04	0.05	0.002	0.15	0.01	2.25
15	3,6-dichlorocatechol	-	-	0.34	0.01	-	-	0.34
16	4,5,6-trichloroguaiacol	0.81	0.02	0.78	0.03	-	-	1.59
17	tetrachloroguaiacol	2.49	0.05	0.57	0.02	0.52	0.02	3.58
18	3,4,6-trichlorocatechol	1.94	0.04	1.68	0.07	0.36	0.01	3.98
19	2,6-dichlorosyringaldehyde	2.55	0.05	1.37	0.05	-	-	3.92
20	5,6-dichlorovanillin	1.17	0.02	2.29	0.09	0.3	0.01	3.76
21	tetrachlorocatechol	5.78	0.11	2.75	0.11	0.82	0.03	9.35
22	2,3,4-trichlorophenol	-	-	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	33.88	0.68	17.56	0.70	3.89	0.16	55.33

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C, Consistency 3%

Table 3.131

Formation of different chlorophenolic compounds in various effluents by bleaching at 60:40 Chlorine charge distribution								
S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	3.74	0.07	-	-	-	-	3.74
2	3-chlorophenol	1.76	0.04	2.19	0.09	0.16	0.01	4.11
3	4-chloroguaiacol	-	-	-	-	0.11	0.004	0.11
4	5-chloroguaiacol	-	-	-	-	0.06	0.002	0.06
5	2,3,5-trichlorophenol	0.12	0.005	0.61	0.02	-	-	0.73
6	2,4,6-trichlorophenol	9.82	0.20	4.96	0.20	0.92	0.04	15.70
7	3,6-dichloroguaiacol	0.13	0.003	0.12	0.005	-	-	0.25
8	3,4-dichlorocatechol	2.18	0.04	1.01	0.04	-	-	3.19
9	4,5-dichloroguaiacol	0.24	0.005	0.57	0.02	0.33	0.01	1.14
10	5,6-dichloroguaiacol	1.19	0.02	-	-	0.14	0.01	1.33
11	2,3,4,6-tetrachlorophenol	0.39	0.01	0.06	0.002	-	-	0.45
12	3,4,5-trichloroguaiacol	0.42	0.01	0.92	0.04	-	-	1.34
13	3,4,6-trichloroguaiacol	3.10	0.06	0.23	0.01	-	-	3.33
14	3,5-dichlorosyringol	2.56	0.05	0.08	0.003	0.18	0.01	2.82
15	3,6-dichlorocatechol	-	-	0.47	0.02	-	-	0.47
16	4,5,6-trichloroguaiacol	1.15	0.02	1.54	0.06	-	-	2.69
17	tetrachloroguaiacol	3.03	0.06	0.78	0.03	0.46	0.02	4.27
18	3,4,6-trichlorocatechol	2.14	0.04	1.75	0.07	0.22	0.01	4.11
19	2,6-dichlorosyringaldehyde	3.20	0.06	1.46	0.06	-	-	4.66
20	5,6-dichlorovanillin	1.12	0.02	2.20	0.09	0.34	0.01	3.66
21	tetrachlorocatechol	8.41	0.17	3.14	0.13	0.74	0.03	12.29
22	2,3,4-trichlorophenol	-	-	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	44.70	0.89	22.09	0.88	3.66	0.16	70.45

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.359 Effect of chlorine charge distribution between C and H stages on the generation of Chlorophenolic compounds

Chlorophenolic compounds (kg/t)				
% Distribution between C & H	C-stage	E-stage	H-stage	TOTAL
40:60	27.08	10.18	4.02	41.28
50:50	33.88	17.56	3.89	55.33
60:40	44.70	22.09	3.66	70.45
70:30	53.19	29.56	3.68	86.43
80:20	60.37	34.04	1.84	96.25

Table 3.360 Effect of chlorine charge distribution between C and H stages on the generation of effluent COD

COD (kg/t)				
% Distribution between C & H	C-stage	E-stage	H-stage	TOTAL
40:60	19.4	23.7	26.8	69.9
50:50	29.4	25.7	25.9	81.1
60:40	32.3	33	24	89.3
70:30	39.9	35.8	21.8	97.5
80:20	43.5	39.5	20.4	103.4

Table 3.361 Effect of chlorine charge distribution between C and H stages on the generation of effluent Colour

Colour (kg/t)				
% Distribution between C & H	C-stage	E-stage	H-stage	TOTAL
40:60	21.2	23.1	0.1	44.4
50:50	25	53.1	0.6	78.7
60:40	36.2	74.3	1.2	111.8
70:30	42.5	81.2	1.9	125.6
80:20	44	87.5	1.9	133.4

Table 3.362 Effect of chlorine charge distribution between C and H stages on Brightness and Viscosity of bleached pulps obtained by CEH bleaching

% Distribution between C & H	Brightness (%)	Viscosity (cp)
40:60	80.9	8.4
50:50	80.7	8.7
60:40	80.5	9
70:30	80.1	9.4
80:20	80.3	9.7

Table 3.131

Formation of different chlorophenolic compounds in various effluents by bleaching at 60:40 Chlorine charge distribution

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	3.74	0.07	-	-	-	-	3.74
2	3-chlorophenol	1.76	0.04	2.19	0.09	0.16	0.01	4.11
3	4-chloroguaiacol	-	-	-	-	0.11	0.004	0.11
4	5-chloroguaiacol	-	-	-	-	0.06	0.002	0.06
5	2,3,5-trichlorophenol	0.12	0.005	0.61	0.02	-	-	0.73
6	2,4,6-trichlorophenol	9.82	0.20	4.96	0.20	0.92	0.04	15.70
7	3,6-dichloroguaiacol	0.13	0.003	0.12	0.005	-	-	0.25
8	3,4-dichlorocatechol	2.18	0.04	1.01	0.04	-	-	3.19
9	4,5-dichloroguaiacol	0.24	0.005	0.57	0.02	0.33	0.01	1.14
10	5,6-dichloroguaiacol	1.19	0.02	-	-	0.14	0.01	1.33
11	2,3,4,6-tetrachlorophenol	0.39	0.01	0.06	0.002	-	-	0.45
12	3,4,5-trichloroguaiacol	0.42	0.01	0.92	0.04	-	-	1.34
13	3,4,6-trichloroguaiacol	3.10	0.06	0.23	0.01	-	-	3.33
14	3,5-dichlorosyringol	2.56	0.05	0.08	0.003	0.18	0.01	2.82
15	3,6-dichlorocatechol	-	-	0.47	0.02	-	-	0.47
16	4,5,6-trichloroguaiacol	1.15	0.02	1.54	0.06	-	-	2.69
17	tetrachloroguaiacol	3.03	0.06	0.78	0.03	0.46	0.02	4.27
18	3,4,6-trichlorocatechol	2.14	0.04	1.75	0.07	0.22	0.01	4.11
19	2,6-dichlorosyringaldehyde	3.20	0.06	1.46	0.06	-	-	4.66
20	5,6-dichlorovanillin	1.12	0.02	2.20	0.09	0.34	0.01	3.66
21	tetrachlorocatechol	8.41	0.17	3.14	0.13	0.74	0.03	12.29
22	2,3,4-trichlorophenol	-	-	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	44.70	0.89	22.09	0.88	3.66	0.16	70.45

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.132

Formation of different chlorophenolic compounds in various effluents by bleaching at 70:30 Chlorine charge distribution

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	4.17	0.08	2.77	0.11	-	-	6.94
2	3-chlorophenol	2.39	0.05	2.37	0.09	0.12	0.004	4.88
3	4-chloroguaiacol	-	-	-	-	0.09	0.003	0.09
4	5-chloroguaiacol	-	-	-	-	0.02	0.008	0.02
5	2,3,5-trichlorophenol	0.14	0.003	0.87	0.03	-	-	1.01
6	2,4,6-trichlorophenol	10.82	0.22	5.23	0.21	0.91	0.04	16.96
7	3,6-dichloroguaiacol	0.17	0.003	0.16	0.01	-	-	0.33
8	3,4-dichlorocatechol	2.98	0.06	1.18	0.05	-	-	4.16
9	4,5-dichloroguaiacol	0.31	0.01	0.89	0.04	0.37	0.01	1.57
10	5,6-dichloroguaiacol	1.48	0.03	-	-	0.11	0.004	1.59
11	2,3,4,6-tetrachlorophenol	0.96	0.02	0.07	0.003	-	-	1.03
12	3,4,5-trichloroguaiacol	1.19	0.02	0.95	0.04	-	-	2.14
13	3,4,6-trichloroguaiacol	3.66	0.07	0.28	0.01	0.04	0.001	3.98
14	3,5-dichlorosyringol	2.69	0.05	1.42	0.06	0.25	0.01	4.36
15	3,6-dichlorocatechol	-	-	0.96	0.04	-	-	0.96
16	4,5,6-trichloroguaiacol	2.20	0.04	2.36	0.09	-	-	4.56
17	tetrachloroguaiacol	3.19	0.06	0.82	0.03	0.32	0.01	4.33
18	3,4,6-trichlorocatechol	2.47	0.05	1.82	0.07	0.13	0.005	4.42
19	2,6-dichlorosyringaldehyde	4.86	0.10	1.62	0.06	-	-	6.48
20	5,6-dichlorovanillin	1.09	0.02	2.14	0.09	0.49	0.02	3.72
21	tetrachlorocatechol	8.42	0.17	3.65	0.15	0.68	0.03	12.75
22	2,3,4-trichlorophenol	-	-	-	-	0.15	0.01	0.15
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	53.19	1.06	29.56	1.18	3.68	0.15	86.43

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.133

Formation of different chlorophenolic compounds in various effluents by bleaching at 80:20 Chlorine charge distribution

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	4.96	0.10	2.87	0.11	-	-	7.83
2	3-chlorophenol	3.06	0.06	2.38	0.10	0.07	0.003	5.51
3	4-chloroguaiacol	-	-	-	-	0.06	0.002	0.06
4	5-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01
5	2,3,5-trichlorophenol	0.25	0.01	1.09	0.04	-	-	1.34
6	2,4,6-trichlorophenol	11.72	0.23	5.38	0.21	0.19	0.01	17.29
7	3,6-dichloroguaiacol	0.20	0.004	0.29	0.01	-	-	0.49
8	3,4-dichlorocatechol	3.59	0.07	2.44	0.10	-	-	6.03
9	4,5-dichloroguaiacol	0.70	0.01	0.92	0.04	0.39	0.02	2.01
10	5,6-dichloroguaiacol	1.56	0.03	-	-	0.06	0.002	1.62
11	2,3,4,6-tetrachlorophenol	1.04	0.02	0.10	0.004	-	-	1.14
12	3,4,5-trichloroguaiacol	1.63	0.03	1.33	0.05	-	-	2.96
13	3,4,6-trichloroguaiacol	4.04	0.08	0.35	0.01	-	-	4.39
14	3,5-dichlorosyringol	3.15	0.06	1.52	0.06	0.27	0.01	4.94
15	3,6-dichlorocatechol	-	-	1.02	0.04	-	-	1.02
16	4,5,6-trichloroguaiacol	2.29	0.05	3.34	0.13	-	-	5.63
17	tetrachloroguaiacol	3.73	0.07	0.97	0.04	0.06	0.002	4.76
18	3,4,6-trichlorocatechol	3.33	0.07	1.92	0.08	0.08	0.003	5.33
19	2,6-dichlorosyringaldehyde	5.42	0.11	1.88	0.08	-	-	7.30
20	5,6-dichlorovanillin	0.84	0.02	2.02	0.08	0.50	0.02	3.36
21	tetrachlorocatechol	8.86	0.18	4.22	0.17	0.15	0.006	13.23
22	2,3,4-trichlorophenol	-	-	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-	-	2.98
	TOTAL	60.37	1.21	34.04	1.36	1.84	0.08	96.25

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.359 Effect of chlorine charge distribution between C and H stages on the generation of Chlorophenolic compounds

	Chlorophenolic compounds (kg/t)			
% Distribution between C & H	C-stage	E-stage	H-stage	TOTAL
40:60	27.08	10.18	4.02	41.28
50:50	33.88	17.56	3.89	55.33
60:40	44.70	22.09	3.66	70.45
70:30	53.19	29.56	3.68	86.43
80:20	60.37	34.04	1.84	96.25

Table 3.360 Effect of chlorine charge distribution between C and H stages on the generation of effluent COD

	COD (kg/t)			
% Distribution between C & H	C-stage	E-stage	H-stage	TOTAL
40:60	19.4	23.7	26.8	69.9
50:50	29.4	25.7	25.9	81.1
60:40	32.3	33	24	89.3
70:30	39.9	35.8	21.8	97.5
80:20	43.5	39.5	20.4	103.4

Table 3.361 Effect of chlorine charge distribution between C and H stages on the generation of effluent Colour

	Colour (kg/t)			
% Distribution between C & H	C-stage	E-stage	H-stage	TOTAL
40:60	21.2	23.1	0.1	44.4
50:50	25	53.1	0.6	78.7
60:40	36.2	74.3	1.2	111.8
70:30	42.5	81.2	1.9	125.6
80:20	44	87.5	1.9	133.4

Table 3.362 Effect of chlorine charge distribution between C and H stages on Brightness and Viscosity of bleached pulps obtained by CEH bleaching

% Distribution between C & H	Brightness (%)	Viscosity (cp)
40:60	80.9	8.4
50:50	80.7	8.7
60:40	80.5	9
70:30	80.1	9.4
80:20	80.3	9.7

Table 3.363 Monochlorophenolic compounds present in different effluents formed by distributing chlorine charge between C and H stages

Monochlorophenolic compounds (g/t)				
% Distribution between C:H	C-stage	E-stage	H-stage	TOTAL
40:60	0.97	0.09	0.42	1.48
50:50	1.27	1.76	0.37	3.40
60:40	1.76	2.19	0.33	4.28
70:30	2.39	2.37	0.23	4.99
80:20	3.06	2.38	0.14	5.58

Table 3.364 Dichlorophenolic compounds present in different effluents formed by distributing chlorine charge between C and H stages

Dichlorophenolic compounds (g/t)				
% Distribution between C:H	C-stage	E-stage	H-stage	TOTAL
40:60	8.00	3.76	0.72	12.48
50:50	10.72	4.97	0.88	16.57
60:40	14.36	5.91	0.99	21.26
70:30	16.27	11.14	1.22	28.63
80:20	20.42	12.96	1.22	34.60

Table 3.365 Trichlorophenolic compounds present in different effluents formed by distributing chlorine charge between C and H stages

Trichlorophenolic compounds (g/t)				
% Distribution between C:H	C-stage	E-stage	H-stage	TOTAL
40:60	11.45	4.44	1.42	17.31
50:50	13.35	7.47	1.30	22.12
60:40	16.75	10.01	1.14	27.90
70:30	20.48	11.51	1.23	33.22
80:20	23.26	13.41	0.27	36.94

Table 3.366 Tetrachlorophenolic compounds present in different effluents formed by distributing chlorine charge between C and H stages

Tetrachlorophenolic compounds (g/t)				
% Distribution between C:H	C-stage	E-stage	H-stage	TOTAL
40:60	6.66	1.89	1.46	10.01
50:50	8.54	3.36	1.34	13.24
60:40	11.83	3.98	1.20	17.01
70:30	11.70	4.54	1.00	17.24
80:20	13.63	5.29	0.21	19.13

Table 3.367 Category wise load of chlorophenols in different effluents formed by distributing chlorine charge between C and H stages

Chlorophenols (g/t)				
% Distribution between C:H	C-stage	E-stage	H-stage	TOTAL
40:60	10.58	2.03	1.19	13.80
50:50	12.20	5.78	1.12	19.10
60:40	15.83	7.82	1.08	24.73
70:30	17.61	11.31	1.18	30.10
80:20	21.03	11.82	0.26	33.11

Table 3.368 Category wise load of chloroguaiacols in different effluents formed by distributing chlorine charge between C and H stages

Chloroguaiacols (g/t)				
% Distribution between C:H	C-stage	E-stage	H-stage	TOTAL
40:60	4.71	1.66	1.16	7.53
50:50	9.82	2.69	1.14	13.65
60:40	9.26	4.16	1.10	14.52
70:30	10.72	5.46	0.95	17.13
80:20	14.15	7.20	0.58	21.93

Table 3.369 Category wise load of chlorocatechols in different effluents formed by distributing chlorine charge between C and H stages

Chlorocatechols (g/t)				
% Distribution between C:H	C-stage	E-stage	H-stage	TOTAL
40:60	7.25	3.54	1.32	12.11
50:50	9.09	5.38	1.18	15.65
60:40	12.73	6.37	0.96	20.06
70:30	13.87	7.61	0.81	22.29
80:20	15.78	9.60	0.23	25.61

Table 3.370 Category wise load of other chlorophenolic compounds in different effluents formed by distributing chlorine charge between C and H stages

Other Chlorophenolic compounds (g/t)				
% Distribution between C:H	C-stage	E-stage	H-stage	TOTAL
40:60	4.54	2.95	0.35	7.84
50:50	5.77	3.71	0.45	9.93
60:40	6.88	3.74	0.52	11.14
70:30	8.64	5.18	0.74	14.56
80:20	9.41	5.42	0.77	15.60

Table 3.327 *Different chlorophenolic compounds formed in C stage by distributing chlorine charge between C & H stages*

Distributing chlorine charge C:H						
S.No.	Chlorophenolic compounds(g/T)	40:60	50:50	60:40	70:30	80:20
1	2,4-dichlorophenol	1.83	2.56	3.74	4.17	4.96
2	3-chlorophenol	0.97	1.27	1.76	2.39	3.06
3	4-chloroguaiacol	-	-	-	-	-
4	5-chloroguaiacol	-	-	-	-	-
5	2,3,5-trichlorophenol	0.06	0.09	0.12	0.14	0.25
6	2,4,6-trichlorophenol	7.54	8.01	9.82	10.82	11.72
7	3,6-dichloroguaiacol	0.04	0.06	0.13	0.17	0.20
8	3,4dichlorocatechol	0.83	1.37	2.18	2.98	3.59
9	4,5-dichloroguaiacol	0.12	0.18	0.24	0.31	0.70
10	5,6-dichloroguaiacol	0.64	0.78	1.19	1.48	1.56
11	2,3,4,6-tetrachlorophenol	0.18	0.27	0.39	0.96	1.04
12	3,4,5-trichloroguaiacol	0.16	0.28	0.42	1.19	1.63
13	3,4,6-trichloroguaiacol	1.44	2.22	3.10	3.66	4.04
14	3,5-dichlorosyringol	1.02	2.05	2.56	2.69	3.15
15	3,6-dichlorocatechol	-	-	-	-	-
16	4,5,6-trichloroguaiacol	0.73	0.81	1.15	2.20	2.29
17	tetrachloroguaiacol	1.58	2.49	3.03	3.19	3.73
18	3,4,6-trichlorocatechol	1.52	1.94	2.14	2.47	3.33
19	2,6-dichlorosyringaldehyde	2.30	2.55	3.20	4.86	5.42
20	5,6-dichlorovanillin	1.22	1.17	1.12	1.09	0.84
21	tetrachlorocatechol	4.9	5.78	8.41	8.42	8.86
22	2,3,4-trichlorophenol	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	27.08	33.88	44.7	53.19	60.37

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.328 Different chlorophenolic compounds formed in E stage by distributing chlorine charge between C & H stages

		Distributing chlorine charge C:H				
S.No.	Chlorophenolic compounds(g/T)	**40:60**	**50:50**	**60:40**	**70:30**	**80:20**
1	2,4-dichlorophenol	-	-	-	2.77	2.87
2	3-chlorophenol	0.09	1.76	2.19	2.37	2.38
3	4-chloroguaiacol	-	-	-	-	-
4	5-chloroguaiacol	-	-	-	-	-
5	2,3,5-trichlorophenol	0.11	0.42	0.61	0.87	1.09
6	2,4,6-trichlorophenol	1.81	3.56	4.96	5.23	5.38
7	3,6-dichloroguaiacol	0.01	0.06	0.12	0.16	0.29
8	3,4dichlorocatechol	0.42	0.61	1.01	1.18	2.44
9	4,5-dichloroguaiacol	0.18	0.25	0.57	0.89	0.92
10	5,6-dichloroguaiacol	-	-	-	-	-
11	2,3,4,6-tetrachlorophenol	0.02	0.04	0.06	0.07	0.10
12	3,4,5-trichloroguaiacol	0.51	0.88	0.92	0.95	1.33
13	3,4,6-trichloroguaiacol	0.04	0.15	0.23	0.28	0.35
14	3,5-dichlorosyringol	0.03	0.05	0.08	1.42	1.52
15	3,6-dichlorocatechol	0.20	0.34	0.47	0.96	1.02
16	4,5,6-trichloroguaiacol	0.45	0.78	1.54	2.36	3.34
17	tetrachloroguaiacol	0.47	0.57	0.78	0.82	0.97
18	3,4,6-trichlorocatechol	1.52	1.68	1.75	1.82	1.92
19	2,6-dichlorosyringaldehyde	0.59	1.37	1.46	1.62	1.88
20	5,6-dichlorovanillin	2.33	2.29	2.20	2.14	2.02
21	tetrachlorocatechol	1.40	2.75	3.14	3.65	4.22
22	2,3,4-trichlorophenol	-	-	-	-	
23	4,5-dichlorocatechol		-	-	-	
	TOTAL	10.18	17.56	22.09	29.56	34.04

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.329 Different chlorophenolic compounds formed in H stage by distributing chlorine charge between C & H stages

		Distributing chlorine charge C:H				
S.No.	Chlorophenolic compounds(g/T)	40:60	50:50	60:40	70:30	80:20
1	2,4-dichlorophenol	-	-	-	-	-
2	3-chlorophenol	0.20	0.18	0.16	0.12	0.07
3	4-chloroguaiacol	0.12	0.11	0.11	0.09	0.06
4	5-chloroguaiacol	0.10	0.08	0.06	0.02	0.01
5	2,3,5-trichlorophenol	-	-	-	-	-
6	2,4,6-trichlorophenol	0.99	0.94	0.92	0.91	0.19
7	3,6-dichloroguaiacol	-	-	-	-	-
8	3,4dichlorocatechol	-	-	-	-	-
9	4,5-dichloroguaiacol	0.18	0.28	0.33	0.37	0.39
10	5,6-dichloroguaiacol	0.19	0.15	0.14	0.11	0.06
11	2,3,4,6-tetrachlorophenol	-	-	-	-	-
12	3,4,5-trichloroguaiacol	-	-	-	-	-
13	3,4,6-trichloroguaiacol	-	-	-	0.04	-
14	3,5-dichlorosyringol	0.10	0.15	0.18	0.25	0.27
15	3,6-dichlorocatechol	-	-	-	-	-
16	4,5,6-trichloroguaiacol	-	-	-	-	-
17	tetrachloroguaiacol	0.57	0.52	0.46	0.32	0.06
18	3,4,6-trichlorocatechol	0.43	0.36	0.22	0.13	0.08
19	2,6-dichlorosyringaldehyde	-	-	-	-	-
20	5,6-dichlorovanillin	0.25	0.3	0.34	0.49	0.50
21	tetrachlorocatechol	0.89	0.82	0.74	0.68	0.15
22	2,3,4-trichlorophenol	-	-	-	0.15	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	4.02	3.89	3.66	3.68	1.84

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.330 Total chlorophenolic compounds formed in CEH bleaching by distributing chlorine charge between C & H stages

		Distributing chlorine charge C:H				
S.No.	Chlorophenolic compounds(g/T)	**40:60**	**50:50**	**60:40**	**70:30**	**80:20**
1	2,4-dichlorophenol	1.83	2.56	3.74	6.94	7.83
2	3-chlorophenol	1.26	3.21	4.11	4.88	5.51
3	4-chloroguaiacol	0.12	0.11	0.11	0.09	0.06
4	5-chloroguaiacol	0.10	0.08	0.06	0.02	0.01
5	2,3,5-trichlorophenol	0.17	0.51	0.73	1.01	1.34
6	2,4,6-trichlorophenol	10.34	12.51	15.7	16.96	17.29
7	3,6-dichloroguaiacol	0.05	0.12	0.25	0.33	0.49
8	3,4dichlorocatechol	1.25	1.98	3.19	4.16	6.03
9	4,5-dichloroguaiacol	0.48	0.71	1.14	1.57	2.01
10	5,6-dichloroguaiacol	0.83	0.93	1.33	1.59	1.62
11	2,3,4,6-tetrachlorophenol	0.2	0.31	0.45	1.03	1.14
12	3,4,5-trichloroguaiacol	0.67	1.16	1.34	2.14	2.96
13	3,4,6-trichloroguaiacol	1.48	2.37	3.33	3.98	4.39
14	3,5-dichlorosyringol	1.15	2.25	2.82	4.36	4.94
15	3,6-dichlorocatechol	0.20	0.34	0.47	0.96	1.02
16	4,5,6-trichloroguaiacol	1.18	1.59	2.69	4.56	5.63
17	tetrachloroguaiacol	2.62	3.58	4.27	4.33	4.76
18	3,4,6-trichlorocatechol	3.47	3.98	4.11	4.42	5.33
19	2,6-dichlorosyringaldehyde	2.89	3.92	4.66	6.48	7.30
20	5,6-dichlorovanillin	3.8	3.76	3.66	3.72	3.36
21	tetrachlorocatechol	7.19	9.35	12.29	12.75	13.23
22	2,3,4-trichlorophenol	-	-	-	0.15	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	41.28	55.33	70.45	86.43	96.25

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C, Consistency 3%

Fig.3.259

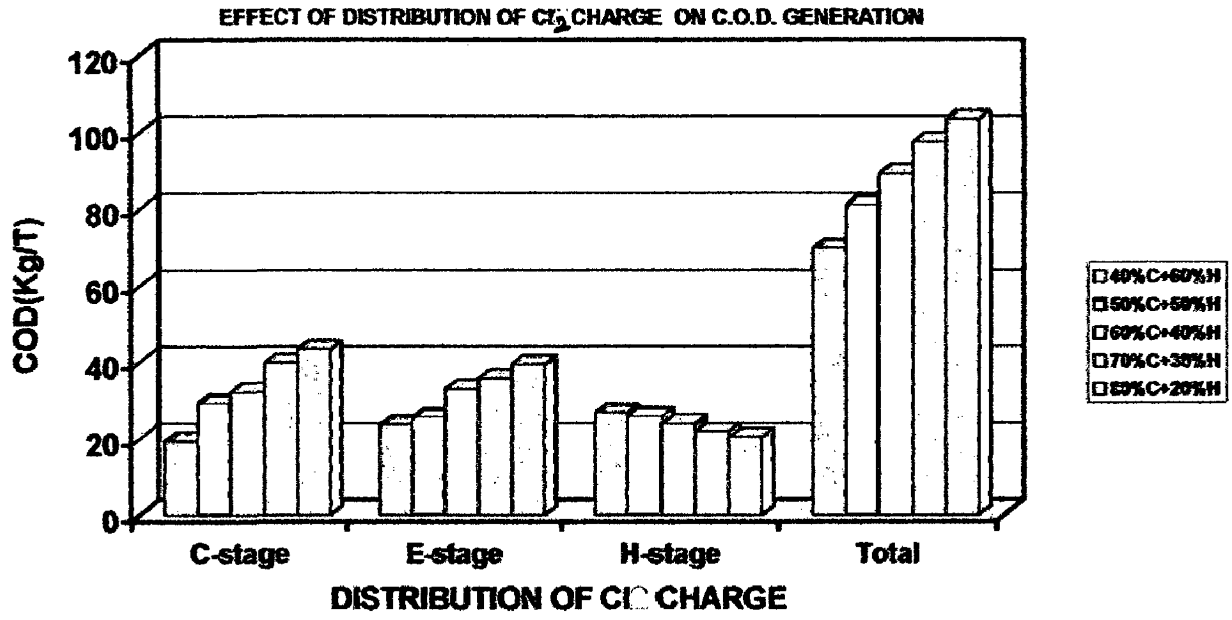


Fig.3.260

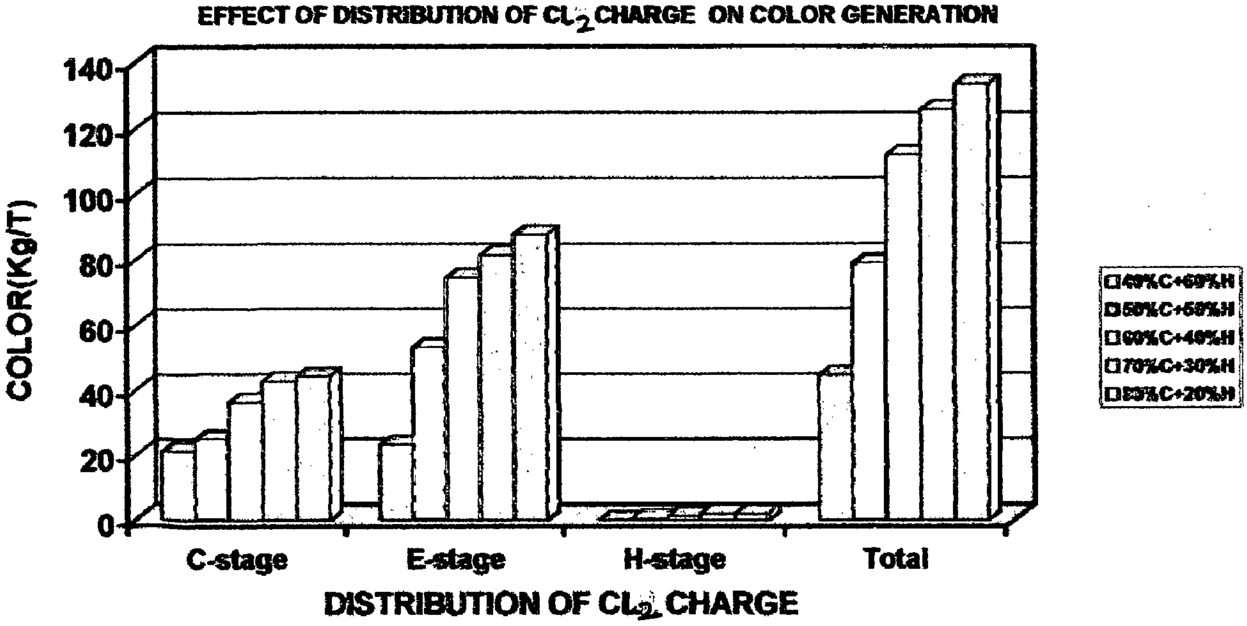


Fig.3.261

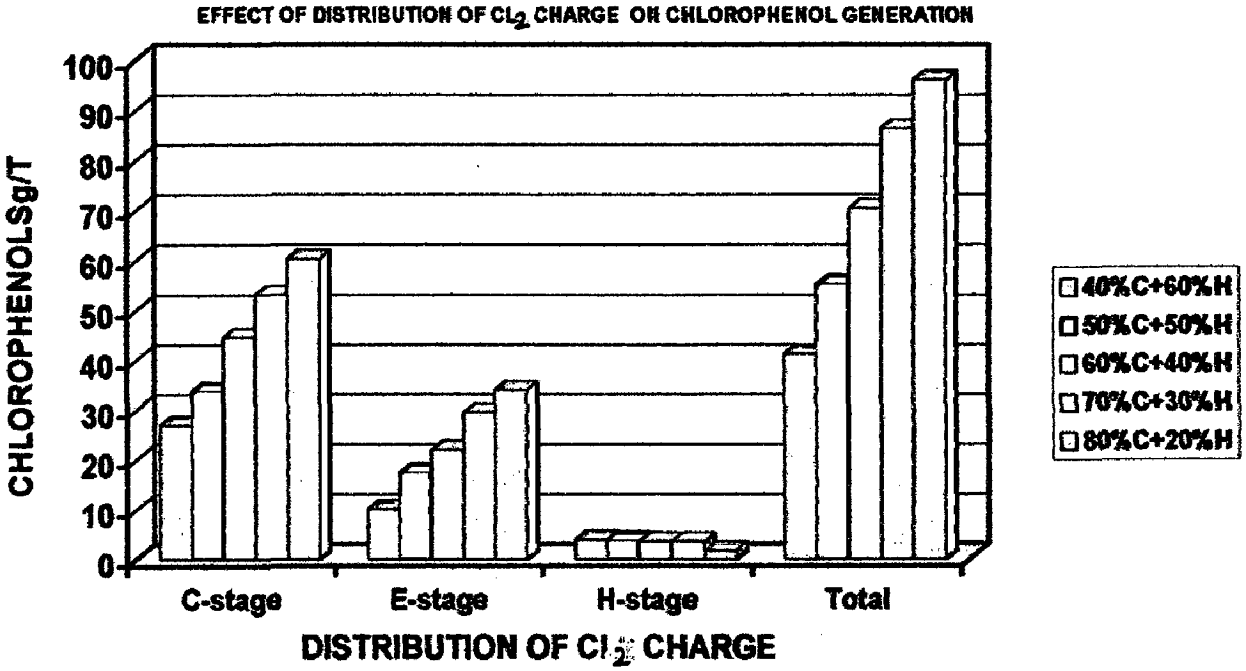


Fig.3.262

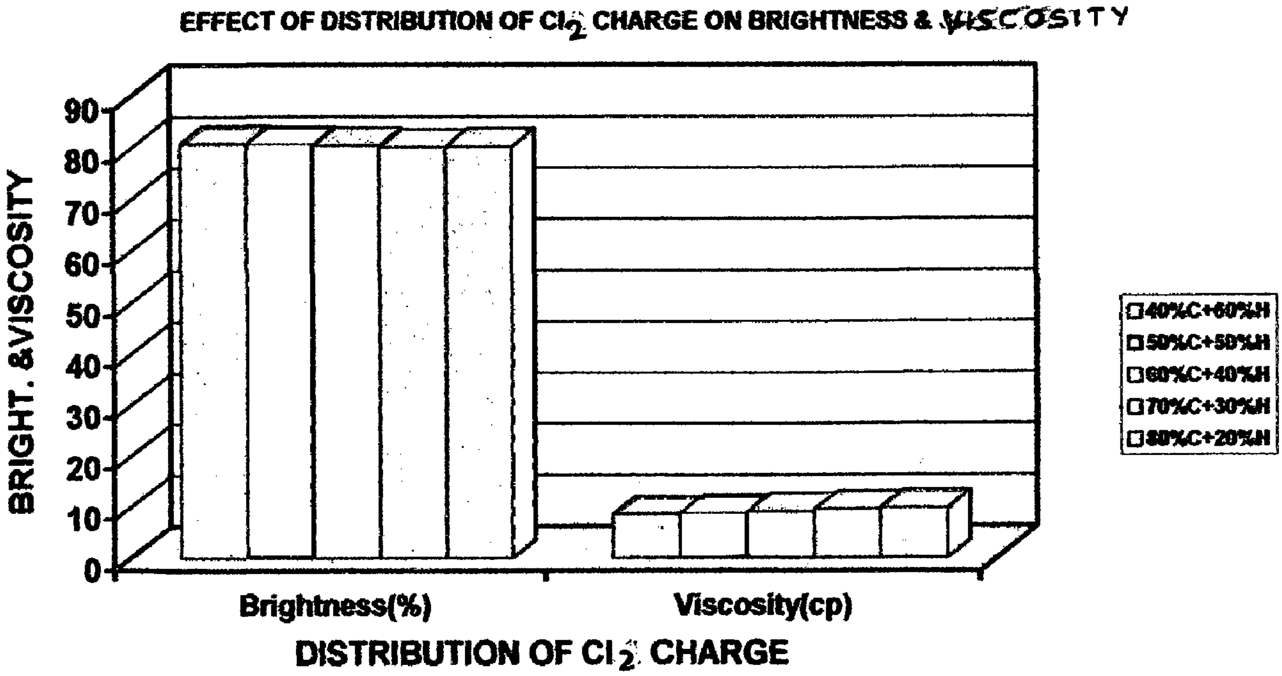


Fig.3.263

EFFECT OF DISTRIBUTION OF Cl_2 CHARGE ON MONOCHPH GENERATION

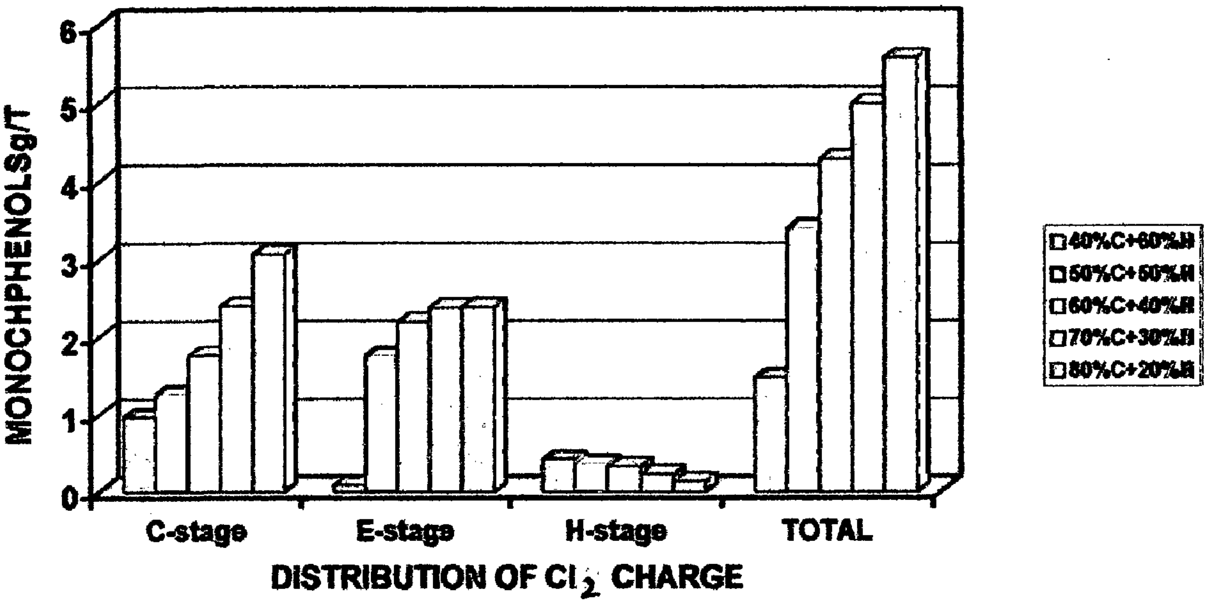


Fig.3.264

EFFECT OF DISTRIBUTION OF Cl_2 CHARGE ON DICHPHENOL GENERATION

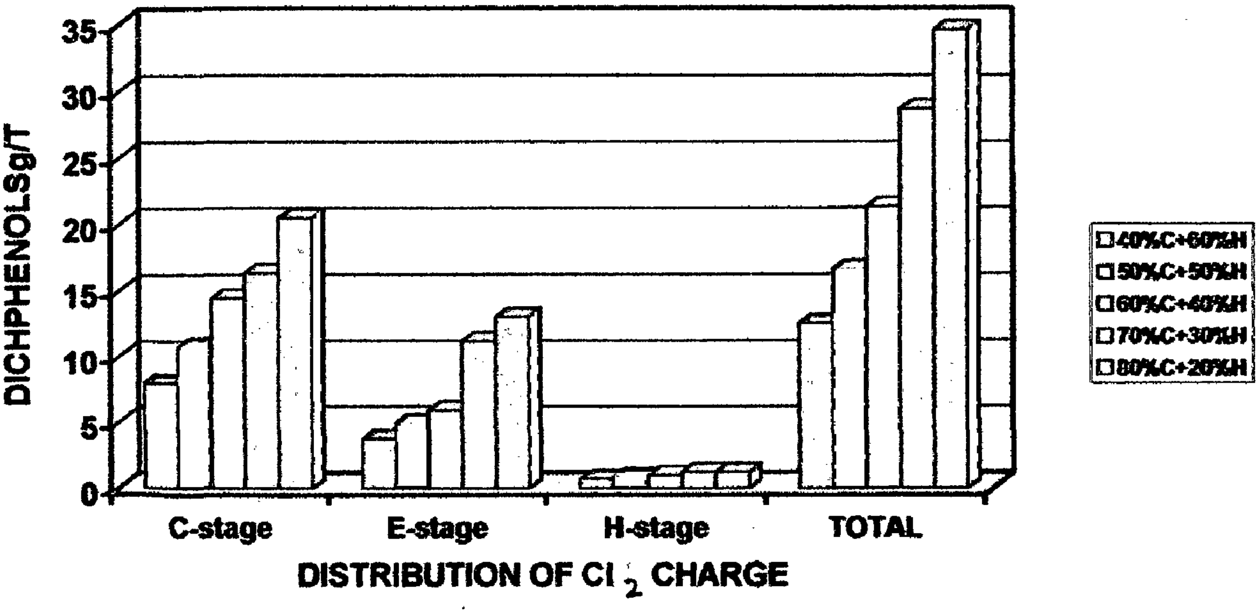


Fig.3.265

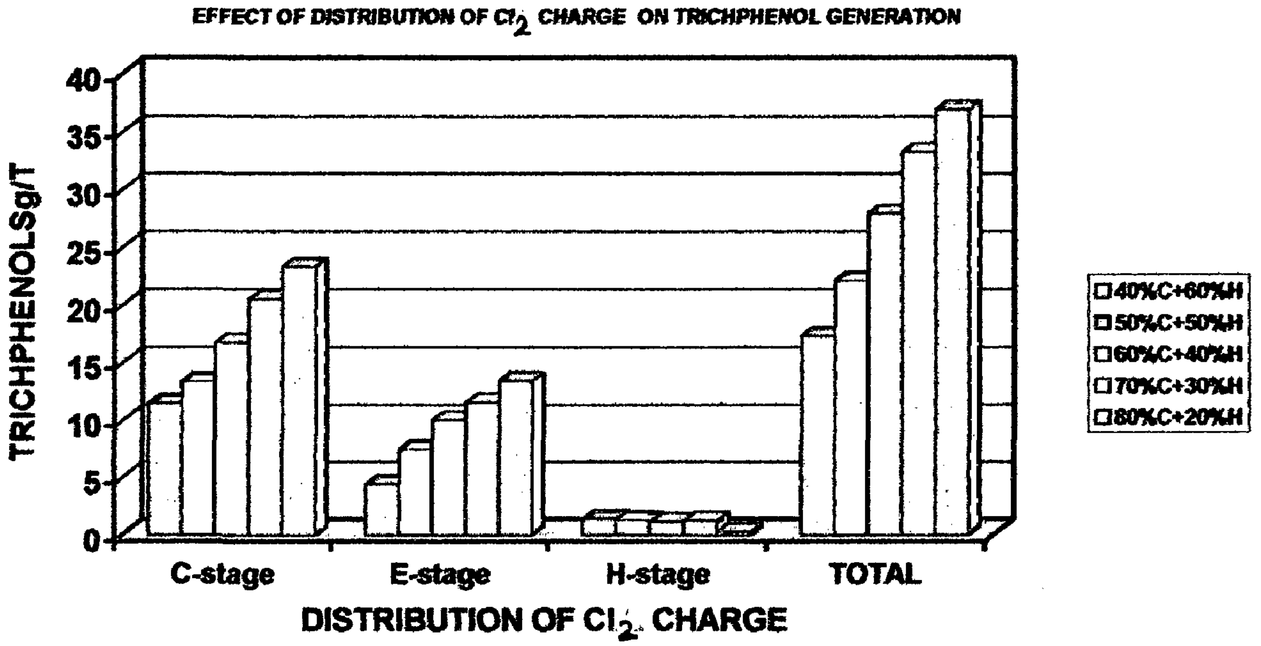


Fig.3.266

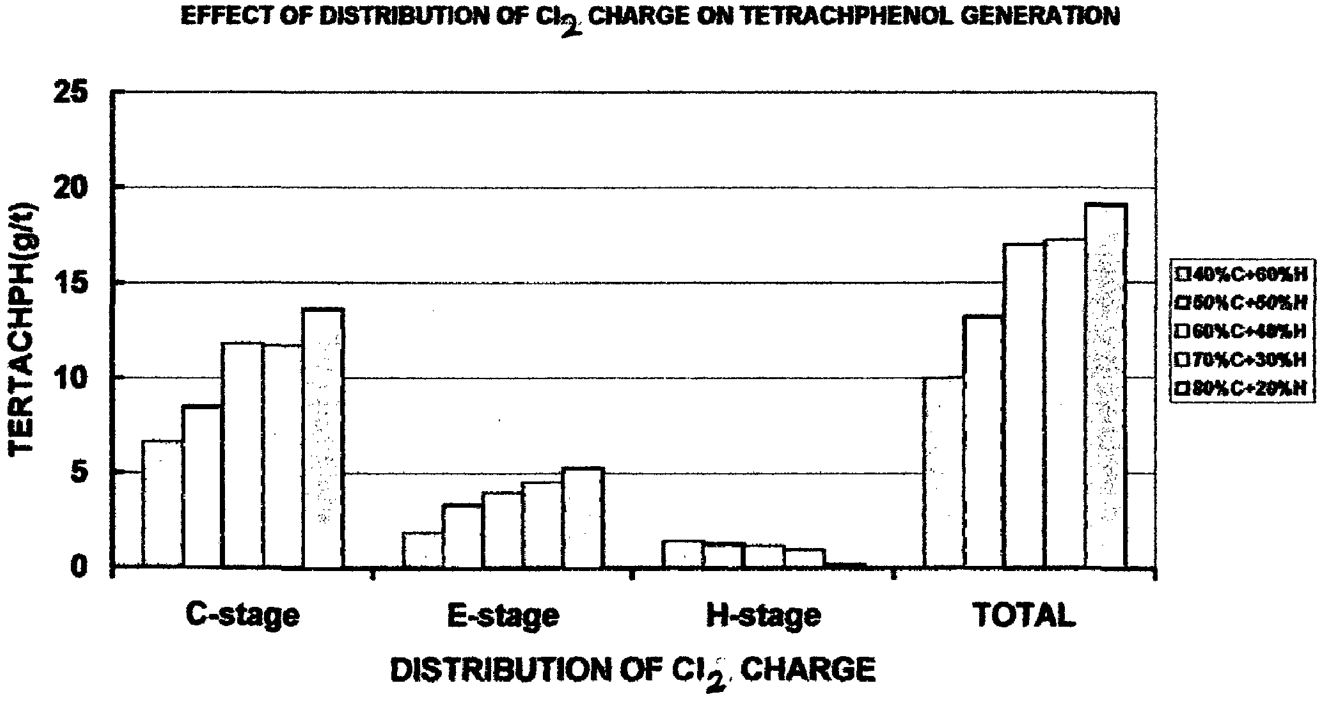


Fig.3.267

EFFECT OF DISTRIBUTION OF Cl_2 CHARGE ON PHENOL GENERATION

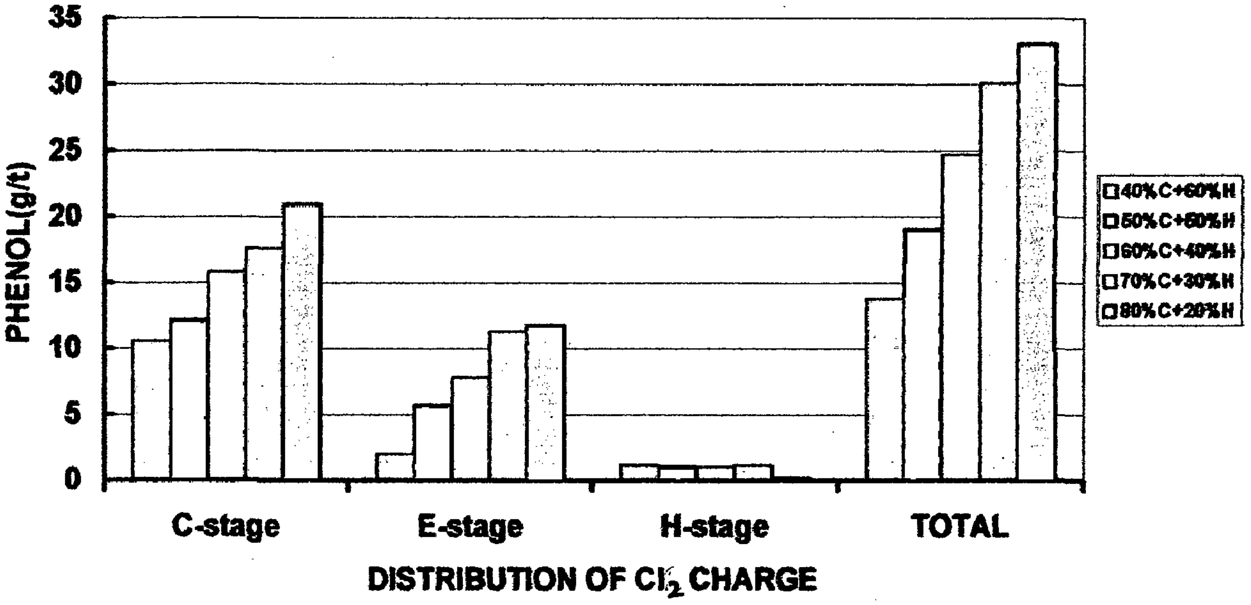


Fig.3.268

EFFECT OF DISTRIBUTION OF Cl_2 CHARGE ON GUAIACOL GENERATION

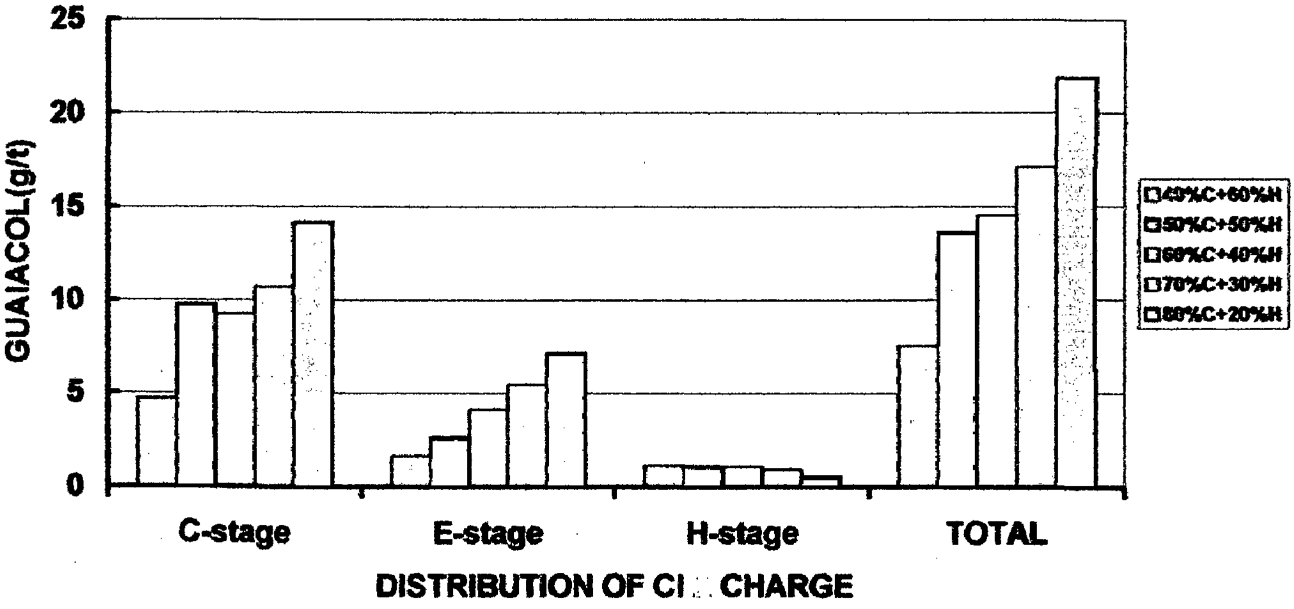


Fig.3.269

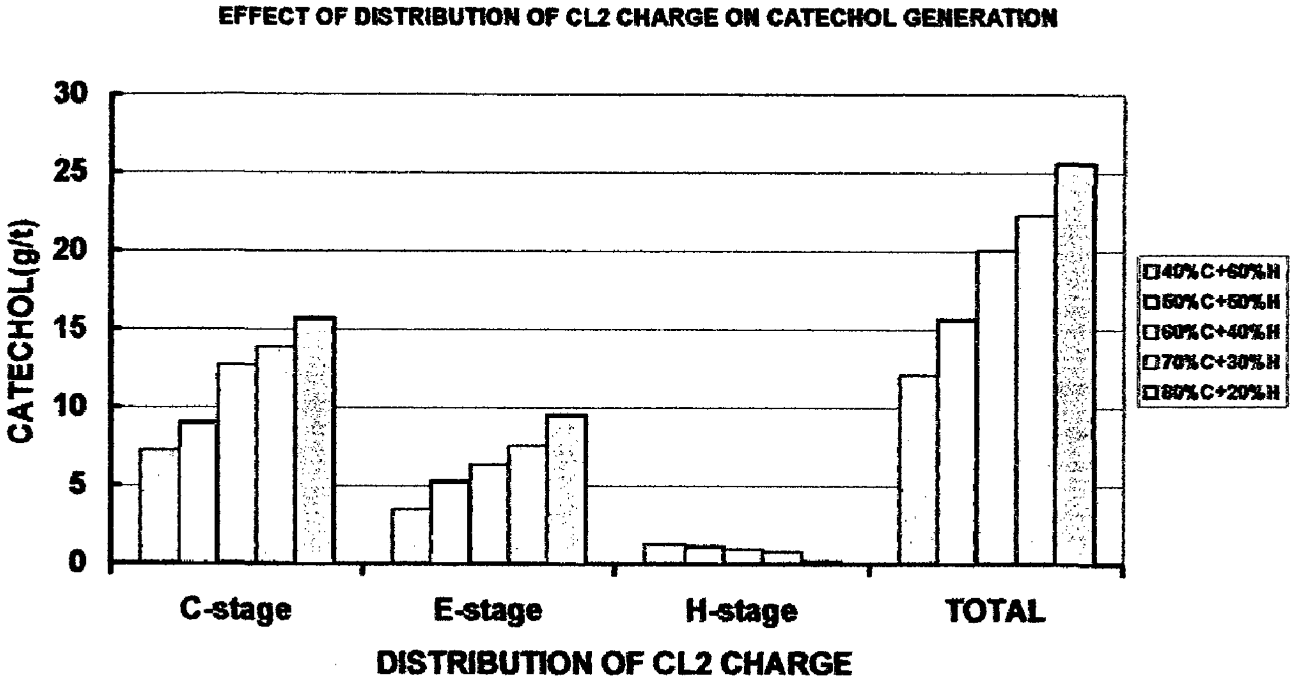

EFFECT OF DISTRIBUTION OF CL2 CHARGE ON CATECHOL GENERATION

Fig.3.270

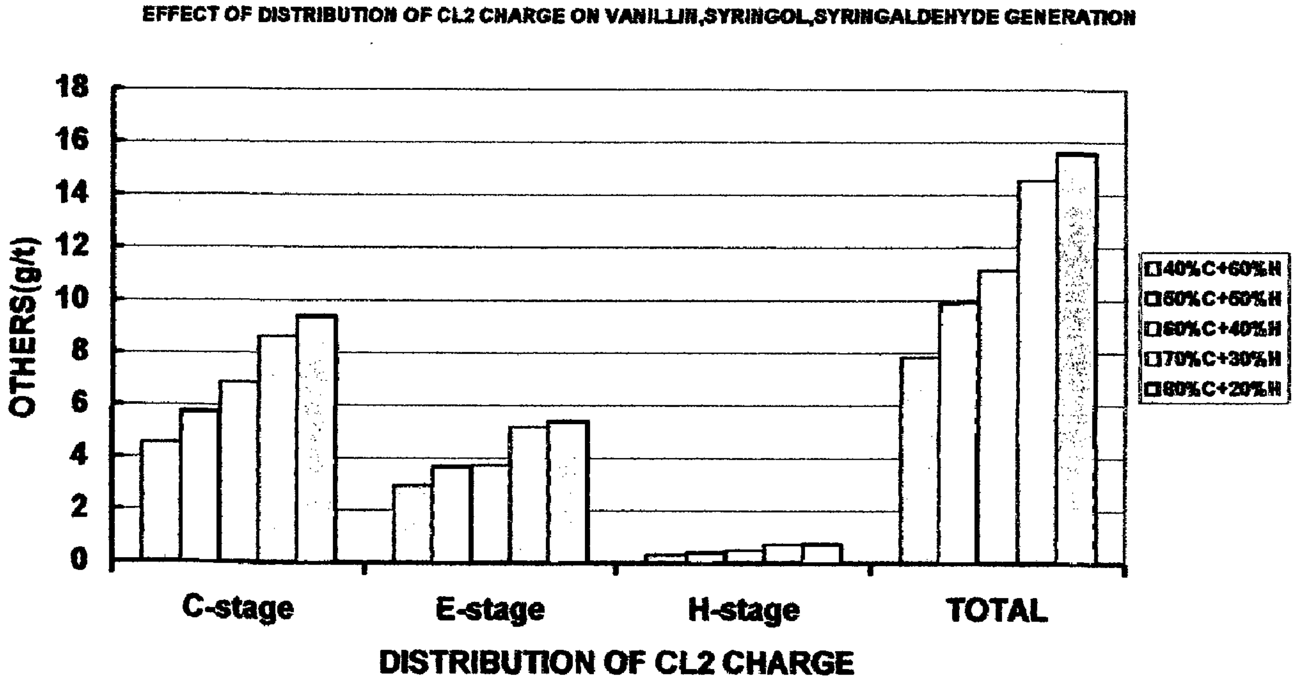

EFFECT OF DISTRIBUTION OF CL2 CHARGE ON VANILLIN,SYRINGOL,SYRINGALDEHYDE GENERATION

Fig.3.325

EFFECT OF DISTRIBUTION OF Cl_2 CHARGE ON TeCC GENERATION

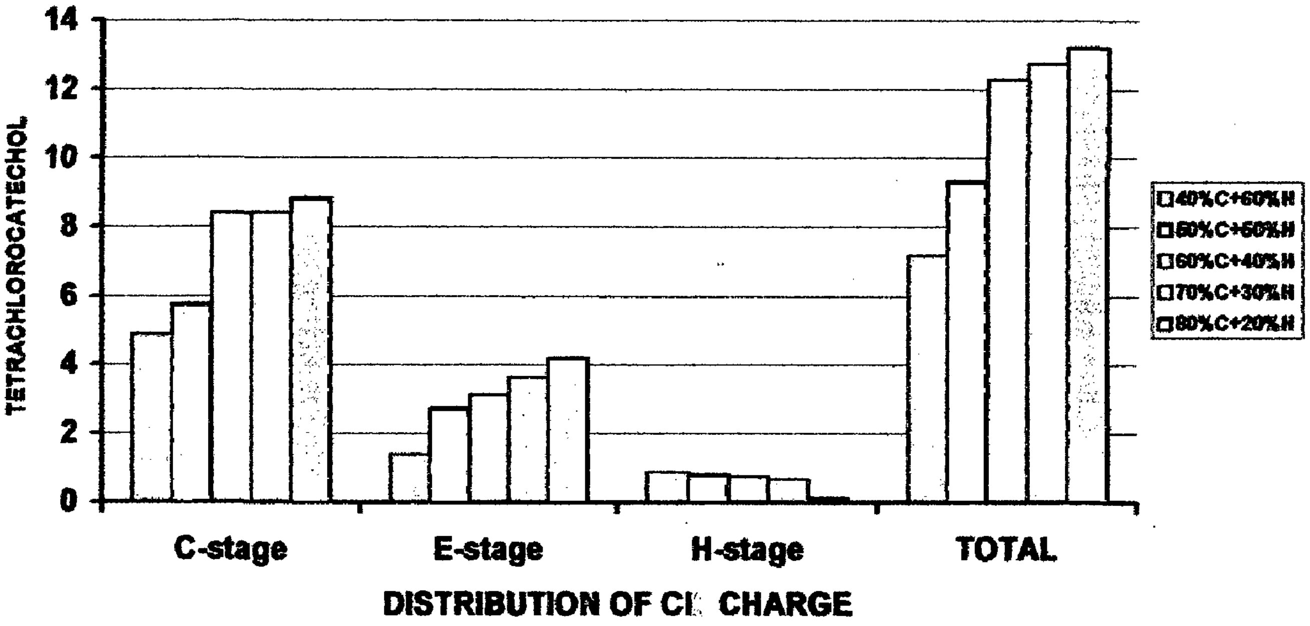


Fig.3.326

EFFECT OF DISTRIBUTION OF CHLORINE CHARGE ON 3,5-DICHLOROSYRINGOL

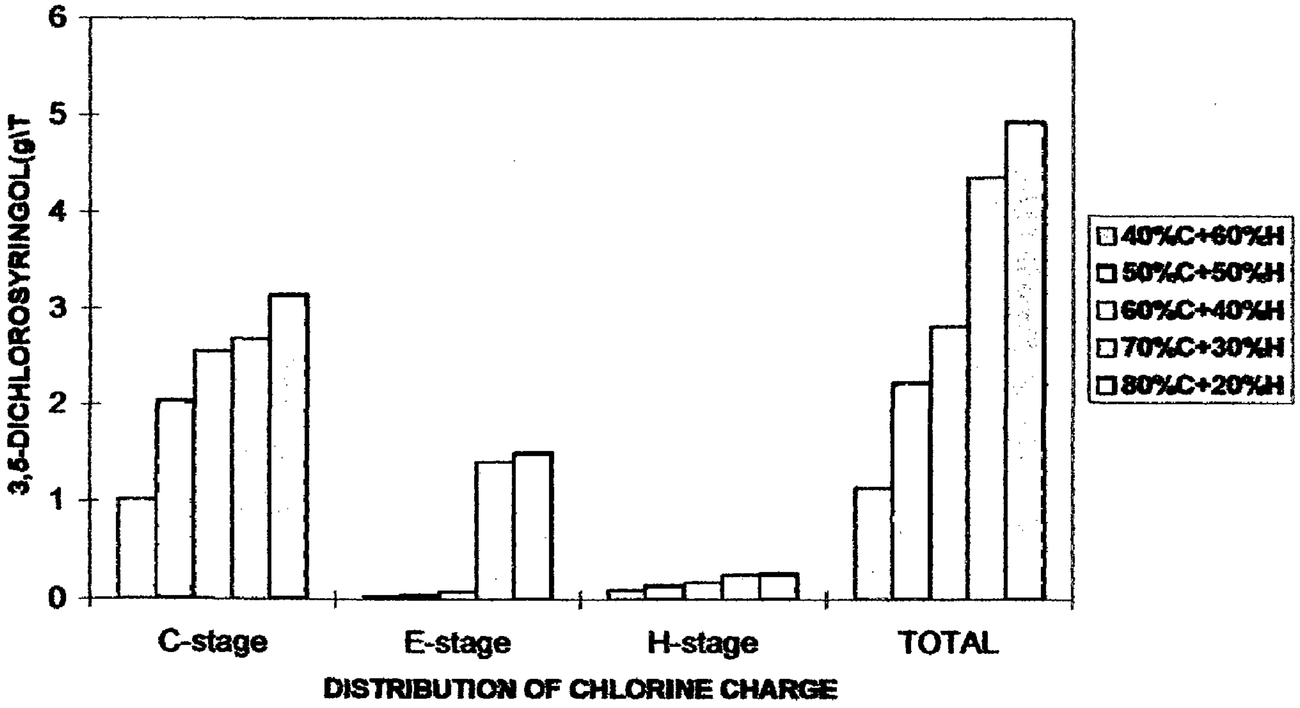


Table 3.134

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
	Formation of different chlorophenolic compounds in various effluents by splitting Chlorine dose in two equal parts in C-stage							
1	2,4-dichlorophenol	0.44	0.01	0.55	0.02	-	-	0.99
2	3-chlorophenol	2.28	0.04	1.53	0.06	-	-	3.81
3	4-chloroguaiacol	-	-	-	-	0.11	0.004	0.11
4	5-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01
5	2,3,5-trichlorophenol	0.54	0.01	0.46	0.02	-	-	1.00
6	2,4,6-trichlorophenol	3.00	0.06	0.15	0.01	-	-	3.15
7	3,6-dichloroguaiacol	0.08	0.002	0.11	0.004	-	-	0.19
8	3,4-dichlorocatechol	2.80	0.06	0.78	0.03	-	-	3.58
9	4,5-dichloroguaiacol	0.34	0.01	0.14	0.005	0.31	0.01	0.79
10	5,6-dichloroguaiacol	-	-	-	-	0.06	0.002	-
11	2,3,4,6-tetrachlorophenol	0.28	0.01	0.03	0.001	-	-	0.31
12	3,4,5-trichloroguaiacol	0.20	0.004	0.76	0.03	-	-	0.96
13	3,4,6-trichloroguaiacol	-	-	0.19	0.01	-	-	0.19
14	3,5-dichlorosyringol	1.42	0.03	1.11	0.04	0.13	0.005	2.66
15	3,6-dichlorocatechol	-	-	0.90	0.04	-	-	0.90
16	4,5,6-trichloroguaiacol	1.46	0.03	1.29	0.05	0.06	0.002	2.75
17	tetrachloroguaiacol	2.19	0.04	0.74	0.03	0.21	0.004	3.14
18	3,4,6-trichlorocatechol	2.88	0.06	1.37	0.05	0.21	0.01	4.34
19	2,6-dichlorosyringaldehyde	1.97	0.04	0.94	0.04	-	-	2.91
20	5,6-dichlorovanillin	0.79	0.01	1.01	0.04	0.27	0.01	2.07
21	tetrachlorocatechol	6.36	0.13	2.84	0.11	0.56	0.02	9.76
22	2,3,4-trichlorophenol	-	-	-	-	0.07	0.003	-
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	27.03	0.55	14.90	0.60	1.82	0.07	43.75

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.371 Effect of splitting of chlorine dose in C stage, replacement of H stage by D stage and using an oxygen deliginification stage prior to CEH sequence on the generation of Chlorophenolic compounds

Chlorophenolic compounds (kg/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	53.19	29.56	3.68	86.43
Split Cl_2 dose	27.03	14.9	1.82	43.75
H replaced by D	53.19	29.56	1.01	83.76
O_2 delignification	13.81	9.05	1.20	24.06

Table 3.372 Effect of splitting of chlorine dose in C stage, replacement of H stage by D stage and using an oxygen deliginification stage prior to CEH sequence on the generation of effluent COD

COD (kg/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	39.9	35.8	21.6	97.5
Split Cl_2 dose	33.4	32.6	18.5	84.5
H replaced by D	39.9	35.8	19.7	95.4
O_2 delignification	27.9	25.1	15.3	68.3

Table 3.373 Effect of splitting of chlorine dose in C stage, replacement of H stage by D stage and using an oxygen deliginification stage prior to CEH sequence on the generation of effluent Colour

Colour (kg/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	42.5	81.2	1.9	125.6
Split Cl_2 dose	33.7	73.1	0.2	107.1
H replaced by D	42.5	81.2	0.001	123.7
O_2 delignification	27.2	43.1	0.2	70.6

Table 3.374 Effect of splitting of chlorine dose in C stage, replacement of H stage by D stage and using an oxygen deliginification stage prior to CEH sequence on Brightness and Viscosity of bleached pulps obtained by CEH bleaching

	Brightness (%)	Viscosity (cp)
Normal CEH	80.1	9.4
Split Cl_2 dose	80.9	11.6
H replaced by D	81.5	15.6
O_2 delignification	80.7	9.2

Table 3.134

Formation of different chlorophenolic compounds in various effluents by splitting Chlorine dose in two equal parts in C-stage

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	0.44	0.01	0.55	0.02	-	-	0.99
2	3-chlorophenol	2.28	0.04	1.53	0.06	-	-	3.81
3	4-chloroguaiacol	-	-	-	-	0.11	0.004	0.11
4	5-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01
5	2,3,5-trichlorophenol	0.54	0.01	0.46	0.02	-	-	1.00
6	2,4,6-trichlorophenol	3.00	0.06	0.15	0.01	-	-	3.15
7	3,6-dichloroguaiacol	0.08	0.002	0.11	0.004	-	-	0.19
8	3,4-dichlorocatechol	2.80	0.06	0.78	0.03	-	-	3.58
9	4,5-dichloroguaiacol	0.34	0.01	0.14	0.005	0.31	0.01	0.79
10	5,6-dichloroguaiacol	-	-	-	-	0.06	0.002	-
11	2,3,4,6-tetrachlorophenol	0.28	0.01	0.03	0.001	-	-	0.31
12	3,4,5-trichloroguaiacol	0.20	0.004	0.76	0.03	-	-	0.96
13	3,4,6-trichloroguaiacol	-	-	0.19	0.01	-	-	0.19
14	3,5-dichlorosyringol	1.42	0.03	1.11	0.04	0.13	0.005	2.66
15	3,6-dichlorocatechol	-	-	0.90	0.04	-	-	0.90
16	4,5,6-trichloroguaiacol	1.46	0.03	1.29	0.05	0.06	0.002	2.75
17	tetrachloroguaiacol	2.19	0.04	0.74	0.03	0.21	0.004	3.14
18	3,4,6-trichlorocatechol	2.88	0.06	1.37	0.05	0.21	0.01	4.34
19	2,6-dichlorosyringaldehyde	1.97	0.04	0.94	0.04	-	-	2.91
20	5,6-dichlorovanillin	0.79	0.01	1.01	0.04	0.27	0.01	2.07
21	tetrachlorocatechol	6.36	0.13	2.84	0.11	0.56	0.02	9.76
22	2,3,4-trichlorophenol	-	-	-	-	0.07	0.003	-
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	27.03	0.55	14.90	0.60	1.82	0.07	43.75

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.135

Formation of different chlorophenolic compounds in various effluents by complete replacement of Hypochlorite stage by Chlorine dioxide stage

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	4.17	0.08	2.77	0.11	0.07	0.003	7.01
2	3-chlorophenol	2.39	0.05	2.37	0.09	0.09	0.004	4.85
3	4-chloroguaiacol	-	-	-	-	0.01	0.004	0.01
4	5-chloroguaiacol	-	-	-	-	0.01	0.004	0.01
5	2,3,5-trichlorophenol	0.14	0.003	0.87	0.03	-	-	1.01
6	2,4,6-trichlorophenol	10.82	0.22	5.23	0.21	0.04	0.001	16.09
7	3,6-dichloroguaiacol	0.17	0.003	0.16	0.01	-	-	0.33
8	3,4-dichlorocatechol	2.98	0.06	1.18	0.05	-	-	4.16
9	4,5-dichloroguaiacol	0.31	0.01	0.89	0.04	0.10	0.004	1.30
10	5,6-dichloroguaiacol	-	-	-	-	0.09	0.004	1.57
11	2,3,4,6-tetrachlorophenol	0.09	0.002	0.07	0.003	-	-	1.03
12	3,4,5-trichloroguaiacol	1.19	0.02	0.95	0.04	-	-	2.14
13	3,4,6-trichloroguaiacol	3.66	0.07	0.28	0.01	0.03	0.001	3.97
14	3,5-dichlorosyringol	2.69	0.05	1.42	0.06	0.17	0.01	4.28
15	3,6-dichlorocatechol	-	-	0.96	0.04	-	-	0.96
16	4,5,6-trichloroguaiacol	2.20	0.04	2.36	0.09	-	-	4.56
17	tetrachloroguaiacol	3.19	0.06	0.82	0.03	0.08	0.003	4.09
18	3,4,6-trichlorocatechol	2.47	0.05	1.82	0.07	0.07	0.003	4.36
19	2,6-dichlorosyringaldehyde	4.86	0.10	1.62	0.06	-	-	6.48
20	5,6-dichlorovanillin	1.09	0.02	2.14	0.09	0.15	0.01	3.38
21	tetrachlorocatechol	8.42	0.17	3.65	0.15	0.10	0.004	12.17
22	2,3,4-trichlorophenol	-	-	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	50.84	1.01	29.56	1.18	1.01	0.04	83.76

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.136

Formation of different chlorophenolic compounds in various effluents by using an Oxygen delignification stage prior to CEH sequence								
S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	0.12	0.002	0.35	0.01	-	-	0.47
2	3-chlorophenol	0.39	0.01	0.94	0.04	-	-	1.33
3	4-chloroguaiacol	-	-	-	-	0.04	0.002	0.04
4	5-chloroguaiacol	-	-	-	-	0.002	0.0001	0.002
5	2,3,5-trichlorophenol	0.09	0.002	0.22	0.001	-	-	0.31
6	2,4,6-trichlorophenol	2.14	0.04	0.04	0.002	0.42	0.02	2.60
7	3,6-dichloroguaiacol	0.04	0.001	0.03	0.001	-	-	0.07
8	3,4-dichlorocatechol	0.54	0.01	0.18	0.01	-	-	0.72
9	4,5-dichloroguaiacol	0.14	0.003	0.06	0.002	0.11	0.004	0.31
10	5,6-dichloroguaiacol	-	-	-	-	0.02	0.001	0.02
11	2,3,4,6-tetrachlorophenol	-	-	0.004	0.0002	-	-	0.004
12	3,4,5-trichloroguaiacol	0.18	0.004	0.45	0.02	-	-	0.63
13	3,4,6-trichloroguaiacol	1.54	0.03	0.09	0.004	0.005	0.0002	1.63
14	3,5-dichlorosyringol	0.57	0.01	0.84	0.03	0.01	0.0004	1.42
15	3,6-dichlorocatechol	-	-	0.47	0.02	-	-	0.47
16	4,5,6-trichloroguaiacol	0.98	0.02	0.97	0.04	-	-	1.95
17	tetrachloroguaiacol	1.39	0.03	0.57	0.02	0.15	0.01	2.11
18	3,4,6-trichlorocatechol	0.78	0.01	0.94	0.04	0.07	0.003	1.79
19	2,6-dichlorosyringaldehyde	2.14	0.04	0.74	0.03	-	-	2.88
20	5,6-dichlorovanillin	0.45	0.01	0.99	0.04	0.09	0.004	1.53
21	tetrachlorocatechol	2.32	0.05	1.17	0.05	0.25	0.01	3.74
22	2,3,4-trichlorophenol	-	-	-	-	0.03	0.001	0.03
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	13.81	0.27	9.05	0.36	1.20	0.05	24.06

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 3.371 Effect of splitting of chlorine dose in C stage, replacement of H stage by D stage and using an oxygen deliginification stage prior to CEH sequence on the generation of Chlorophenolic compounds

Chlorophenolic compounds (kg/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	53.19	29.56	3.68	86.43
Split Cl_2 dose	27.03	14.9	1.82	43.75
H replaced by D	53.19	29.56	1.01	83.76
O_2 delignification	13.81	9.05	1.20	24.06

Table 3.372 Effect of splitting of chlorine dose in C stage, replacement of H stage by D stage and using an oxygen deliginification stage prior to CEH sequence on the generation of effluent COD

COD (kg/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	39.9	35.8	21.6	97.5
Split Cl_2 dose	33.4	32.6	18.5	84.5
H replaced by D	39.9	35.8	19.7	95.4
O_2 delignification	27.9	25.1	15.3	68.3

Table 3.373 Effect of splitting of chlorine dose in C stage, replacement of H stage by D stage and using an oxygen deliginification stage prior to CEH sequence on the generation of effluent Colour

Colour (kg/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	42.5	81.2	1.9	125.6
Split Cl_2 dose	33.7	73.1	0.2	107.1
H replaced by D	42.5	81.2	0.001	123.7
O_2 delignification	27.2	43.1	0.2	70.6

Table 3.374 Effect of splitting of chlorine dose in C stage, replacement of H stage by D stage and using an oxygen deliginification stage prior to CEH sequence on Brightness and Viscosity of bleached pulps obtained by CEH bleaching

	Brightness (%)	Viscosity (cp)
Normal CEH	80.1	9.4
Split Cl_2 dose	80.9	11.6
H replaced by D	81.5	15.6
O_2 delignification	80.7	9.2

Table 3.375 Monochlorophenolic compounds present in different effluents formed by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

	Monochlorophenolic compounds (g/t)			
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	2.39	2.37	0.23	4.99
Split Cl_2 dose	2.28	1.53	0.12	3.93
H replaced by D	2.39	2.37	0.11	4.87
O_2 delignification	0.39	0.94	0.04	1.37

Table 3.376 Dichlorophenolic compounds present in different effluents formed by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

	Dichlorophenolic compounds (g/t)			
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	16.27	11.14	1.22	28.63
Split Cl_2 dose	7.84	5.54	1.02	14.4
H replaced by D	16.27	11.14	0.58	27.99
O_2 delignification	4.00	3.66	0.23	7.89

Table 3.377 Trichlorophenolic compounds present in different effluents formed by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

	Trichlorophenolic compounds (g/t)			
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	20.48	11.51	1.23	33.22
Split Cl_2 dose	8.08	4.22	0.27	12.57
H replaced by D	20.48	11.51	0.14	32.13
O_2 delignification	5.71	2.71	0.52	8.94

Table 3.378 Tetrachlorophenolic compounds present in different effluents formed by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

	Tetrachlorophenolic compounds (g/t)			
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	11.7	4.54	1.00	17.24
Split Cl_2 dose	8.83	3.61	1.82	14.26
H replaced by D	11.70	4.54	0.18	16.42
O_2 delignification	3.71	1.74	0.40	5.85

Table 3.379 Category wise load of chlorophenols in different effluents formed by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

Chlorophenols (g/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	17.61	11.31	1.18	30.10
Split Cl_2 dose	6.54	2.72	0.07	9.33
H replaced by D	17.61	11.31	0.20	29.12
O_2 delignification	2.74	1.55	0.45	4.74

Table 3.380 Category wise load of chloroguaiacols in different effluents formed by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

Chloroguaiacols (g/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	10.72	5.46	0.95	17.13
Split Cl_2 dose	4.27	3.23	0.70	8.20
H replaced by D	10.72	5.46	0.32	16.50
O_2 delignification	4.27	2.17	0.33	6.77

Table 3.381 Category wise load of chlorocatechols in different effluents formed by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

Chlorocatechols (g/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	13.87	7.61	0.81	22.29
Split Cl_2 dose	12.04	5.89	0.65	18.58
H replaced by D	13.87	7.61	0.17	21.65
O_2 delignification	3.64	2.76	0.32	6.72

Table 3.382 Category wise load of other chlorophenolic compounds in different effluents formed by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

Other Chlorophenolic compounds (g/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	8.64	5.18	0.74	14.56
Split Cl_2 dose	4.18	3.06	0.40	7.64
H replaced by D	8.64	5.18	0.32	14.14
O_2 delignification	3.16	2.57	0.10	5.83

Table 3.331 Different chlorophenolic compounds formed in C stage by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence					
S.No.	Chlorophenolic compounds(g/T)	Normal CEH	Split Cl_2 dose	H replaced by D	O_2delignifi c-ation
1	2,4-dichlorophenol	4.17	0.44	4.17	0.12
2	3-chlorophenol	2.39	2.28	2.39	0.39
3	4-chloroguaiacol	-	-	-	-
4	5-chloroguaiacol	-	-	-	-
5	2,3,5-trichlorophenol	0.14	0.54	0.14	0.09
6	2,4,6-trichlorophenol	10.82	3.00	10.82	2.14
7	3,6-dichloroguaiacol	0.17	0.08	0.17	0.04
8	3,4dichlorocatechol	2.98	2.8	2.98	0.54
9	4,5-dichloroguaiacol	0.31	0.34	0.31	0.14
10	5,6-dichloroguaiacol	1.48	-	1.48	-
11	2,3,4,6-tetrachlorophenol	0.96	0.28	0.96	-
12	3,4,5-trichloroguaiacol	1.19	0.20	1.19	0.18
13	3,4,6-trichloroguaiacol	3.66	-	3.66	1.54
14	3,5-dichlorosyringol	2.69	1.42	2.69	0.57
15	3,6-dichlorocatechol	-	-	-	-
16	4,5,6-trichloroguaiacol	2.20	1.46	2.20	0.98
17	tetrachloroguaiacol	3.19	2.19	3.19	1.39
18	3,4,6-trichlorocatechol	2.47	2.88	2.47	0.78
19	2,6-dichlorosyringaldehyde	4.86	1.97	4.86	2.14
20	5,6-dichlorovanillin	1.09	0.79	1.09	0.45
21	tetrachlorocatechol	8.42	6.36	8.42	2.32
22	2,3,4-trichlorophenol	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-
	TOTAL	53.19	27.03	53.19	13.81

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C

Table 3.332 Different chlorophenolic compounds formed in E stage by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence					
S.No.	Chlorophenolic compounds(g/T)	**Normal CEH**	**Split Cl_2 dose**	**H replaced by D**	**O_2delignifi c-ation**
1	2,4-dichlorophenol	2.77	0.55	2.77	0.35
2	3-chlorophenol	2.37	1.53	2.37	0.94
3	4-chloroguaiacol	-	-	-	-
4	5-chloroguaiacol	-	-	-	-
5	2,3,5-trichlorophenol	0.87	0.46	0.87	0.22
6	2,4,6-trichlorophenol	5.23	0.15	5.23	0.04
7	3,6-dichloroguaiacol	0.16	0.11	0.16	0.03
8	3,4dichlorocatechol	1.18	0.78	1.18	0.18
9	4,5-dichloroguaiacol	0.89	0.14	0.89	0.06
10	5,6-dichloroguaiacol	-	-	-	-
11	2,3,4,6-tetrachlorophenol	0.07	0.03	0.07	0.004
12	3,4,5-trichloroguaiacol	0.95	0.76	0.95	0.45
13	3,4,6-trichloroguaiacol	0.28	0.19	0.28	0.09
14	3,5-dichlorosyringol	1.42	1.11	1.42	0.84
15	3,6-dichlorocatechol	0.96	0.90	0.96	0.47
16	4,5,6-trichloroguaiacol	2.36	1.29	2.36	0.97
17	tetrachloroguaiacol	0.82	0.74	0.82	0.57
18	3,4,6-trichlorocatechol	1.82	1.37	1.82	0.94
19	2,6-dichlorosyringaldehyde	1.62	0.94	1.62	0.74
20	5,6-dichlorovanillin	2.14	1.01	2.14	0.99
21	tetrachlorocatechol	3.65	2.84	3.65	1.17
22	2,3,4-trichlorophenol	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-
	TOTAL	29.56	14.9	29.56	9.054

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C

Table 3.333 Different chlorophenolic compounds formed in II stage by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence					
S.No.	Chlorophenolic compounds(g/T)	Normal CEH	Split Cl_2 dose	H replaced by D	O_2delignifi c-ation
1	2,4-dichlorophenol	-	-	0.07	-
2	3-chlorophenol	0.12	-	0.09	-
3	4-chloroguaiacol	0.09	0.11	0.01	0.04
4	5-chloroguaiacol	0.02	0.01	0.01	0.002
5	2,3,5-trichlorophenol	-	-	-	-
6	2,4,6-trichlorophenol	0.91	-	0.04	0.42
7	3,6-dichloroguaiacol	-	-	-	-
8	3,4dichlorocatechol	-	-	-	-
9	4,5-dichloroguaiacol	0.37	0.31	0.10	0.11
10	5,6-dichloroguaiacol	0.11	0.06	0.09	0.02
11	2,3,4,6-tetrachlorophenol	-	-	-	-
12	3,4,5-trichloroguaiacol	-	-	-	-
13	3,4,6-trichloroguaiacol	0.04	-	0.03	0.005
14	3,5-dichlorosyringol	0.25	0.13	0.17	0.01
15	3,6-dichlorocatechol	-	-	-	-
16	4,5,6-trichloroguaiacol	-	-	-	-
17	tetrachloroguaiacol	0.32	0.21	0.08	0.15
18	3,4,6-trichlorocatechol	0.13	0.09	0.07	0.07
19	2,6-dichlorosyringaldehyde	-	-	-	-
20	5,6-dichlorovanillin	0.49	0.27	0.15	0.09
21	tetrachlorocatechol	0.68	0.56	0.10	0.25
22	2,3,4-trichlorophenol	0.15	0.07	-	0.03
23	4,5-dichlorocatechol	-	-	-	-
	TOTAL	3.68	1.82	1.01	1.20

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30°C

Table 3.334 Total chlorophenolic compounds formed in CEH bleaching by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence					
S.No.	Chlorophenolic compounds(g/T)	Normal CEH	Split Cl_2 dose	H replaced by D	O_2delignifi c-ation
1	2,4-dichlorophenol	6.94	0.99	7.01	0.47
2	3-chlorophenol	4.88	3.81	4.85	1.33
3	4-chloroguaiacol	0.09	0.11	0.01	0.04
4	5-chloroguaiacol	0.02	0.01	0.01	0.002
5	2,3,5-trichlorophenol	1.01	1.00	1.01	0.31
6	2,4,6-trichlorophenol	16.96	3.15	16.09	2.60
7	3,6-dichloroguaiacol	0.33	0.19	0.33	0.07
8	3,4dichlorocatechol	4.16	3.58	4.16	0.72
9	4,5-dichloroguaiacol	1.57	0.79	1.3	0.31
10	5,6-dichloroguaiacol	1.59	-	1.57	0.02
11	2,3,4,6-tetrachlorophenol	1.03	0.31	1.03	0.004
12	3,4,5-trichloroguaiacol	2.14	0.96	2.14	0.63
13	3,4,6-trichloroguaiacol	3.98	0.19	3.97	1.635
14	3,5-dichlorosyringol	4.36	2.66	4.28	1.42
15	3,6-dichlorocatechol	0.96	0.9	0.96	0.47
16	4,5,6-trichloroguaiacol	4.56	2.75	4.56	1.95
17	tetrachloroguaiacol	4.33	3.14	4.09	2.11
18	3,4,6-trichlorocatechol	4.42	4.34	4.36	1.79
19	2,6-dichlorosyringaldehyde	6.48	2.91	6.48	2.88
20	5,6-dichlorovanillin	3.72	2.07	3.38	1.53
21	tetrachlorocatechol	12.75	9.76	12.17	3.74
22	2,3,4-trichlorophenol	0.15	-	-	0.03
23	4,5-dichlorocatechol	-	-	-	-
	TOTAL	86.43	43.75	83.76	24.064

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C

Fig.3.271

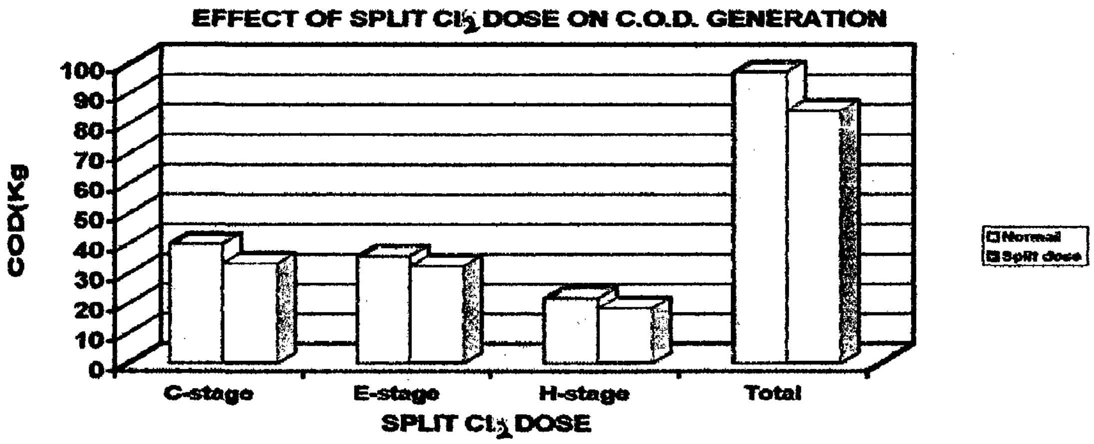


Fig.3.272

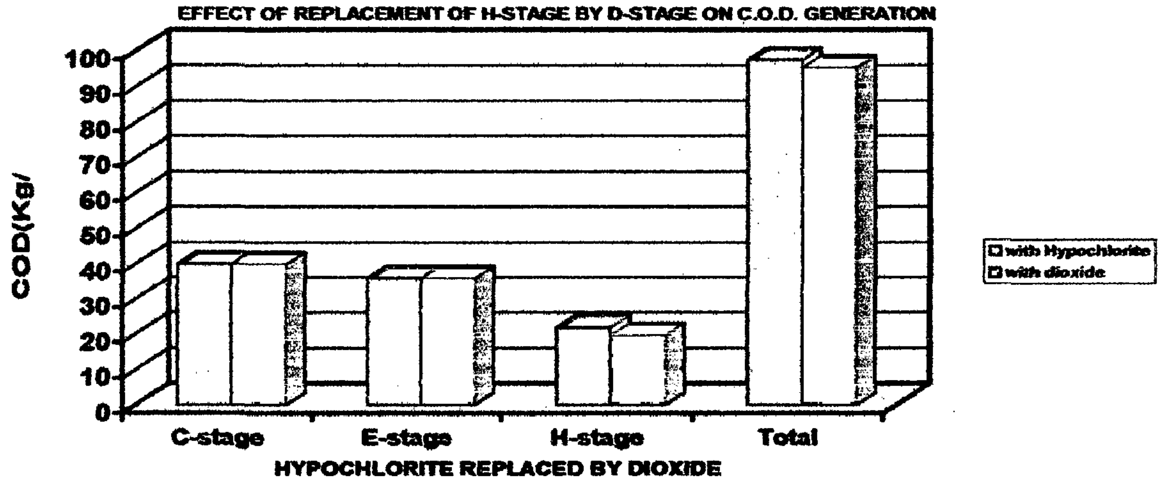


Fig.3.273

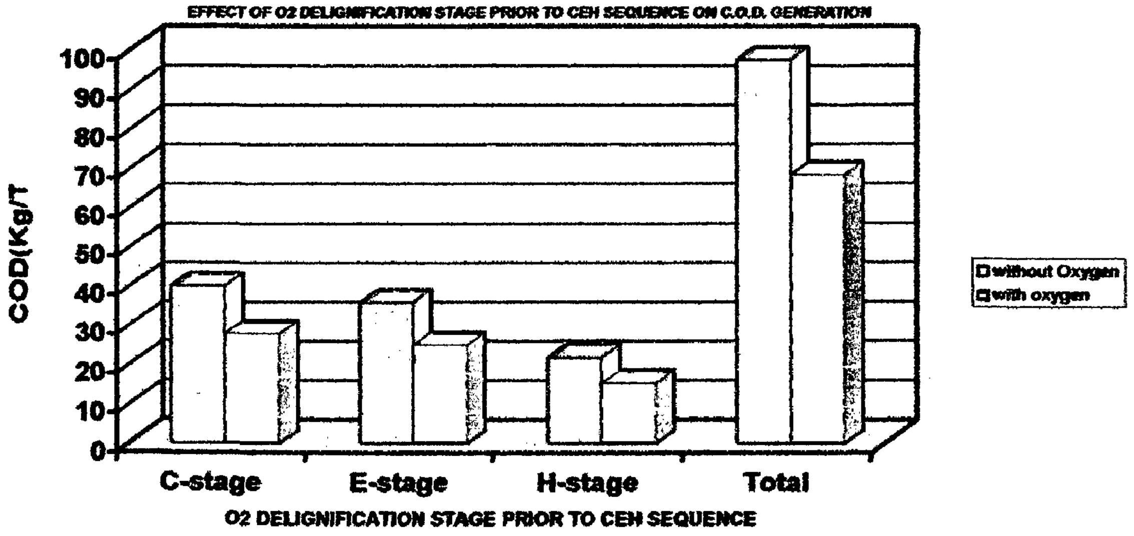


Fig.3.274

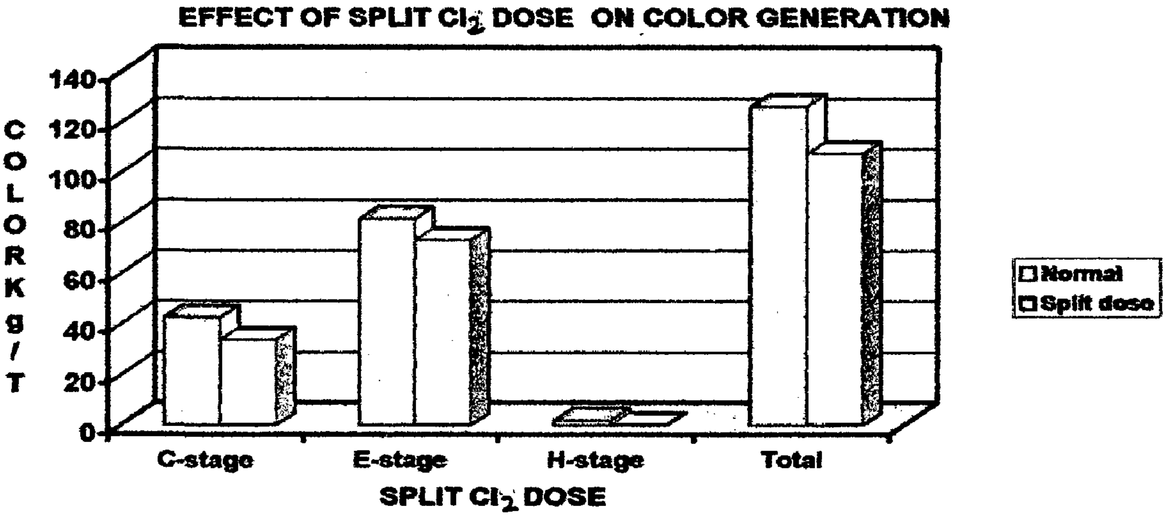


Fig.3.275

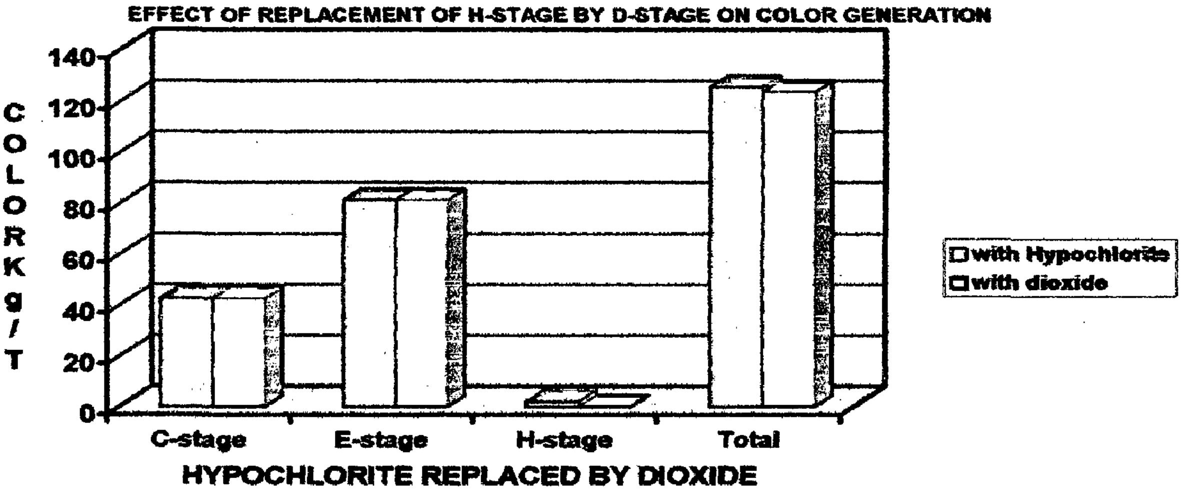


Fig.3.276

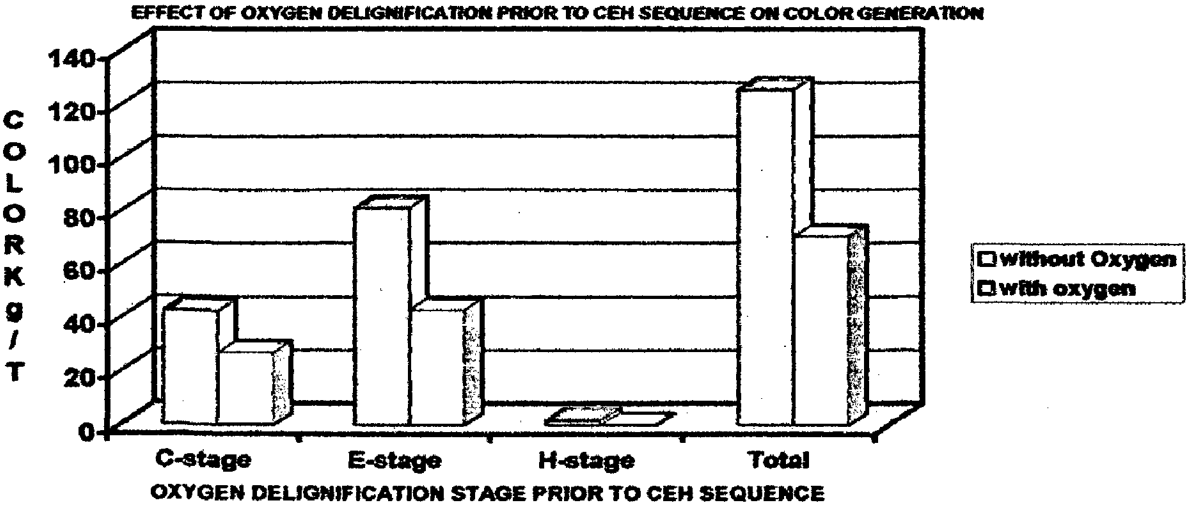


Fig.3.277

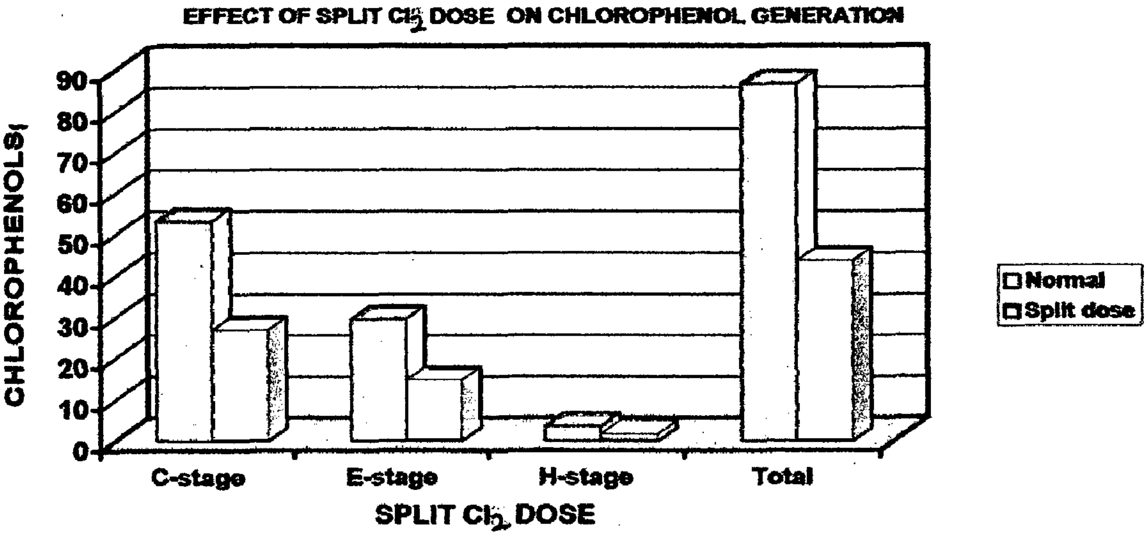


Fig.3.278

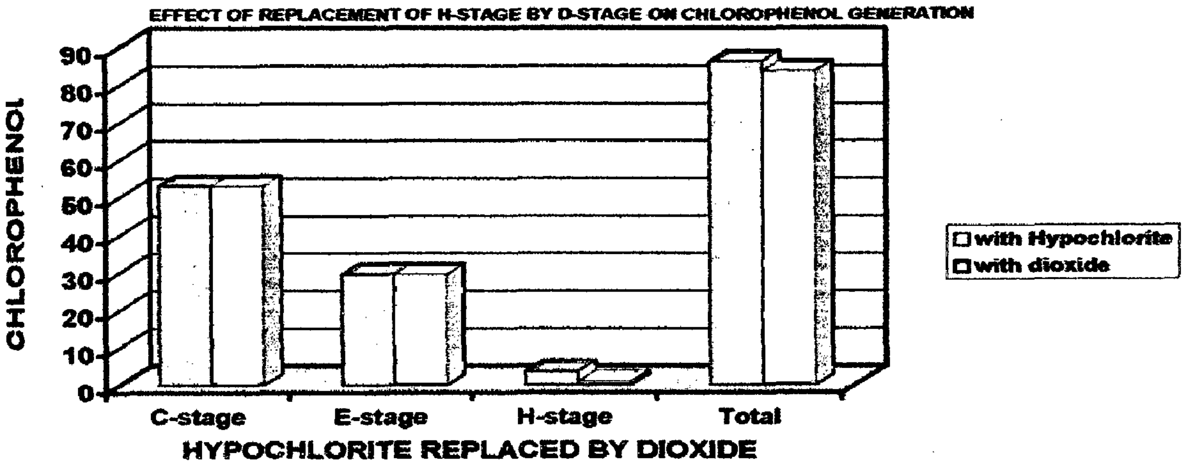


Fig.3.279

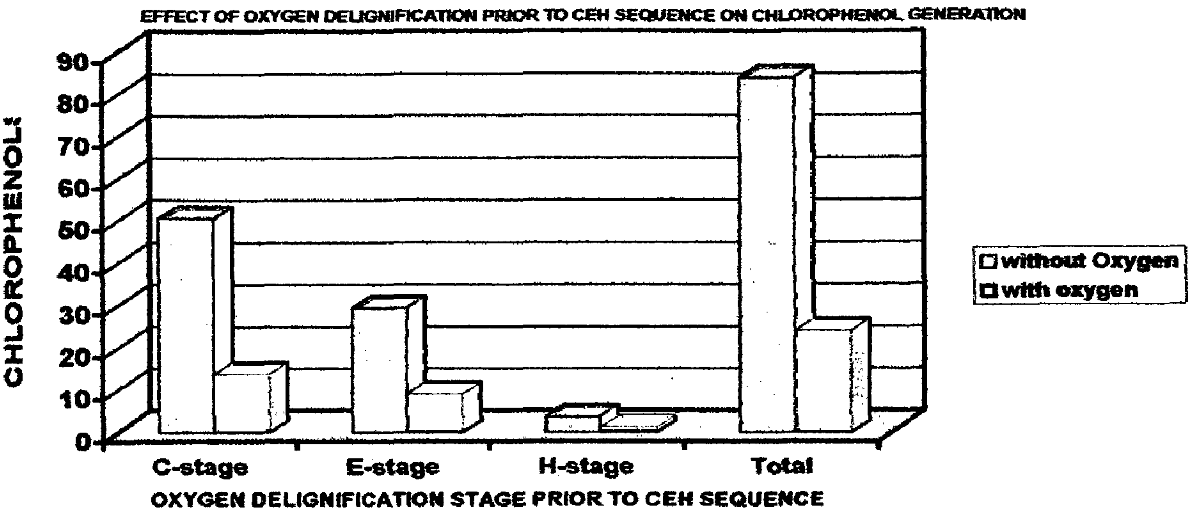


Fig.3.280

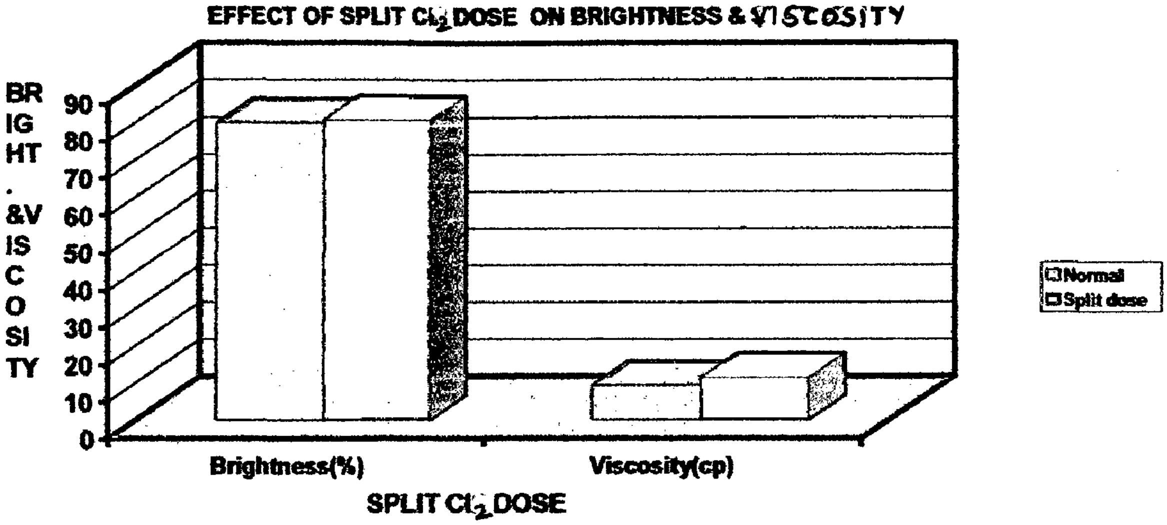


Fig.3.281

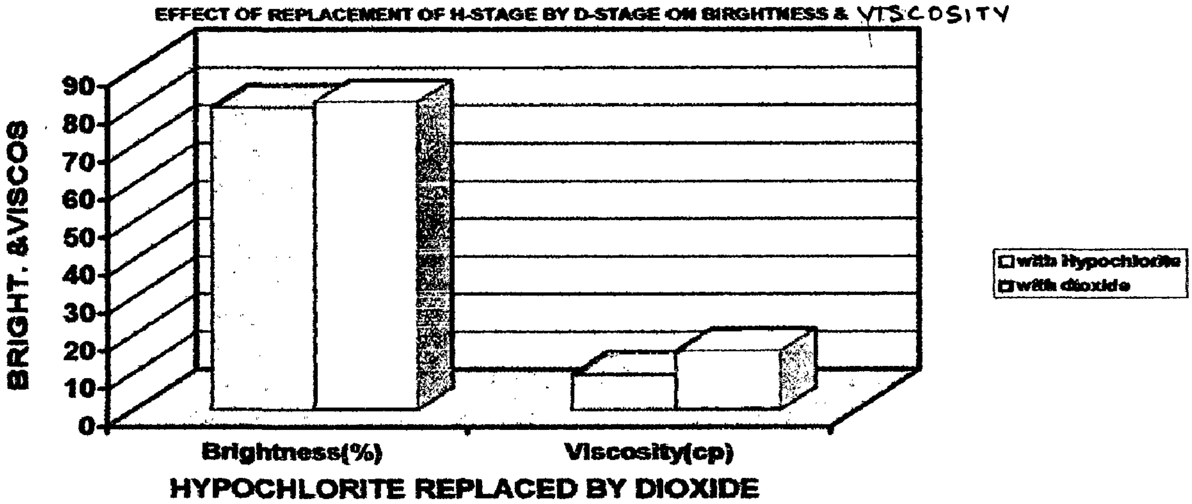
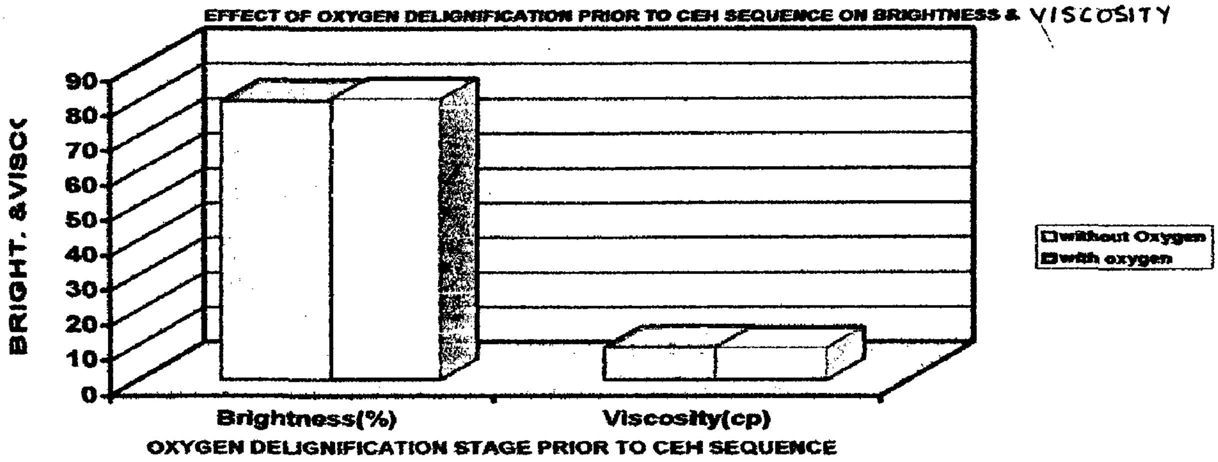


Fig.3.282



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CHAPTER 4

IDENTIFICATION AND ESTIMATION OF CHLORORGANICS IN SARKANDA (*Saccharum munja*)

4.1 INTRODUCTION

Sarkanda, botanical name *S. munja,* is a promising raw material which can easily supplement the growing requirements of Indian paper industry in view of the depleting resources of wood. It is used as raw material by the agro-based paper mills in North India, where it is abundantly available as agricultural residue or waste. Sarkanda grows to its full height in barely 4 to 5 months and so have a less developed and open morphological structure.(1)

It is a very large erect grass growing in clumps with flowering culms up to 6 m tall, growing well on alluvial sandy banks of streams not subjected to water logging. Culms are biennial, pale solid, pithy smooth with an inconspicuous growth ring and root zone. Leaves are 1-2 metres long and upto 3 cms broad. The upper leaf sheaths of the flowering culms of Sarkanda contain valuable fibre content. The fibre obtained from Sarkanda grass is strong and elastic and not affected by moisture. These species include a large number of forms varying in habit, nature of inflorescence and adaptability to soil conditions. It is extensively used for manufacture of cordage, ropes and for making mats, baskets etc. The leaves are also used for thatching and for the purpose of pulp manufacturing.(2)

The fibres of Sarkanda vary from 0.2 to 3.5 mm length with an average of 1.3 mm and 7 to 40 μm in width (average 15.7 μm). The fibres are suitable for writing and printing paper. It can also be used for the preparation of rayon grade pulps. Sarkanda is normally converted to chemical pulp using soda process in Indian Paper mills. The pulp consists of fibres, parenchyma, vessel and epidermal cells. The fibres are narrow, long, straight and with thick walls and pointed tapering ends and occasional transverse markings. The fibres are narrow than bamboo and bagasse. The parenchyma cells are small to medium sized, narrow and rectangular. The vessels are fairly long and narrow. The epidermal cells are numerous, rectangular in shape and conspicuous with serrated margins. Sarkanda contains (oven dry basis): Cellulose 58.2%, Lignin 20.5 %, Pentosans 23.7% and ash 2.3 %.(1) The analysis of Sarkanda shows that it is rich in Hemicellulose; hence does not require high refining for the manufacture of paper.(3)

Sarkanda is being used as a raw material by small and medium sized paper mills in India, where conventional CEH or CEHH bleaching sequences are still being followed. Since most of these mills are not having chemical recovery, they produce pulp of higher kappa number and subsequently use higher chlorine dosage in bleaching stage to achieve desired brightness levels. Moreover, due to inherent poor drainage properties coupled with poor washing efficiency of the washers, a large amount of dissolved organics are also carried over along with pulp to bleaching process. The low bleaching response of the pulp gives higher consumption of chlorine. This results in generation of high level of AOX, colour, BOD and COD.(4)

The Chlorination (C) and first extraction stage (E_1) account for the largest amount of toxic chlorinated organic compounds in pulp mill bleachery effluent.(6-12) Approximately 75 to 80% of the organically bound chlorine in bleach plant effluent is in high molecular weight material, which is not easily identified or even characterized.(12-15) These high molecular weight chlorinated organic compounds constitute the major contributor to the colour and TOCl of the effluent. They accumulate in the receiving streams and over a period of time break down into low molecular mass compounds with detrimental biological effects.(16) Low molecular weight chlorinated organic compounds formed during bleaching of pulp using elemental chlorine is reported to cause acute toxicity and mutagenicity due to their ability to penetrate living cell membrane.(17) The use of hypochlorite in bleaching has been reported to be the major source of carcinogenic compounds like Chloroform and Carbon tetra chloride.(18) Therefore, the chlorinated organic compounds generated in bleach plant effluent are of great environmental concern.

4.2 RESULTS AND DISCUSSION

Before the results of the investigations are discussed, reference is drawn to Table 2.005, where in the retention time, response factor and extraction efficiencies of pure chlorophenolic compounds have been given, which are the averages of minimum three values.

During chlorination of pulp, toxic chlorinated compounds are formed. Their quantities as mentioned previously will depend upon nature of lignin, raw material used and pulping process, the bleaching chemical and bleaching conditions.(4,19-23) The estimation of different chlorophenolic compounds have been carried out in C, E, H bleaching stage effluents and combined CEH effluent. The effects of changes in C stage bleaching conditions are shown in Tables 4.111 to 4.136 and Figures 4.211 to 4.242 and the values of bleached pulp brightness, CED pulp viscosity, effluent COD and colour are given in Tables 4.212 to 4.271. The chlorophenolic compounds which are identified in different bleaching stage effluents are shown in Tables 4.311 to 4.334.

The results show that different chlorophenolic compounds viz. phenols, catechols, guaiacols, vanillins, syringaldehyde and syringols are present in various bleaching effluents. The quantities of these chlorophenolic compounds are given in Tables 4.219 to 4.281 and Figures 4.219 to 4.345. These have been categorized into mono, di, tri, tetrachlorophenolic compounds and their results are shown in Tables 4.215 to 4.280 and Figures 4.215 to 4.230. Some important chlorophenolic compounds, whose concentrations are higher or whose toxicity values are high i.e. lower $^{96}LC_{50}$ values have also been chosen for analysis. The results of these individual compounds are given in Tables 4.311 to 4.334.

The effect of bleaching conditions on the formation of chlorophenolic compounds have been investigated under the following heads:

Changes in C stage conditions

- pH
- Temperature
- Pulp Consistency
- Substitution of Chlorine in C stage by Chlorine dioxide
- Distribution of total Chlorine dosage between C and H stages
- Splitting of chlorine dose in C stage.

Changes in bleaching sequence

- Replacement of Hypochlorite by Chlorine dioxide.
- Oxygen deliginification stage prior to CEH sequence.

The above mentioned studies have been carried out by changing one bleaching parameter while other bleaching parameters/conditions were kept constant. For each bleaching performed, different chlorophenolic compounds formed in C,E,H bleaching stage effluents and combined CEH effluent were estimated, pulp brightness and CED viscosity were determined and effluent COD and colour were also measured.

4.2.1 Effect of C Stage bleaching conditions

4.2.1.1 pH

This study has been performed between pH 1.5 and 4. The results are shown in Tables 4.111 to 4.115 and Figures 4.211 to 4.224.

The results show (Table 4.211 and Figure 4.211) that with the increase in C stage pH from 1.5 to 4, the quantities of total chlorophenolic compounds formed decrease both in C, E, H stage effluents and combined CEH effluent. When we look at the Figures 4.216 to 4.218, we find that quantity of tetra, tri, di and monochlorophenolic compounds in C, E, H stage effluents and combined CEH effluent decrease with increase in pH.

The results given in Tables 4.219 to 4.222 further reveal that the quantities of different categories of chlorophenolic compounds viz. phenols, catechols, guaiacols, other chlorinated compounds (vanillin, syringaldehyde and syringols) decrease substantially with increase in pH, with the exception of other chlorinated compounds in H stage effluent which increase with increase in pH.

It has been reported that different categories of chlorophenolic compounds generated in bleach plant effluent are in the order of C>E>>H.(19,23) A similar behaviour has been reported by Voss et al in the CEH bleaching of hard wood and soft wood pulps, showing that the quantity of total chlorophenolic compounds decreases with increase in end pH in C stage ranging from 1 to 2.5, when bleaching is performed at 25^0C and 80% of chlorine demand is charged in C stage.(24-25)

The change in the proportions of some individual chlorophenolic compounds which are present in higher amounts or have high values of toxicity are shown in Figures 4.309 to 4.325. It shows that the amounts of 2,4 dichlorophenol, 2,4,6 trichlorophenol, 3,6 dichlorocatechol, 3,4 dichlorocatechol, 3,4,6,trichlorocatechol and tetrachloroguaiacol decrease with increase in pH from1.5 to 4 in C, E, H stage effluents and combined CEH effluent with the exception of 3, 4, 6 trichlorocatechol in H stage effluent which increases with increase in pH. In chlorination, alkali extraction and hypochlorite stage effluents and in most of combined CEH effluent, the quantity of chlorinated guaiacols also decreases with increase in pH.

About 75% of total chlorophenolic compounds consist of the di and trichlorinated phenolic compounds, while the remaining 25% is tetra and mono chlorinated phenolic compounds.

With increase in pH, there is a decrease in proportion of dichlorophenolic compounds and increase in tri and tetrachlorophenolic compounds, while the proportions of monochlorophenols remain unchanged. The results (Table 4.211 and Figure 4.211) further show that the proportion of total chlorophenolic compounds between the C, E, H stage is about 60, 35 and 5%, which changes to 75, 20 and 5% respectively when the C stage pH is raised from 1.5 to 4.0. The results given in Tables 4.211 to 4.222 also indicate that much higher proportions of phenols (38%), catechols (26%) and guaiacols (21%) are formed.

Effluent toxicity depends upon concentration of individual compounds. The $^{96}LC_{50}$ values given in Table 3.001 indicate that the toxicity of pentachlorophenol, catechols, tri and tetrachloroguaiacol and 2,4,6 trichlorophenol are relatively much higher than 2,4, dichlorophenol and dichloroguaiacol.

Appreciable reduction in the quantities of di, tri and tetra chlorophenolic compounds is observed, when the pH is raised from 1.0 to 2.5, which is likely to give substantial reduction in effluent toxicity.

The COD and colour values of C, E, H stage effluents and combined CEH effluent decrease by nearly 20% with increase in C stage pH from 1.5 to 4.0, which is an indication of reduction in pollution load.

The pulp brightness drops by one point between pH 2.5 and 4, which is nearly constant in the pH range 1.5 to 2.5. The pulp viscosity drops by 20%, indicating increased pulp degradation with increase in pH in C stage.

The chlorine acts on lignin firstly as a fast electrophillic substitution followed by slower oxidation leading to fragmentation of lignin macromolecule and formation of chlorinated phenolic compounds. Lower quantity of molecular chlorine is available at higher C stage pH, which is responsible for lower electrophillic substitution leading to lower formation of all categories of chlorinated phenolic compounds as given in Tables 4.312 to 4.314 and Figures 4.311 to 4.325.

At higher C stage pH, the lesser quantity of molecular chlorine is available which reduces the hydrophillic character of lignin and this may be responsible for lower dissolution of lignin leading to reduction in effluent COD and colour at higher pH.

4.2.1.2 Temperature

This study has been performed at C stage temperatures between 15 - 35^{0}C. The results are shown in Tables 4.116 to 4.120 and Figures 4.215 to 4.218.

The results as shown in Table 4.221 and Figure 4.217 indicate that the total chlorophenolic compounds generated in C, E, H stage effluents and combined CEH effluent increase with increase in C stage temperature in the range 15 - 35^{0}C. The quantity of mono, di, tri and tetrachlorinated phenolic compounds also increase in C, E, H stage effluents and combined CEH effluent with increase in temperature.

Similarly, the quantities of phenols, catechols, guaiacols and other chlorinated phenolic compounds also increase with increase in temperature in case of C, E, H stage effluents and combined CEH effluent.

These results are also similar to those reported by Voss et al on the CEH bleaching of softwood and hardwood pulp. The total chlorophenolic compounds formed at end pH 2 and at temperature of 60^0C are higher than at 25^0C when 50 or 80% of chlorine demand is applied in C stage. (24-25)

The amounts of 2,4 dichlorophenol, 2,4,6 trichlorophenol, 4,5 dichloroguaiacol, 3,4,5 trichloroguaiacol, 4,5,6 trichloroguaiacol, tetrachloroguaiacol, 3,4,6 trichlorocatechol, tetrachlorocatechol, 2,6 dichlorosyringaldehyde, 5,6 dichlorovanillin, 3,5 dichlorosyringol, also increase with increase in temperature in C,E,H stage effluents and combined CEH effluent.

Steady increase has been observed in the values of COD and effluent colour in C, E, H stage effluents and combined CEH effluent (30%) indicating that pollution load increases with increase in temperature.

With increase in C stage bleaching temperature in the range15-35^0C, increased pulp degradation was observed with drop of the CED pulp viscosity by 15%. There is also marginal increase in the pulp brightness which is comparable at 25-30^0C.

The increase in temperature increases the reaction rate of bleach chemicals on both lignin and carbohydrates thereby giving additional dissolution of lignin and cellulose/hemicellulose components forming higher amounts of chlorinated phenolic compounds, COD and effluent colour and improvement in pulp brightness.

4.2.1.3 Consistency

These studies have been performed at C stage pulp consistency between 2.5 and 4.0. The results are given in Tables 4.121 to 4.124 and Figures 4.219 to 4.222.

The total chlorophenolic compounds generated in C, E, H stage effluents and combined CEH effluent increase with increase in C stage consistency. The quantities of mono, di, tri and tetrachlorophenolic compounds also increase with increase in pulp consistency in C, E, H stage effluents and combined CEH effluent. Likewise, the quantities of phenols, catechols, guaiacols and other chlorinated compounds also increase with increase in C stage pulp consistency in C, E, H stage effluents and combined CEH effluent.

This is consistent with the results of Earl and Douglas Reeve, wherein higher chlorophenolic compounds are reported at 10% Cy than 4% Cy. The quantity of dichloro and trichlorophenolic compounds increase where as that of tetrachloro compounds decrease when the pulp consistency is raised from 4% to 10%.(20,21)

The amount of 2,4 dichlorophenol, 2,4,6 trichlorophenol, 3,6 dichloroguaiacol, 4,5 dichloroguaiacol 3,4,5 trichloroguaiacol, 4,5,6 trichloroguaiacol, tetrachloroguaiacol, 3,6 dichlorocatechol, 3,4,6 trichlorocatechol, tetrachlorocatechol, 2,6 dichlorosyringaldehyde, 5,6 dichlorovanillin, 3,5 dichlorosyringol, also increase with increase in consistency in C,E,H stage effluent and combined CEH effluent.

With increase in pulp consistency, it has been found that the effluent COD and colour also increase by approx 25 and 30% respectively. There was mild increase in brightness of 0.7 points and drop in CED viscosity by about 12%.

The increase in pulp consistency at the same bleach chemical charge gives higher concentration of bleach chemicals and increased reaction, which may be responsible for increased formation of chlorinated phenolic compounds, effluent COD and color and small increase in pulp brightness.

4.2.1.4 Substitution of chlorine by chlorine dioxide in C stage

This study has been performed by substituting chlorine by chlorine dioxide in C stage to the extent of 75%. The results are given in Table 4.125 to 4.128 and Figures 4.223 to 4.226.

The results (Table 4.245 and Figure 4.225) indicate that formation of total chlorophenolic compounds decrease appreciably with increased substitution of chlorine by chlorine dioxide in C stage i.e. about 80% reduction of chlorophenolic compounds at 75% substitution level.(24,5,28,8,31-32)

The amount of total chlorinated phenolics formed increases with increase in chlorine dioxide substitution passed through a maximum at 50% substitution and decreases rapidly to a near zero at 100% chlorine dioxide substitution, as reported by Voss et al.(24,26,30)

The formation of mono, di, tri and tetrachlorinated phenolic compounds decrease with increase in substitution of chlorine by chlorine dioxide (Table 4.259 to 4.252), with the exception of monochlorophenolic compounds at 75% substitution in case of C stage effluent and combined CEH effluent, tri and tetra chlorinated phenolic compounds at 50 and 75% substitution levels in case of H stage effluent. Similarly, the formation of phenols, catechols, guaiacols and other chlorinated phenolic compounds also reduces very significantly (Table 4.253 to 4.256), with the exception being mono chlorophenols which increase with increased substitution in C stage and guaiacols in E stage effluent which increases till 50% substitution and decreases rapidly at 75 % substitution .

The amount of 3,6 dichloroguaiacol, 3,4 dichlorocatechol, 4,5 dichlorocatechol, 3,4,6 trichlorocatechol, 4,5 dichloroguaiacol increase with increase in substitution of chlorine by chlorine dioxide in C stage in C,E,H stage effluents and combined CEH effluent, where as the quantity of 4,5,6 trichloroguaiacol, 3,4,5 trichloroguaiacol and tetrachloroguaiacol decrease with increase in chlorine dioxide substitution. The amount of 5,6 dichloroguaiacol, 2,4 dichlorophenol, 4,5 dichloroguaiacol and 2,4,6 trichlorophenol increase with increase in substitution up to 50% and then drops substantially at 100% substitution in C stage effluent.

There is a substantial reduction in effluent COD (40%) and colour (80%) in C, E, H stage effluents and combined CEH effluent which indicates drastic drop in pollution load.(8,28-29)

By substitution of chlorine dioxide in C stage, it has been found that the pulp viscosity is improved by 60% and brightness by 2%. Due to high selectivity of chlorine dioxide in its attack on lignin, increased substitution of chlorine by chlorine dioxide abate the attack on cellulose which reduces very significantly the drop in pulp viscosity and dissolution of cellulose fragments giving much lower effluent COD and colour. Being a strong decolourization agent, chlorine dioxide gives higher pulp brightness.

4.2.1.5 Distribution of bleaching chemical between C and H Stage

These studies have been performed by varying the distribution (40:60 to 80:20) of total chlorine demand between C and H stages of CEH sequence. The results are given in Tables 4.129 to 4.133 and Figures 4.227 to 4.230.

The results given in Table 4.257 and Figure 4.229 show that the quantity of chlorinated phenolic compounds formed in C, E, H stage effluents and combined CEH effluent increases with increase in proportion of chlorine in C stage from 40% to 80%. The quantity of chlorinated phenolic compounds formed in H stage effluent decrease with decrease in proportion of hypochlorite from 60% to 20%.(24,25)

Similar trend is observed with different categories of chlorophenolic compounds i.e. mono, di, tri and tetrachlorophenols, guaiacols and catechols and other chlorinated compounds in C, E, H stage effluents and combined CEH effluent (Tables 4.261 to 4.268), with the exception of dichlorophenols and other chlorinated compounds in H stage effluent.

The amount of 2,4 dichlorophenol, 2,4,6 trichlorophenol, 3,6 dichloroguaiacol, 4,5 dichloroguaiacol 3,4,5 trichloroguaiacol, 3,4,6 trichloroguaiacol, 4,5,6 trichloroguaiacol, tetrachloroguaiacol, 3,6 dichlorocatechol, 3,4 dichlorocatechol, 3,4,6 trichlorocatechol, tetrachlorocatechol, 2,6 dichlorosyringaldehyde, 3,5 dichlorosyringol, increase with increase in proportion of hypochlorite in C,E,H stage effluent and combined CEH effluent, but 5,6 dichlorovanillin decreases, with the exception of 5,6 dichloroguaiacol, 3,4,6 trichlorocatechol, tetrachlorocatechol and tetrachloroguaiacol in H stage effluent where the quantities of these chemicals decrease with increase in proportion of hypochlorite.

The effluent COD and colour also increase in C, E, H stage effluents and combined CEH effluent. The exception being COD which decreases with change in proportion from 40:60 to 80:20. A small decrease in pulp brightness (0.6 points) and drop in viscosity (9%), were observed.

The change in proportion from 40:60 to 80:20 means charging more chlorine in C stage and less hypochlorite in H stage. The formation of chlorinated phenolic compounds results from the action of chlorine on lignin in C stage. Increase in proportion of chlorine will give rise to increased formation of chlorinated phenolic compounds in C stage and E stage effluents. Alkali extraction stage solubilize the chlorinated phenolic compounds formed during C stage pulp bleaching; thus this stage becomes the major contributor to pollution in terms of COD, colour and TOCl. The lower quantity of hypochlorite charged in H stage will give lower amounts of chlorinated phenolics in H stage effluent.

Increased quantity of chlorine in C stage gives more hydrophilic lignin, which is fragmented by hypochlorite. As a result, dissolution of lignin is increased giving higher effluent COD and effluent colour.

4.2.1.6 Splitting of chlorine dose in C Stage

The chlorine dose in C stage has been divided into two equal parts. Chlorination has been performed with half the dose and then again performed with remaining half dose. However, there was no change in the conditions in the ensuing extraction and hypochlorite stages. The results are shown in Table 4.134 and Figure 4.237.

The results shown in Tables 4.273 to 4.280 further show that quantity of mono, di, tri and tetrachlorinated phenolic compounds, phenols, catechols, guaiacols and other chlorinated compounds in C, E, H stage effluents and combined CEH effluent all decrease with the use of split chlorine dose in C stage, which is in concurrence with the observation of Liebergott that splitting of chlorine dosage into two portions showed a decrease in the amount of chlorophenols. The exception being tetrachlorophenols in H stage effluent which increase with split chlorine dose.

The results show a very large decrease in the amounts of 2,4 dichlorophenol, 2,4,6 trichlorophenol, 2,6 dichlorosyringaldehyde, 5,6 dichlorovanillin, 3,5 dichlorosyringol and appreciable decrease in 3,6 dichloroguaiacol, 3,4 dichlorocatechol and Tetrachlorocatechol and decrease in the amounts of 5,6 dichloroguaiacol, 4,5,6 trichloroguaiacol formed in C,E,H stage effluents and combined CEH effluent when chlorine dose in C stage is split in two equal doses, with the exception of 4,5 dichloroguaiacol in C stage.

The results show that splitting of chlorine dose gives 48% lower formation of chlorinated phenolic compounds in C, E, H stage effluents and combined CEH effluent.(33-36) The effluent COD and colour is reduced by 13%. The pulp brightness is improved by 0.8 point and viscosity is improved by about 25% indicating that splitting of chlorine dose reduces the pollution load by 13% and gives a stronger and brighter pulp. The splitting of chlorine dose means applying lower concentration of chlorine over longer period making mild attack on cellulose and hemicellulose. This gives lower dissolution of carbohydrate fraction and lowers effluent COD and colour. Mild attack on cellulose gives lower pulp degradation and will yield stronger pulp with higher viscosity.

4.2.2 Changes in bleaching sequence

4.2.2.1 Replacement of hypochlorite by chlorine dioxide in H stage

The complete replacement of hypochlorite by chlorine dioxide will change the bleaching sequence from CEH to CED. The results of this replacement are given in Table 4.135 and Figure 4.238.

The results show that there is practically no change in the quantity of various chlorophenolic compounds formed in H stage and combined CEH effluent, but there is decrease in the quantity of 2,4,6 trichlorophenols, 4,5 dichloroguaiacol, Tetrachloroguaiacol and Tetrachlorocatechol in H stage and combined CEH effluent. The quantity of 5,6 dichlorovanillin decreases substantially.

The bleaching results and environmental loads from C and E stage effluents remain unchanged. The contribution of H stage effluent to the bleaching sequence in terms of chlorinated phenolic compounds, effluent COD and colour is small, about 2 - 5%. The replacement of H by D reduces the formation of chlorophenolic compounds, effluent COD and colour, but the overall impact remains small i.e. improvement of 2 – 5% only.

One of the major advantages of replacing H by D is in terms of pulp viscosity and brightness. Hypochlorite is strongly pulp degrading where as chlorine dioxide is inert to pulp thus giving a stronger pulp. The improvement in pulp viscosity was by 65%. Chlorine dioxide is also known to give lower colour reversion tendency. The chlorine dioxide also improves the pulp brightness by 0.8 points.

4.2.2.2 Oxygen deliginification stage prior to CEH

The results on bleaching are given in Table 4.136 and Figure 4.239, which show that introduction of oxygen pre-bleaching stage reduces the formation of mono, di, tri, tetraphenols, guaiacols, catechols and other chlorinated compounds by 75% in C, E, H stage effluents and combined CEH effluent.(37,38) The effluent COD and colour reduce by 30% and 44% respectively. The pulp brightness shows minor improvement by 0.6% and viscosity drops by 2%.

The results indicate that the quantities of all the individual chlorophenolic compounds decrease on using an oxygen deliginification stage, but there is large reduction in the quantities of 2,4 dichlorophenol, 2,4,6 trichlorophenol, 4,5 dichloroguaiacol 3,4,5 trichloroguaiacol, 3,4 dichlorocatechol, tetrachlorocatechol, 2,6 dichlorosyringaldehyde, 5,6 dichlorovanillin, 3,5 dichlorosyringol and the reduction of other compounds is substantial.

Some reports indicate that oxygen deliginification is an efficient method of lowering the organic load from the bleach plant.

Oxygen deliginification is known to reduce the pulp kappa number by 40 - 50% which in turn reduces the active chlorine multiple in the following C,E and H stages to nearly the same extent and consequently lowers the environmental loads – chlorophenolic compounds, COD and colour very significantly.

4.3 CONCLUSIONS

The following conclusions are drawn from the results on bleaching of sarkanda pulp:

a) pH

1) Increase in C stage pH from 1.5 to 4 lowers the formation of various categories of chlorophenolic compounds substantially and reduces effluent COD and colour by about 18%.
2) Generation of chlorophenolic compounds in C stage effluents decrease by 15% and that in E stage effluent increases by same amount, but the proportion of H stage remains unchanged.
3) The proportion of dichlorophenolic compounds decreases and that of tri and tetrachlorophenolic compounds increases.
4) The pulp brightness remains unchanged between pH 1.5 and 2.5 where as in pH 2.5 – 4.0 it drops by one point. A drop in CED viscosity by 20% indicates towards increased pulp degradation.

b) Temperature and consistency

1) Raising of C stage temperature (15^0C – 30^0C)/consistency (2.5% - 4%) increases the rate of reaction and the generation of chlorophenolic compounds, effluent COD and colour.
2) A reduction in pulp viscosity points towards increased pulp degradation.

c) Chlorine dioxide substitution

1) The substitution of chlorine by chlorine dioxide decreases the formation of chlorophenolic compounds, effluent COD, colour and toxicity significantly.
2) Higher pulp viscosity shows that chlorine dioxide protects the pulp from degradation.

d) Increasing C : H ratio

1) Reduction in the formation of chlorophenolic compounds in H stage effluent.
2) Increment in the effluent COD and colour.
3) Improvement in pulp viscosity approximately by 9%.

e) Splitting of chlorine dose

1) Reduces the formation of chlorophenolic compounds.

2) Abates effluent COD and colour.

3) Improvement in pulp viscosity and brightness.

f) Replacement of hypochlorite by chlorine dioxide

1) Reduction (2 – 5%) in the quantity of chlorophenolic compounds.
2) Reduction (2 – 5%) in effluent COD and colour.
3) Significant improvement in pulp viscosity (65%).
4) Marginal improvement (0.8 point) in pulp brightness.

g) Oxygen deliginification stage

1) Reduces the quantity of chlorophenolic compounds by 75%.
2) Significant reduction in effluent toxicity.
3) Appreciable reduction in effluent COD and colour.
4) Reduction in pulp viscosity by 2%.

Table 4.111

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage pH of 1.5									
S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total	
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T	
1	2,4-dichlorophenol	4.92	0.10	3.27	0.13	-	-	8.19	
2	3-chlorophenol	3.57	0.07	2.42	0.10	0.10	0.004	6.09	
3	4-chloroguaiacol	-		-		0.15	0.01	0.15	
4	5-chloroguaiacol	-		-		0.01	0.0004	0.01	
5	2,3,5-trichlorophenol	0.53	0.01	0.85	0.03	-	-	1.38	
6	2,4,6-trichlorophenol	10.51	0.21	5.11	0.20	0.84	0.03	16.46	
7	3,6-dichloroguaiacol	0.14	0.003	0.22	0.01	-	-	0.36	
8	3,4dichlorocatechol	3.95	0.08	1.54	0.06	-	-	5.49	
9	4,5-dichloroguaiacol	0.54	0.01	1.78	0.07	0.35	0.01	2.67	
10	5,6-dichloroguaiacol	2.57	0.05	0.61	0.02	0.33	0.01	3.51	
11	2,3,4,6-tetrachlorophenol	1.33	0.03	0.23	0.01	-	-	1.56	
12	3,4,5-trichloroguaiacol	1.76	0.03	0.93	0.04	-	-	2.69	
13	3,4,6-trichloroguaiacol	3.64	0.07	0.48	0.02	-	-	4.12	
14	3,5-dichlorosyringol	2.65	0.05	1.37	0.05	0.21	0.01	4.23	
15	3,6-dichlorocatechol	-	-	0.98	0.04	-	-	0.98	
16	4,5,6-trichloroguaiacol	2.76	0.05	2.53	0.10	-	-	5.29	
17	tetrachloroguaiacol	3.26	0.06	1.36	0.05	0.31	0.01	4.93	
18	3,4,6-trichlorocatechol	3.86	0.08	1.88	0.07	0.05	0.002	5.79	
19	2,6-dichlorosyringaldehyde	5.25	0.10	2.43	0.10	-	-	7.68	
20	5,6-dichlorovanillin	1.43	0.03	2.86	0.11	0.21	0.01	4.50	
21	tetrachlorocatechol	8.75	0.17	4.07	0.16	0.87	0.03	13.69	
22	2,3,4-trichlorophenol	-	-	-	-	0.21	0.01	0.21	
23	4,5-dichlorocatechol	-	-	-	-	-	-	-	
	TOTAL	61.42	1.20	34.92	1.37	3.64	0.14	99.98	2.71

C Stage bleaching conditions: Charge 5.1%, Temperature 30^{0}C, Consistency 3%

Table 4.112

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage pH of 2

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total	
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T	mg\l
1	2,4-dichlorophenol	3.97	0.08	2.34	0.09	-	0.01	6.31	
2	3-chlorophenol	2.21	0.04	2.04	0.08	0.09	0.02	4.34	
3	4-chloroguaiacol	-	-	-	-	0.04	0.004	0.04	
4	5-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01	
5	2,3,5-trichlorophenol	0.10	0.002	0.72	0.03	-	0.03	0.82	
6	2,4,6-trichlorophenol	9.74	0.19	5.01	0.2	0.78	-	15.53	
7	3,6-dichloroguaiacol	0.09	0.002	0.14	0.006	-	-	0.23	
8	3,4-dichlorocatechol	2.87	0.06	0.97	0.04	-	0.01	3.84	
9	4,5-dichloroguaiacol	0.25	0.005	0.76	0.03	0.28	0.003	1.29	
10	5,6-dichloroguaiacol	1.31	0.03	0.57	0.02	0.07	-	1.95	
11	2,3,4,6-tetrachlorophenol	0.84	0.02	0.06	0.002	-	-	0.90	
12	3,4,5-trichloroguaiacol	1.08	0.02	0.89	0.03	-	-	1.97	
13	3,4,6-trichloroguaiacol	3.53	0.07	0.21	0.01	-	0.007	3.74	
14	3,5-dichlorosyringol	2.58	0.05	1.12	0.04	0.17	-	3.87	
15	3,6-dichlorocatechol	-		0.87	0.03	-	-	0.87	
16	4,5,6-trichloroguaiacol	2.12	0.04	2.12	0.08	-	-	4.24	
17	tetrachloroguaiacol	3.10	0.06	0.77	0.03	0.27	0.01	4.14	
18	3,4,6-trichlorocatechol	2.36	0.05	1.74	0.07	0.10	0.004	4.20	
19	2,6-dichlorosyringaldehyde	4.95	0.1	1.74	0.07	-	-	6.69	
20	5,6-dichlorovanillin	1.16	0.02	2.23	0.09	0.35	0.01	3.74	
21	tetrachlorocatechol	8.32	0.17	3.15	0.13	0.54	0.02	12.01	
22	2,3,4-trichlorophenol	-		-	-	0.11	0.004	0.11	
23	4,5-dichlorocatechol	-		-	-	-	-	-	
	TOTAL	50.58	1.01	27.45	1.08	2.81	0.10	80.84	2.19

C Stage bleaching conditions: Charge 5.1%, Temperature 30^{0}C, Consistency 3%

Table 4.113

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage pH of 2.5									
S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total	
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T	mg\l
1	2,4-dichlorophenol	3.84	0.08	0.94	0.04	-	-	4.78	
2	3-chlorophenol	2.02	0.04	0.85	0.03	0.02	0.001	2.89	
3	4-chloroguaiacol	-	-	-	-	0.001	0.00004	0.001	
4	5-chloroguaiacol	-	-	-	-	0.005	0.0002	0.005	
5	2,3,5-trichlorophenol	0.07	0.001	0.57	0.02	-	-	0.64	
6	2,4,6-trichlorophenol	8.87	0.18	3.45	0.14	0.63	0.02	12.95	
7	3,6-dichloroguaiacol	0.07	0.001	0.09	0.004	-	-	0.16	
8	3,4-dichlorocatechol	2.41	0.05	0.89	0.03	-	-	3.3	
9	4,5-dichloroguaiacol	0.21	0.004	0.67	0.03	0.13	0.005	1.01	
10	5,6-dichloroguaiacol	0.96	0.02	0.51	0.02	0.01	0.0004	1.48	
11	2,3,4,6-tetrachlorophenol	0.76	0.01	0.03	0.001	-	-	0.79	
12	3,4,5-trichloroguaiacol	0.98	0.02	0.47	0.02	-	-	1.45	
13	3,4,6-trichloroguaiacol	2.76	0.05	0.19	0.01	-	-	2.95	
14	3,5-dichlorosyringol	1.33	0.03	0.96	0.04	0.12	0.0005	2.41	
15	3,6-dichlorocatechol	-	-	0.65	0.03	-	-	0.65	
16	4,5,6-trichloroguaiacol	1.86	0.04	1.31	0.05	-	-	3.17	
17	tetrachloroguaiacol	2.74	0.05	0.67	0.03	0.15	0.01	3.56	
18	3,4,6-trichlorocatechol	2.31	0.05	0.74	0.03	0.16	0.01	3.21	
19	2,6-dichlorosyringaldehyde	4.61	0.09	1.64	0.06	-	-	6.25	
20	5,6-dichlorovanillin	0.65	0.01	1.42	0.06	0.42	0.02	2.49	
21	tetrachlorocatechol	7.82	0.16	2.76	0.11	0.36	0.01	10.94	
22	2,3,4-trichlorophenol	-		-		0.07	0.003	0.07	
23	4,5-dichlorocatechol	-		-		-	-	-	
	TOTAL	44.27	0.89	18.81	0.75	2.08	0.08	65.16	1.72

C Stage bleaching conditions: Charge 5.1%, Temperature 30^{0}C, Consistency 3%

Table 4.114

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage pH of 3

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total	
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T	
1	2,4-dichlorophenol	3.76	0.07	0.69	0.03	-	-	4.45	
2	3-chlorophenol	1.87	0.04	0.67	0.03	0.01	0.0004	2.55	
3	4-chloroguaiacol	-		-	-	0.005	0.0002	0.005	
4	5-chloroguaiacol	-		-	-	0.003	0.0001	0.003	
5	2,3,5-trichlorophenol	0.05	0.001	0.42	0.02	-	-	0.47	
6	2,4,6-trichlorophenol	8.29	0.16	1.89	0.07	0.57	0.02	10.75	
7	3,6-dichloroguaiacol	0.05	0.001	0.05	0.002	-	-	0.10	
8	3,4-dichlorocatechol	2.36	0.05	0.76	0.03	-	-	3.12	
9	4,5-dichloroguaiacol	0.17	0.003	0.25	0.01	0.05	0.002	0.47	
10	5,6-dichloroguaiacol	0.74	0.01	0.44	0.02	0.01	0.0004	1.19	
11	2,3,4,6-tetrachlorophenol	0.58	0.01	0.01	0.0004	-	-	0.59	
12	3,4,5-trichloroguaiacol	0.91	0.02	0.31	0.01	-	-	1.22	
13	3,4,6-trichloroguaiacol	2.12	0.04	0.14	0.006	-	-	2.26	
14	3,5-dichlorosyringol	0.54	0.01	0.87	0.03	0.07	0.003	1.48	
15	3,6-dichlorocatechol	-	-	0.44	0.02	-	-	0.44	
16	4,5,6-trichloroguaiacol	1.01	0.02	1.27	0.05	-	-	2.28	
17	tetrachloroguaiacol	2.57	0.05	0.47	0.02	0.09	0.004	3.13	
18	3,4,6-trichlorocatechol	2.24	0.04	0.57	0.02	0.22	0.001	3.03	
19	2,6-dichlorosyringaldehyde	4.23	0.08	1.61	0.06	-	-	5.84	
20	5,6-dichlorovanillin	0.54	0.01	1.24	0.05	0.47	0.02	2.25	
21	tetrachlorocatechol	6.18	0.12	2.37	0.09	0.27	0.01	8.82	
22	2,3,4-trichlorophenol	-	-	-	-	0.04	0.002	0.04	
23	4,5-dichlorocatechol	-	-	-	-	-	-	-	
	TOTAL	38.21	0.73	14.47	0.57	1.81	0.0631	54.49	

C Stage bleaching conditions: Charge 5.1%, Temperature 30^0C, Consistency 3%

Table 4.115

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage pH of 4

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	2.52	0.05	0.04	0.002	-	-	2.56
2	3-chlorophenol	1.65	0.03	0.01	0.0004	0.003	0.0001	1.66
3	4-chloroguaiacol	-	-	-	-	0.01	0.0003	0.01
4	5-chloroguaiacol	-	-	-	-	0.001	0.00004	0.001
5	2,3,5-trichlorophenol	0.01	0.0002	0.31	0.01	-	-	0.32
6	2,4,6-trichlorophenol	7.25	0.14	0.48	0.02	0.42	0.02	8.15
7	3,6-dichloroguaiacol	0.02	0.0004	0.02	0.001	-	-	0.04
8	3,4-dichlorocatechol	1.53	0.03	0.29	0.01	-	-	1.82
9	4,5-dichloroguaiacol	0.14	0.003	0.19	0.01	0.01	0.0004	0.34
10	5,6-dichloroguaiacol	0.57	0.01	0.38	0.01	0.004	0.0002	0.954
11	2,3,4,6-tetrachlorophenol	0.44	0.01		-	-	-	0.44
12	3,4,5-trichloroguaiacol	0.87	0.02	0.17	0.01	-	-	1.04
13	3,4,6-trichloroguaiacol	1.71	0.03	0.05	0.002	-		1.76
14	3,5-dichlorosyringol	0.05	0.001	0.17	0.01	0.01	0.0004	0.23
15	3,6-dichlorocatechol		-	0.26	0.01	-	-	0.26
16	4,5,6-trichloroguaiacol	0.92	0.02	0.76	0.03	-	-	1.68
17	tetrachloroguaiacol	1.34	0.03	0.27	0.01	0.02	0.001	1.63
18	3,4,6-trichlorocatechol	1.26	0.02	0.15	0.01	0.26	0.01	1.67
19	2,6-dichlorosyringaldehyde	3.65	0.07	0.19	0.01	-	-	3.84
20	5,6-dichlorovanillin	0.44	0.01	0.94	0.04	0.68	0.03	2.06
21	tetrachlorocatechol	5.37	0.11	1.82	0.07	0.07	0.003	7.26
22	2,3,4-trichlorophenol	-	-	-	-	0.03	0.001	0.03
23	4,5-dichlorocatechol	-	-	-	-	-	-	
	TOTAL	29.74	0.58	6.50	0.26	1.51	0.07	37.7

C Stage bleaching conditions: Charge 5.1%, Temperature 30^{0}C, Consistency 3%

Table 4.211 Effect of change in C Stage pH values on the generation of Chlorophenolic compounds

Chlorophenolic compounds (kg/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	61.42	34.92	3.64	99.98
2.0	50.58	27.45	2.81	80.84
2.5	44.27	18.81	2.08	65.16
3.0	38.21	14.47	1.81	54.49
4.0	29.74	6.50	1.52	37.76

Table 4.212 Effect of change in C Stage pH values on the generation of effluent COD

COD (kg/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	35.3	31.6	20.6	87.5
2.0	34.2	29.4	19.4	83.0
2.5	32.4	26.7	17.5	76.6
3.0	30.2	22.1	16.4	68.7
4.0	29.7	20.5	15.2	65.4

Table 4.213 Effect of change in C Stage pH values on the generation of effluent Colour

Colour (kg/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	37.5	74.6	2.1	114.2
2.0	35.3	67.3	1.7	104.3
2.5	33.4	65.2	1.3	99.9
3.0	31.6	61.4	1.1	94.1
4.0	29.7	58.5	1.0	89.2

Table 4.214 Effect of change in C Stage pH values on Brightness and Viscosity of bleached pulps obtained by CEH bleaching

pH	Brightness (%)	Viscosity (cp)
1.5	80.2	10.7
2.0	80.1	10.1
2.5	80.1	9.7
3.0	79.9	9.1
4.0	79.5	8.5

Table 4.215 Monochlorophenolic compounds present in different effluents formed by bleaching at various C Stage pH values

Monochlorophenolic compounds (g/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	3.57	2.42	0.26	6.25
2.0	2.21	2.04	0.14	4.39
2.5	2.02	0.85	0.03	2.90
3.0	1.87	0.67	0.02	2.56
4.0	1.65	0.01	0.01	1.67

Table 4.216 Dichlorophenolic compounds present in different effluents formed by bleaching at various C Stage pH values

Dichlorophenolic compounds (g/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	21.45	15.06	0.26	36.77
2.0	17.18	10.74	0.14	28.06
2.5	14.08	7.77	0.03	21.88
3.0	12.39	6.35	0.02	18.76
4.0	8.92	2.48	0.01	11.41

Table 4.217 Trichlorophenolic compounds present in different effluents formed by bleaching at various C Stage pH values

Trichlorophenolic compounds (g/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	23.06	11.78	1.10	35.94
2.0	18.93	10.69	0.99	30.61
2.5	16.85	6.73	0.86	24.44
3.0	14.62	4.60	0.83	20.05
4.0	12.02	1.92	0.71	14.65

Table 4.218 Tetrachlorophenolic compounds present in different effluents formed by bleaching at various C Stage pH values

Tetrachlorophenolic compounds (g/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	13.34	5.66	1.18	20.18
2.0	12.26	3.98	0.81	17.05
2.5	11.32	3.46	0.51	15.29
3.0	9.33	2.85	0.36	12.54
4.0	7.15	2.09	0.09	9.33

Table 4.219 Category wise load of chlorophenols in different effluents formed by bleaching at various C Stage pH

Chlorophenols (g/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	20.86	11.88	1.15	33.89
2.0	16.86	10.17	0.98	28.01
2.5	15.56	5.84	0.72	22.12
3.0	14.55	3.68	0.62	18.85
4.0	11.87	0.84	0.45	13.16

Table 4.220 Category wise load of chloroguaiacols in different effluents formed by bleaching at various C Stage pH

Chloroguaiacols (g/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	14.67	7.91	1.15	23.73
2.0	11.48	5.46	0.67	17.61
2.5	9.58	3.91	0.30	13.79
3.0	7.57	2.93	0.16	10.66
4.0	5.57	1.84	0.04	7.45

Table 4.221 Category wise load of chlorocatechols in different effluents formed by bleaching at various C Stage pH

Chlorocatechols (g/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	16.56	8.47	0.92	25.95
2.0	13.55	6.73	0.64	20.92
2.5	12.54	5.04	0.52	18.10
3.0	10.78	4.14	0.49	15.41
4.0	8.16	2.52	0.33	11.01

Table 4.222 Category wise load of other chlorophenolic compounds in different effluents formed by bleaching at various C Stage pH

Other Chlorophenolic compounds (g/t)				
pH	C-stage	E-stage	H-stage	TOTAL
1.5	9.33	6.66	0.42	16.41
2.0	8.69	5.09	0.52	14.30
2.5	6.59	4.02	0.54	11.15
3.0	9.33	3.72	0.54	13.59
4.0	4.14	1.30	0.69	6.13

Table 4.311 Different chlorophenolic compounds formed in C stage at various pH values

		C stage pH				
S.No.	Chlorophenolic compounds(g/T)	**1.5**	**2.0**	**2.5**	**3.0**	**4.0**
1	2,4-dichlorophenol	4.92	3.97	3.84	3.76	2.52
2	3-chlorophenol	3.57	2.21	2.02	1.87	1.65
3	4-chloroguaiacol	-	-	-	-	-
4	5-chloroguaiacol	-	-	-	-	-
5	2,3,5-trichlorophenol	0.53	0.10	0.07	0.05	0.01
6	2,4,6-trichlorophenol	10.51	9.74	8.87	8.29	7.25
7	3,6-dichloroguaiacol	0.14	0.09	0.07	0.05	0.02
8	3,4dichlorocatechol	3.95	2.87	2.41	2.36	1.53
9	4,5-dichloroguaiacol	0.54	0.25	0.21	0.17	0.14
10	5,6-dichloroguaiacol	2.57	1.31	0.96	0.74	0.57
11	2,3,4,6-tetrachlorophenol	1.33	0.84	0.76	0.58	0.44
12	3,4,5-trichloroguaiacol	1.76	1.08	0.98	0.91	0.87
13	3,4,6-trichloroguaiacol	3.64	3.53	2.76	2.12	1.71
14	3,5-dichlorosyringol	2.65	2.58	1.33	0.54	0.05
15	3,6-dichlorocatechol	-	-	-	-	-
16	4,5,6-trichloroguaiacol	2.76	2.12	1.86	1.01	0.92
17	tetrachloroguaiacol	3.26	3.1	2.74	2.57	1.34
18	3,4,6-trichlorocatechol	3.86	2.36	2.31	2.24	1.26
19	2,6-dichlorosyringaldehyde	5.25	4.95	4.61	4.23	3.65
20	5,6-dichlorovanillin	1.43	1.16	0.65	0.54	0.44
21	tetrachlorocatechol	8.75	8.32	7.82	6.18	5.37
22	2,3,4-trichlorophenol	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	61.42	50.58	44.27	38.21	29.74

C Stage bleaching conditions: Charge 5.1%, Temperature 30^{0}C, Consistency 3%

Table 4.312 Different chlorophenolic compounds formed in E stage at various pH values

		C stage pH				
S.No.	Chlorophenolic compounds(g/T)	**1.5**	**2.0**	**2.5**	**3.0**	**4.0**
1	2,4-dichlorophenol	3.27	2.34	0.94	0.69	0.04
2	3-chlorophenol	2.42	2.04	0.85	0.67	0.01
3	4-chloroguaiacol	-	-	-	-	-
4	5-chloroguaiacol	-	-	-	-	-
5	2,3,5-trichlorophenol	0.85	0.72	0.57	0.42	0.31
6	2,4,6-trichlorophenol	5.11	5.01	3.45	1.89	0.48
7	3,6-dichloroguaiacol	0.22	0.14	0.09	0.05	0.02
8	3,4dichlorocatechol	1.54	0.97	0.89	0.76	0.29
9	4,5-dichloroguaiacol	1.78	0.76	0.67	0.25	0.19
10	5,6-dichloroguaiacol	0.61	0.57	0.51	0.44	0.38
11	2,3,4,6-tetrachlorophenol	0.23	0.06	0.03	0.01	-
12	3,4,5-trichloroguaiacol	0.93	0.89	0.47	0.31	0.17
13	3,4,6-trichloroguaiacol	0.48	0.21	0.19	0.14	0.05
14	3,5-dichlorosyringol	1.37	1.12	0.96	0.87	0.17
15	3,6-dichlorocatechol	0.98	0.87	0.65	0.44	0.26
16	4,5,6-trichloroguaiacol	2.53	2.12	1.31	1.27	0.76
17	tetrachloroguaiacol	1.36	0.77	0.67	0.47	0.27
18	3,4,6-trichlorocatechol	1.88	1.74	0.74	0.57	0.15
19	2,6-dichlorosyringaldehyde	2.43	1.74	1.64	1.61	0.19
20	5,6-dichlorovanillin	2.86	2.23	1.42	1.24	0.94
21	tetrachlorocatechol	4.07	3.15	2.76	2.37	1.82
22	2,3,4-trichlorophenol	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	34.92	27.45	18.81	14.47	6.5

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.313 Different chlorophenolic compounds formed in H stage at various pH values

		C stage pH				
S.No.	Chlorophenolic compounds(g/T)	1.5	2.0	2.5	3.0	4.0
1	2,4-dichlorophenol	-	-	-	-	-
2	3-chlorophenol	0.10	0.09	0.02	0.01	0.003
3	4-chloroguaiacol	0.15	0.04	0.001	0.005	0.01
4	5-chloroguaiacol	0.01	0.01	0.005	0.003	0.001
5	2,3,5-trichlorophenol	-	-	-	-	-
6	2,4,6-trichlorophenol	0.84	0.78	0.63	0.57	0.42
7	3,6-dichloroguaiacol	-	-	-	-	-
8	3,4dichlorocatechol	-	-	-	-	-
9	4,5-dichloroguaiacol	0.35	0.28	0.13	0.05	0.01
10	5,6-dichloroguaiacol	0.33	0.07	0.01	0.01	0.004
11	2,3,4,6-tetrachlorophenol	-	-	-	-	-
12	3,4,5-trichloroguaiacol	-	-	-	-	-
13	3,4,6-trichloroguaiacol	-	-	-	-	-
14	3,5-dichlorosyringol	0.21	0.17	0.12	0.07	0.01
15	3,6-dichlorocatechol	-	-	-	-	-
16	4,5,6-trichloroguaiacol	-	-	-	-	-
17	tetrachloroguaiacol	0.31	0.27	0.15	0.09	0.02
18	3,4,6-trichlorocatechol	0.05	0.10	0.16	0.22	0.26
19	2,6-dichlorosyringaldehyde	-	-	-	-	-
20	5,6-dichlorovanillin	0.21	0.35	0.42	0.47	0.68
21	tetrachlorocatechol	0.87	0.54	0.36	0.27	0.07
22	2,3,4-trichlorophenol	0.21	0.11	0.07	0.04	0.03
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	3.64	2.81	2.08	1.81	1.52

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.314 Total chlorophenolic compounds formed in CEH bleaching at various pH values

		C stage pH				
S.No.	Chlorophenolic compounds(g/T)	1.5	2.0	2.5	3.0	4.0
1	2,4-dichlorophenol	8.19	6.31	4.78	4.45	2.56
2	3-chlorophenol	6.09	4.34	2.89	2.55	1.66
3	4-chloroguaiacol	0.15	0.04	0.001	0.005	0.01
4	5-chloroguaiacol	0.01	0.01	0.005	0.003	0.001
5	2,3,5-trichlorophenol	1.38	0.82	0.64	0.47	0.32
6	2,4,6-trichlorophenol	16.46	15.53	12.95	10.75	8.15
7	3,6-dichloroguaiacol	0.36	0.23	0.16	0.1	0.04
8	3,4dichlorocatechol	5.49	3.84	3.3	3.12	1.82
9	4,5-dichloroguaiacol	2.67	1.29	1.01	0.47	0.34
10	5,6-dichloroguaiacol	3.51	1.95	1.48	1.19	0.95
11	2,3,4,6-tetrachlorophenol	1.56	0.9	0.79	0.59	0.44
12	3,4,5-trichloroguaiacol	2.69	1.97	1.45	1.22	1.04
13	3,4,6-trichloroguaiacol	4.12	3.74	2.95	2.26	1.76
14	3,5-dichlorosyringol	4.23	3.87	2.41	1.48	0.23
15	3,6-dichlorocatechol	0.98	0.87	0.65	0.44	0.26
16	4,5,6-trichloroguaiacol	5.29	4.24	3.17	2.28	1.68
17	tetrachloroguaiacol	4.93	4.14	3.56	3.13	1.63
18	3,4,6-trichlorocatechol	5.79	4.2	3.21	3.03	1.67
19	2,6-dichlorosyringaldehyde	7.68	6.69	6.25	5.84	3.84
20	5,6-dichlorovanillin	4.5	3.74	2.49	2.25	2.06
21	tetrachlorocatechol	13.69	12.01	10.94	8.82	7.26
22	2,3,4-trichlorophenol	0.21	0.11	0.07	0.04	0.03
23	4,5-dichlorocatechol		-	-	-	-
	TOTAL	99.98	80.84	65.16	54.49	37.76

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Fig. 4.211

EFFECT OF C-STAGE pH ON C.O.D. GENERATION

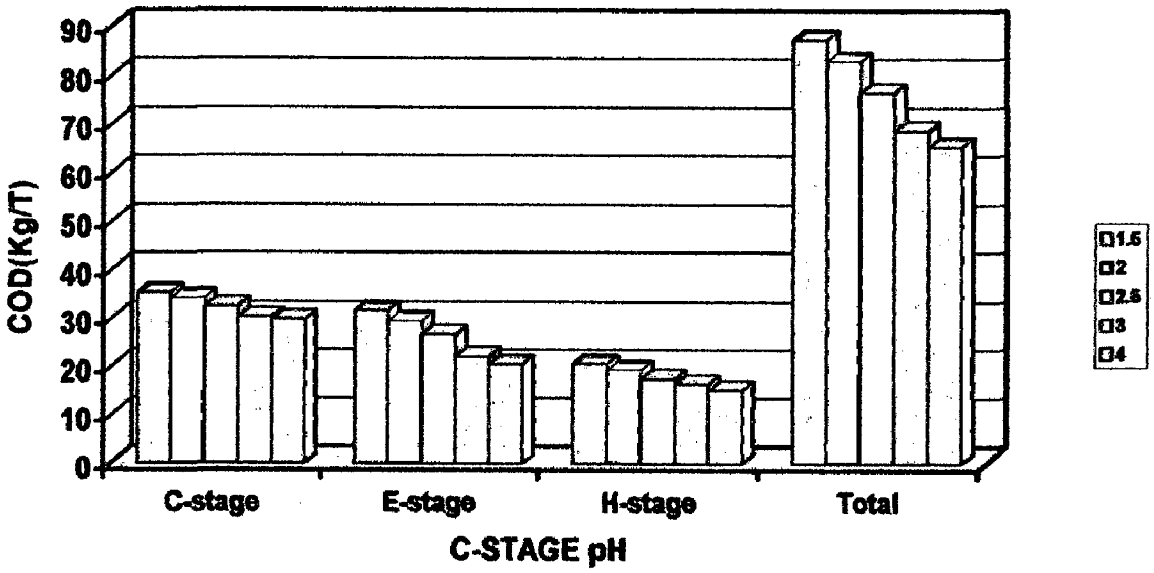


Fig. 4.212

EFFECT OF C-STAGE pH ON COLOR. GENERATION

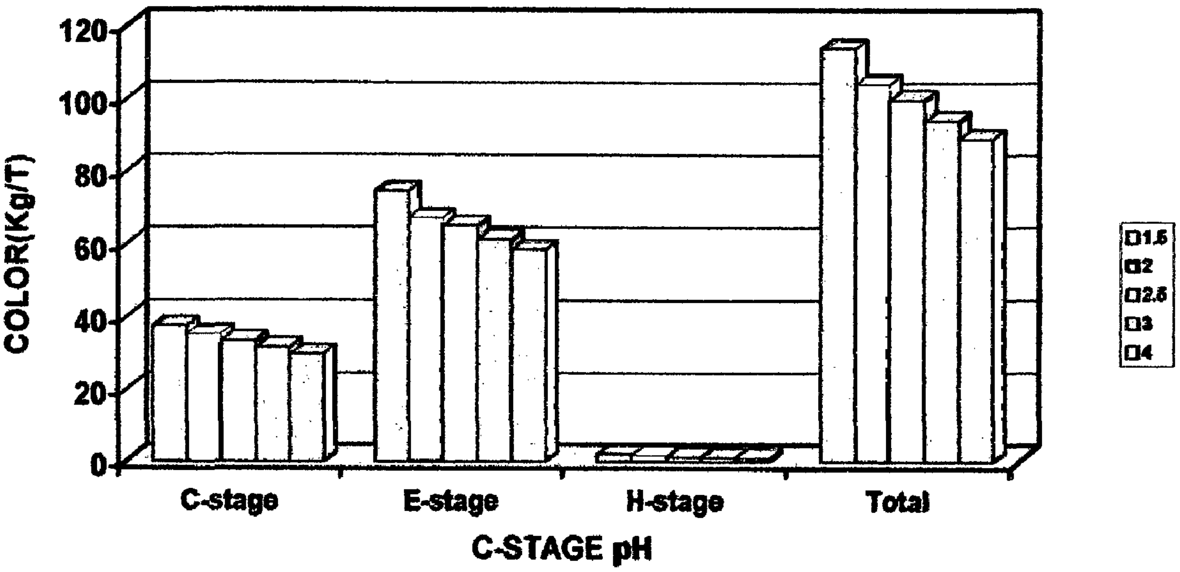


Fig. 4.213

EFFECT OF C-STAGE pH ON CHLOROPHENOL GENERATION

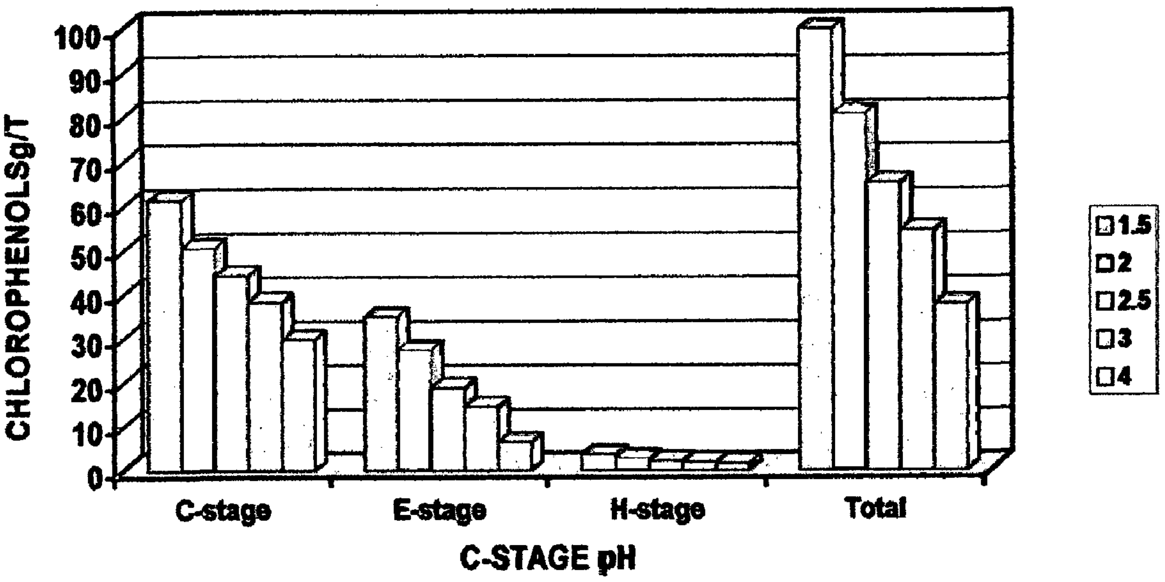


Fig. 4.214

EFFECT OF C-STAGE pH ON BRIGHTNESS & VISCOSITY

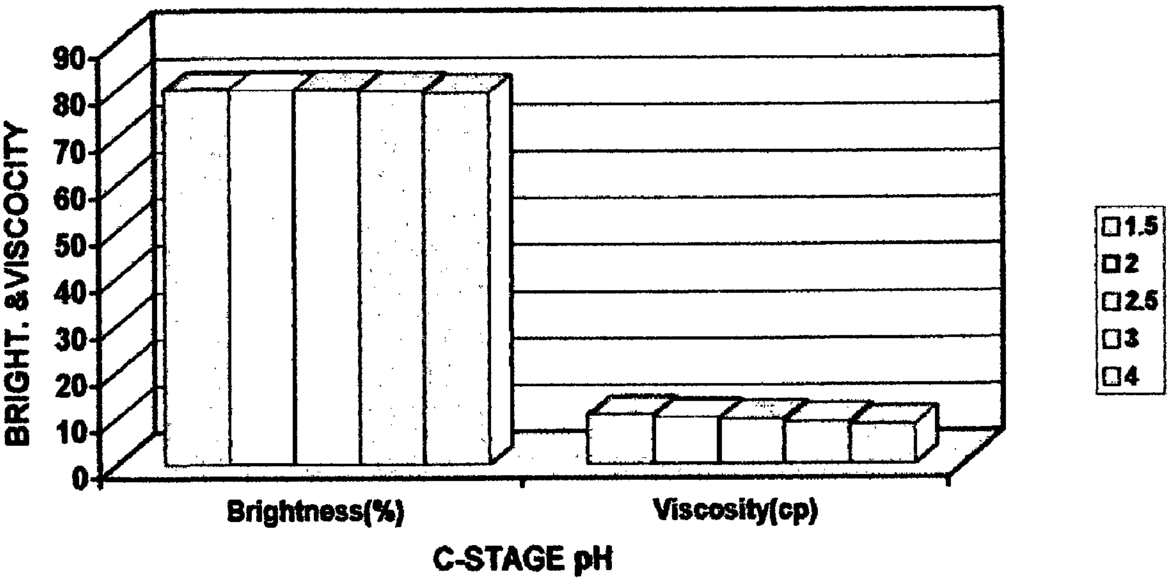


Table 4.116

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Temperature of 15^{0}C

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	1.05	0.02	0.67	0.03	-	-	1.72
2	3-chlorophenol	0.01	0.0002	1.29	0.05	0.04	0.002	1.34
3	4-chloroguaiacol	-	-	-	-	0.001	0.00004	0.001
4	5-chloroguaiacol	-	-	-	-	0.001	0.00004	0.001
5	2,3,5-trichlorophenol	0.01	0.0002	0.19	0.01	-	-	0.20
6	2,4,6-trichlorophenol	7.15	0.14	3.74	0.15	0.25	0.01	11.14
7	3,6-dichloroguaiacol	0.01	0.0002	0.25	0.01	-	-	0.26
8	3,4-dichlorocatechol	1.15	0.02	0.14	0.006	-	-	1.29
9	4,5-dichloroguaiacol	0.04	0.001	0.05	0.002	0.04	0.002	0.13
10	5,6-dichloroguaiacol	0.45	0.01	0.03	0.001	0.04	0.002	0.52
11	2,3,4,6-tetrachlorophenol	0.22	0.004	-	-	-	-	0.22
12	3,4,5-trichloroguaiacol	0.10	0.002	0.73	0.03	-	-	0.83
13	3,4,6-trichloroguaiacol	0.77	0.01	-	-	-	-	0.77
14	3,5-dichlorosyringol	0.39	0.01	0.19	0.01	0.07	0.003	0.65
15	3,6-dichlorocatechol	0.45	0.01	-	-	-	-	0.45
16	4,5,6-trichloroguaiacol	0.19	0.004	0.49	0.02	-	-	0.68
17	tetrachloroguaiacol	0.04	0.001	0.19	0.01	0.08	0.003	0.31
18	3,4,6-trichlorocatechol	0.42	0.01	0.67	0.03	0.01	0.0004	1.10
19	2,6-dichlorosyringaldehyde	1.22	0.02	1.33	0.05	-	-	2.55
20	5,6-dichlorovanillin	0.35	0.01	1.48	0.06	0.21	0.01	2.04
21	tetrachlorocatechol	2.96	0.06	1.63	0.06	0.27	0.01	4.86
22	2,3,4-trichlorophenol	-	-	-	-	0.01	0.0004	0.01
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	16.98	0.33	13.07	0.53	1.022	0.04	31.07

C Stage bleaching conditions: Charge 5.1%, pH 2, Consistency 3%

Table 4.117

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Temperature of 20^{0}C

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	1.87	0.04	1.57	0.06	-	-	3.44
2	3-chlorophenol	1.24	0.02	1.89	0.07	0.05	0.002	3.18
3	4-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01
4	5-chloroguaiacol	-	-	-	-	0.003	0.0001	0.003
5	2,3,5-trichlorophenol	0.03	0.001	0.37	0.01	-	-	0.40
6	2,4,6-trichlorophenol	8.10	0.16	4.32	0.17	0.56	0.02	12.98
7	3,6-dichloroguaiacol	0.04	0.001	0.19	0.01	-	-	0.23
8	3,4-dichlorocatechol	1.28	0.02	0.48	0.02	-	-	1.76
9	4,5-dichloroguaiacol	0.12	0.002	0.19	0.01	0.15	0.01	0.46
10	5,6-dichloroguaiacol	0.54	0.01	0.20	0.01	0.05	0.002	0.79
11	2,3,4,6-tetrachlorophenol	0.35	0.01	0.03	0.001	-	-	0.38
12	3,4,5-trichloroguaiacol	0.15	0.003	0.79	0.03	-	-	0.94
13	3,4,6-trichloroguaiacol	1.87	0.04	0.16	0.01	-	-	2.03
14	3,5-dichlorosyringol	0.89	0.02	0.79	0.03	0.11	0.004	1.79
15	3,6-dichlorocatechol	0.76	0.01	0.23	0.01	-	-	0.99
16	4,5,6-trichloroguaiacol	0.71	0.01	1.36	0.05	-	-	2.07
17	tetrachloroguaiacol	0.67	0.01	0.46	0.02	0.17	0.01	1.30
18	3,4,6-trichlorocatechol	0.65	0.01	0.81	0.03	0.06	0.002	1.52
19	2,6-dichlorosyringaldehyde	1.99	0.04	1.59	0.06	-	-	3.58
20	5,6-dichlorovanillin	0.71	0.01	1.79	0.07	0.32	0.01	2.82
21	tetrachlorocatechol	3.45	0.07	2.55	0.10	0.43	0.02	6.43
22	2,3,4-trichlorophenol	-		-	-	0.04	0.002	0.04
23	4,5-dichlorocatechol	-		-	-	-	-	-
	TOTAL	25.42	0.49	19.77	0.77	1.95	0.08	47.14

C Stage bleaching conditions: Charge 5.1%, pH 2, Consistency 3%

Table 4.118

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Temperature of 25^{0}C

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	2.19	0.04	2.39	0.09	-	-	4.58
2	3-chlorophenol	1.84	0.04	2.00	0.08	0.07	0.003	3.91
3	4-chloroguaiacol	-	-	-	-	0.02	0.0001	0.02
4	5-chloroguaiacol	-	-	-	-	0.005	0.0002	0.005
5	2,3,5-trichlorophenol	0.07	0.001	0.54	0.02	-	-	0.61
6	2,4,6-trichlorophenol	8.78	0.17	4.71	0.19	0.67	0.03	14.16
7	3,6-dichloroguaiacol	0.07	0.001	0.17	0.01	-	-	0.24
8	3,4-dichlorocatechol	1.66	0.03	0.83	0.03	-	-	2.49
9	4,5-dichloroguaiacol	0.19	0.004	0.64	0.02	0.23	0.01	1.06
10	5,6-dichloroguaiacol	0.65	0.01	0.25	0.01	0.06	0.002	0.96
11	2,3,4,6-tetrachlorophenol	0.57	0.01	0.04	0.002	-	-	0.61
12	3,4,5-trichloroguaiacol	0.58	0.01	0.84	0.03	-	-	1.42
13	3,4,6-trichloroguaiacol	2.63	0.05	0.19	0.01	-	-	2.82
14	3,5-dichlorosyringol	1.28	0.02	0.97	0.04	0.15	0.01	2.40
15	3,6-dichlorocatechol	-	-	0.37	0.01	-	-	0.37
16	4,5,6-trichloroguaiacol	0.96	0.02	1.72	0.07	-	-	2.68
17	tetrachloroguaiacol	2.75	0.05	0.54	0.02	0.22	0.01	3.51
18	3,4,6-trichlorocatechol	1.67	0.03	1.05	0.04	0.08	0.003	2.8
19	2,6-dichlorosyringaldehyde	3.05	0.06	1.67	0.07	-	-	4.72
20	5,6-dichlorovanillin	0.92	0.02	2.13	0.08	0.34	0.01	3.39
21	tetrachlorocatechol	4.37	0.09	2.97	0.12	0.55	0.02	7.89
22	2,3,4-trichlorophenol	-	-	-	-	0.09	0.004	0.09
23	4,5-dichlorocatechol	-	-	-	-	-	-	
	TOTAL	34.23	0.66	24.02	0.94	2.48	0.10	60.73

C Stage bleaching conditions: Charge 5.1%, pH 2, Consistency 3%

Table 4.119

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Temperature of 30^0C

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total	
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T	
1	2,4-dichlorophenol	3.97	0.08	2.34	0.09	-	0.01	6.31	
2	3-chlorophenol	2.21	0.04	2.04	0.08	0.09	0.02	4.34	
3	4-chloroguaiacol	-	-	-	-	0.04	0.004	0.04	
4	5-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01	
5	2,3,5-trichlorophenol	0.10	0.002	0.72	0.03	-	0.03	0.82	
6	2,4,6-trichlorophenol	9.74	0.19	5.01	0.2	0.78	-	15.53	
7	3,6-dichloroguaiacol	0.09	0.002	0.14	0.006	-	-	0.23	
8	3,4-dichlorocatechol	2.87	0.06	0.97	0.04	-	0.01	3.84	
9	4,5-dichloroguaiacol	0.25	0.005	0.76	0.03	0.28	0.003	1.29	
10	5,6-dichloroguaiacol	1.31	0.03	0.57	0.02	0.07	-	1.95	
11	2,3,4,6-tetrachlorophenol	0.84	0.02	0.06	0.002	-	-	0.90	
12	3,4,5-trichloroguaiacol	1.08	0.02	0.89	0.03	-	-	1.97	
13	3,4,6-trichloroguaiacol	3.53	0.07	0.21	0.01	-	0.007	3.74	
14	3,5-dichlorosyringol	2.58	0.05	1.12	0.04	0.17	-	3.87	
15	3,6-dichlorocatechol	-		0.87	0.03	-	-	0.87	
16	4,5,6-trichloroguaiacol	2.12	0.04	2.12	0.08	-	-	4.24	
17	tetrachloroguaiacol	3.10	0.06	0.77	0.03	0.27	0.01	4.14	
18	3,4,6-trichlorocatechol	2.36	0.05	1.74	0.07	0.10	0.004	4.20	
19	2,6-dichlorosyringaldehyde	4.95	0.1	1.74	0.07	-	-	6.69	
20	5,6-dichlorovanillin	1.16	0.02	2.23	0.09	0.35	0.01	3.74	
21	tetrachlorocatechol	8.32	0.17	3.15	0.13	0.54	0.02	12.01	
22	2,3,4-trichlorophenol	-		-	-	0.11	0.004	0.11	
23	4,5-dichlorocatechol	-		-	-	-	-	-	
	TOTAL	50.58	1.01	27.45	1.08	2.81	0.10	80.84	

C Stage bleaching conditions: Charge 5.1%, pH 2, Consistency 3%

Table 4.120

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Temperature of 35^{0}C

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	4.15	0.08	3.07	0.12	-	-	7.22
2	3-chlorophenol	2.46	0.05	2.76	0.11	0.21	0.01	5.43
3	4-chloroguaiacol	-	-	-	-	0.08	0.003	0.08
4	5-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01
5	2,3,5-trichlorophenol	1.10	0.02	0.87	0.03	-	-	1.97
6	2,4,6-trichlorophenol	9.97	0.20	5.94	0.24	0.84	0.03	16.75
7	3,6-dichloroguaiacol	0.25	0.005	0.09	0.004	-	-	0.34
8	3,4-dichlorocatechol	2.96	0.06	1.54	0.06	-	-	4.50
9	4,5-dichloroguaiacol	0.37	0.01	0.97	0.04	0.31	0.01	1.65
10	5,6-dichloroguaiacol	1.39	0.03	0.65	0.03	0.12	0.005	2.16
11	2,3,4,6-tetrachlorophenol	0.96	0.02	0.31	0.01	-	-	1.27
12	3,4,5-trichloroguaiacol	1.54	0.03	1.32	0.05	-	-	2.86
13	3,4,6-trichloroguaiacol	3.07	0.06	0.63	0.02	-	-	3.70
14	3,5-dichlorosyringol	2.97	0.06	1.62	0.06	0.21	0.01	4.80
15	3,6-dichlorocatechol	-	-	2.44	0.10	-	-	2.44
16	4,5,6-trichloroguaiacol	2.57	0.05	2.32	0.09	-	-	4.89
17	tetrachloroguaiacol	3.18	0.06	2.17	0.09	0.33	0.01	5.68
18	3,4,6-trichlorocatechol	2.47	0.05	1.85	0.07	0.11	0.004	4.43
19	2,6-dichlorosyringaldehyde	5.57	0.11	1.87	0.07	-	-	7.44
20	5,6-dichlorovanillin	1.83	0.04	2.29	0.09	0.57	0.02	4.69
21	tetrachlorocatechol	8.73	0.17	5.56	0.22	0.72	0.03	15.01
22	2,3,4-trichlorophenol	-	-	-	-	0.10	0.004	0.1
23	4,5-dichlorocatechol	-	-	-	-	-	-	
	TOTAL	55.54	1.10	38.27	1.50	3.61	0.14	97.42

C Stage bleaching conditions: Charge 5.1%, pH 2, Consistency 3%

Table 4.221 Effect of change in C Stage temperature on the generation of Chlorophenolic compounds

	Chlorophenolic compounds (kg/t)			
Temperature^{0}C	C-stage	E-stage	H-stage	TOTAL
15	16.98	13.07	1.02	31.07
20	25.42	19.77	1.95	47.14
25	34.23	24.02	2.48	60.73
30	50.58	27.45	2.81	80.84
35	55.54	38.27	3.61	97.42

Table 4.222 Effect of change in C Stage temperature on the generation of effluent COD

	COD (kg/t)			
Temperature^{0}C	C-stage	E-stage	H-stage	TOTAL
15	28.4	20.4	14.8	63.6
20	31.6	23.4	16.3	71.3
25	32.7	25.8	17.6	76.1
30	34.2	29.4	19.4	83.0
35	35.1	31.2	21.3	87.6

Table 4.223 Effect of change in C Stage temperature on the generation of effluent Colour

	Colour (kg/t)			
Temperature^{0}C	C-stage	E-stage	H-stage	TOTAL
15	19.6	58.6	0.8	79
20	31.4	60.4	1.0	92.8
25	33.7	63.8	1.2	98.7
30	35.3	67.3	1.7	104.3
35	37.8	71.2	1.8	110.8

Table 4.224 Effect of change in C Stage temperature on Brightness and Viscosity of bleached pulps obtained by CEH bleaching

Temperature^{0}C	Brightness (%)	Viscosity (cp)
15	79.9	10.4
20	80.3	10.3
25	80.2	10.2
30	80.1	10.1
35	80.1	8.9

Table 4.225 Monochlorophenolic compounds present in different effluents formed by bleaching at various C Stage temperature

Monochlorophenolic compounds (g/t)				
Temperature(⁰C)	C-stage	E-stage	H-stage	TOTAL
15	0.01	1.29	0.04	1.34
20	1.24	1.89	0.06	3.19
25	1.84	2.00	0.09	3.93
30	2.21	2.04	0.14	4.39
35	2.46	2.76	0.30	5.52

Table 4.226 Dichlorophenolic compounds present in different effluents formed by bleaching at various C Stage temperature

Dichlorophenolic compounds (g/t)				
Temperature(⁰C)	C-stage	E-stage	H-stage	TOTAL
15	5.11	4.14	0.04	9.29
20	8.20	7.03	0.06	15.29
25	10.01	9.42	0.09	19.52
30	17.18	10.74	0.14	28.06
35	19.49	14.54	0.3	34.33

Table 4.227 Trichlorophenolic compounds present in different effluents formed by bleaching at various C Stage temperature

Trichlorophenolic compounds (g/t)				
Temperature(⁰C)	C-stage	E-stage	H-stage	TOTAL
15	8.64	5.82	0.27	14.73
20	11.51	7.81	0.66	19.98
25	14.69	9.05	0.84	24.58
30	18.93	10.69	0.99	30.61
35	20.72	12.93	1.05	34.70

Table 4.228 Tetrachlorophenolic compounds present in different effluents formed by bleaching at various C Stage temperature

Tetrachlorophenolic compounds (g/t)				
Temperature(⁰C)	C-stage	E-stage	H-stage	TOTAL
15	3.22	1.82	0.35	5.39
20	4.47	3.04	0.60	8.11
25	7.69	3.55	0.77	12.01
30	12.26	3.98	0.81	17.05
35	12.87	8.04	1.05	21.96

Table 4.229 Category wise load of chlorophenols in different effluents formed by bleaching at various C Stage temperature

Chlorophenols (g/t)				
Temperature(°C)	C-stage	E-stage	H-stage	TOTAL
15	8.44	5.89	0.3	14.63
20	11.59	8.18	0.65	20.42
25	13.45	9.68	0.83	23.96
30	16.86	10.17	0.98	28.01
35	18.64	12.95	1.15	32.74

Table 4.230 Category wise load of chloroguaiacols in different effluents formed by bleaching at various C Stage temperature

Chloroguaiacols (g/t)				
Temperature(°C)	C-stage	E-stage	H-stage	TOTAL
15	1.60	1.74	0.16	3.50
20	4.10	3.35	0.38	7.83
25	7.83	4.35	0.53	12.71
30	11.48	5.46	0.67	17.61
35	12.37	8.15	0.85	21.37

Table 4.231 Category wise load of chlorocatechols in different effluents formed by bleaching at various C Stage temperature

Chlorocatechols (g/t)				
Temperature(°C)	C-stage	E-stage	H-stage	TOTAL
15	4.98	2.44	0.28	7.70
20	6.14	4.07	0.49	10.70
25	7.70	5.22	0.63	13.55
30	13.55	6.73	0.64	20.92
35	14.16	11.39	0.83	26.38

Table 4.232 Category wise load of other chlorophenolic compounds in different effluents formed by bleaching at various C Stage temperature

Other Chlorophenolic compounds (g/t)				
Temperature(°C)	C-stage	E-stage	H-stage	TOTAL
15	1.96	3.00	0.28	5.24
20	3.59	4.17	0.43	8.19
25	5.25	4.77	0.49	10.51
30	8.69	5.09	0.52	14.30
35	10.37	5.78	0.78	16.93

Table 4.315 Different chlorophenolic compounds formed in C stage at various temperature

		C stage Temperature(⁰C)				
S.No.	Chlorophenolic compounds(g/T)	15	20	25	30	35
1	2,4-dichlorophenol	1.05	1.87	2.19	3.97	4.15
2	3-chlorophenol	0.01	1.24	1.84	2.21	2.46
3	4-chloroguaiacol	-	-	-	-	-
4	5-chloroguaiacol	-	-	-	-	-
5	2,3,5-trichlorophenol	0.01	0.03	0.07	0.10	1.10
6	2,4,6-trichlorophenol	7.15	8.10	8.78	9.74	9.97
7	3,6-dichloroguaiacol	0.01	0.04	0.07	0.09	0.25
8	3,4dichlorocatechol	1.15	1.28	1.66	2.87	2.96
9	4,5-dichloroguaiacol	0.04	0.12	0.19	0.25	0.37
10	5,6-dichloroguaiacol	0.45	0.54	0.65	1.31	1.39
11	2,3,4,6-tetrachlorophenol	0.22	0.35	0.57	0.84	0.96
12	3,4,5-trichloroguaiacol	0.1	0.15	0.58	1.08	1.54
13	3,4,6-trichloroguaiacol	0.77	1.87	2.63	3.53	3.07
14	3,5-dichlorosyringol	0.39	0.89	1.28	2.58	2.97
15	3,6-dichlorocatechol	0.45	0.76	-	-	-
16	4,5,6-trichloroguaiacol	0.19	0.71	0.96	2.12	2.57
17	tetrachloroguaiacol	0.04	0.67	2.75	3.10	3.18
18	3,4,6-trichlorocatechol	0.42	0.65	1.67	2.36	2.47
19	2,6-dichlorosyringaldehyde	1.22	1.99	3.05	4.95	5.57
20	5,6-dichlorovanillin	0.35	0.71	0.92	1.16	1.83
21	tetrachlorocatechol	2.96	3.45	4.37	8.32	8.73
22	2,3,4-trichlorophenol	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	16.98	25.42	34.23	50.58	55.54

C Stage bleaching conditions: Charge 5.1%, pH 2, Consistency 3%

Table 4.316 Different chlorophenolic compounds formed in E stage at various temperature

		C stage Temperature(^{0}C)				
S.No.	Chlorophenolic compounds(g/T)	15	20	25	30	35
1	2,4-dichlorophenol	0.67	1.57	2.39	2.34	3.07
2	3-chlorophenol	1.29	1.89	2.00	2.04	2.76
3	4-chloroguaiacol	-	-	-	-	-
4	5-chloroguaiacol	-	-	-	-	-
5	2,3,5-trichlorophenol	0.19	0.37	0.54	0.72	0.87
6	2,4,6-trichlorophenol	3.74	4.32	4.71	5.01	5.94
7	3,6-dichloroguaiacol	0.25	0.19	0.17	0.14	0.09
8	3,4dichlorocatechol	0.14	0.48	0.83	0.97	1.54
9	4,5-dichloroguaiacol	0.05	0.19	0.64	0.76	0.97
10	5,6-dichloroguaiacol	0.03	0.2	0.25	0.57	0.65
11	2,3,4,6-tetrachlorophenol	-	0.03	0.04	0.06	0.31
12	3,4,5-trichloroguaiacol	0.73	0.79	0.84	0.89	1.32
13	3,4,6-trichloroguaiacol	-	0.16	0.19	0.21	0.63
14	3,5-dichlorosyringol	0.19	0.79	0.97	1.12	1.62
15	3,6-dichlorocatechol	-	0.23	0.37	0.87	2.44
16	4,5,6-trichloroguaiacol	0.49	1.36	1.72	2.12	2.32
17	tetrachloroguaiacol	0.19	0.46	0.54	0.77	2.17
18	3,4,6-trichlorocatechol	0.67	0.81	1.05	1.74	1.85
19	2,6-dichlorosyringaldehyde	1.33	1.59	1.67	1.74	1.87
20	5,6-dichlorovanillin	1.48	1.79	2.13	2.23	2.29
21	tetrachlorocatechol	1.63	2.55	2.97	3.15	5.56
22	2,3,4-trichlorophenol	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	13.07	19.77	24.02	27.45	38.27

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.317 Different chlorophenolic compounds formed in H stage at various temperature

C stage Temperature(^{0}C)						
S.No.	Chlorophenolic compounds(g/T)	**15**	**20**	**25**	**30**	**35**
1	2,4-dichlorophenol	-	-	-	-	-
2	3-chlorophenol	0.04	0.05	0.07	0.09	0.21
3	4-chloroguaiacol	0.001	0.01	0.02	0.04	0.08
4	5-chloroguaiacol	0.001	0.003	0.005	0.01	0.01
5	2,3,5-trichlorophenol	-	-	-	-	-
6	2,4,6-trichlorophenol	0.25	0.56	0.67	0.78	0.84
7	3,6-dichloroguaiacol	-	-	-	-	-
8	3,4dichlorocatechol	-	-	-	-	-
9	4,5-dichloroguaiacol	0.04	0.15	0.23	0.28	0.31
10	5,6-dichloroguaiacol	0.04	0.05	0.06	0.07	0.12
11	2,3,4,6-tetrachlorophenol	-	-	-	-	-
12	3,4,5-trichloroguaiacol	-	-	-	-	-
13	3,4,6-trichloroguaiacol	-	-	-	-	-
14	3,5-dichlorosyringol	0.07	0.11	0.15	0.17	0.21
15	3,6-dichlorocatechol	-	-	-	-	-
16	4,5,6-trichloroguaiacol	-	-	-	-	-
17	tetrachloroguaiacol	0.08	0.17	0.22	0.27	0.33
18	3,4,6-trichlorocatechol	0.01	0.06	0.08	0.10	0.11
19	2,6-dichlorosyringaldehyde	-	-	-	-	-
20	5,6-dichlorovanillin	0.21	0.32	0.34	0.35	0.57
21	tetrachlorocatechol	0.27	0.43	0.55	0.54	0.72
22	2,3,4-trichlorophenol	0.01	0.04	0.09	0.11	0.10
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	1.02	1.95	2.48	2.81	3.61

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.318 Total chlorophenolic compounds formed in CEH bleaching at various temperature

C stage Temperature(^{0}C)						
S.No.	Chlorophenolic compounds(g/T)	15	20	25	30	35
1	2,4-dichlorophenol	1.72	3.44	4.58	6.31	7.22
2	3-chlorophenol	1.34	3.18	3.91	4.34	5.43
3	4-chloroguaiacol	0.001	0.01	0.02	0.04	0.08
4	5-chloroguaiacol	0.001	0.003	0.005	0.01	0.01
5	2,3,5-trichlorophenol	0.20	0.40	0.61	0.82	1.97
6	2,4,6-trichlorophenol	11.14	12.98	14.16	15.53	16.75
7	3,6-dichloroguaiacol	0.26	0.23	0.24	0.23	0.34
8	3,4dichlorocatechol	1.29	1.76	2.49	3.84	4.5
9	4,5-dichloroguaiacol	0.13	0.46	1.06	1.29	1.65
10	5,6-dichloroguaiacol	0.52	0.79	0.96	1.95	2.16
11	2,3,4,6-tetrachlorophenol	0.22	0.38	0.61	0.9	1.27
12	3,4,5-trichloroguaiacol	0.83	0.94	1.42	1.97	2.86
13	3,4,6-trichloroguaiacol	0.77	2.03	2.82	3.74	3.70
14	3,5-dichlorosyringol	0.65	1.79	2.40	3.87	4.80
15	3,6-dichlorocatechol	0.45	0.99	0.37	0.87	2.44
16	4,5,6-trichloroguaiacol	0.68	2.07	2.68	4.24	4.89
17	tetrachloroguaiacol	0.31	1.30	3.51	4.14	5.68
18	3,4,6-trichlorocatechol	1.10	1.52	2.8	4.20	4.43
19	2,6-dichlorosyringaldehyde	2.55	3.58	4.72	6.69	7.44
20	5,6-dichlorovanillin	2.04	2.82	3.39	3.74	4.69
21	tetrachlorocatechol	4.86	6.43	7.89	12.01	15.01
22	2,3,4-trichlorophenol	0.01	0.04	0.09	0.11	0.10
23	4,5-dichlorocatechol					
	TOTAL	31.07	47.14	60.73	80.84	97.42

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Fig. 4.215

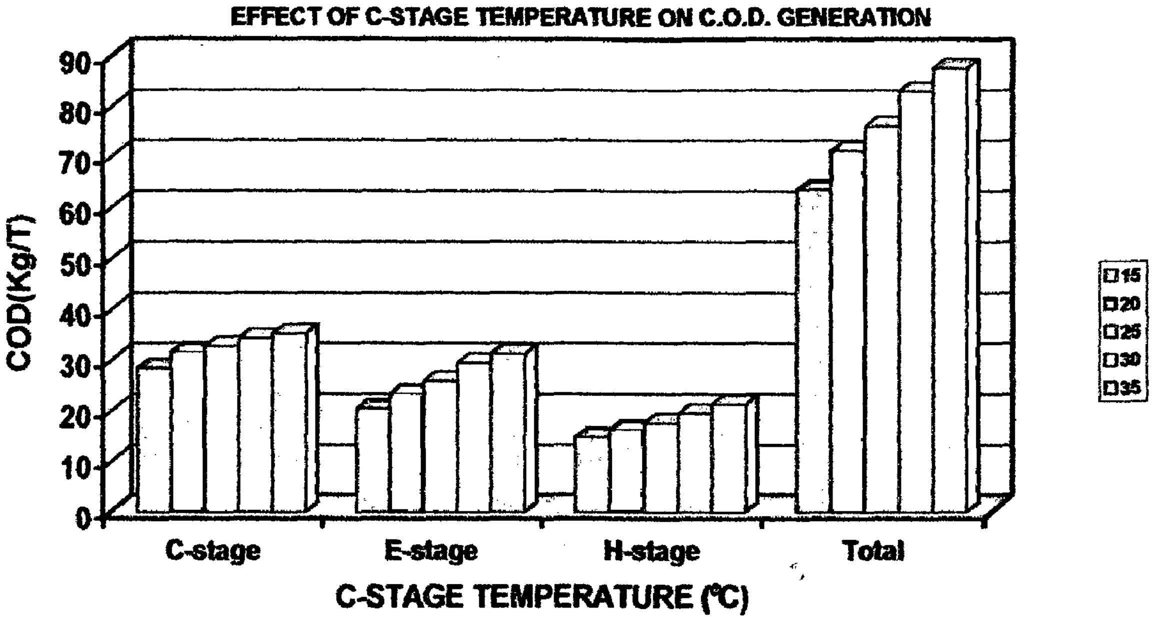


Fig. 4.216

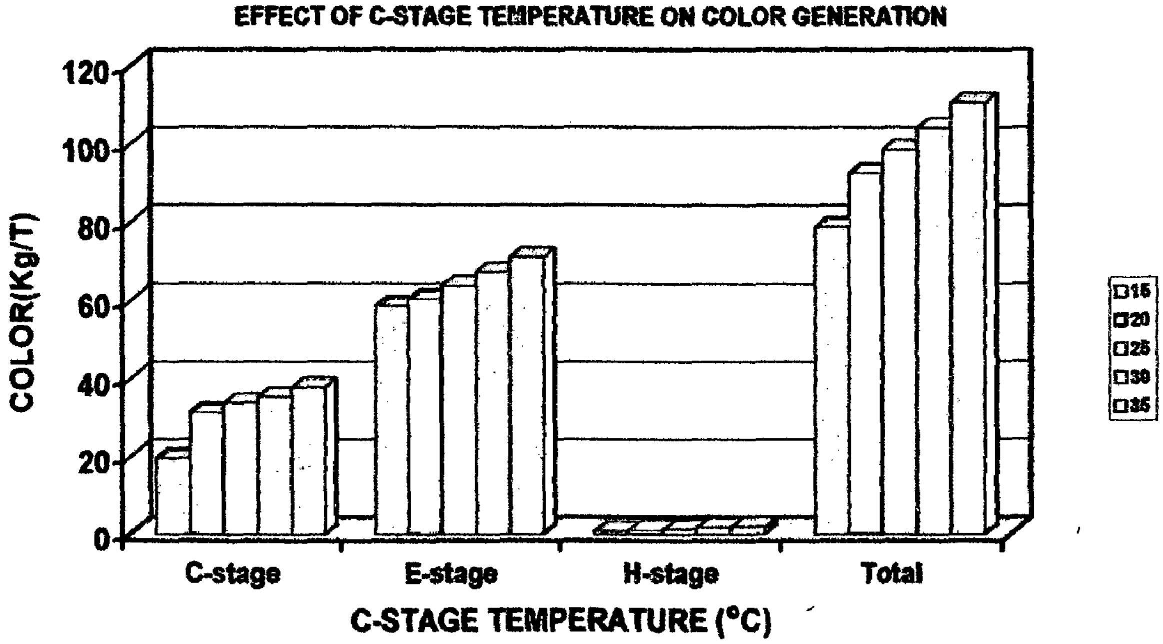


Fig. 4.217

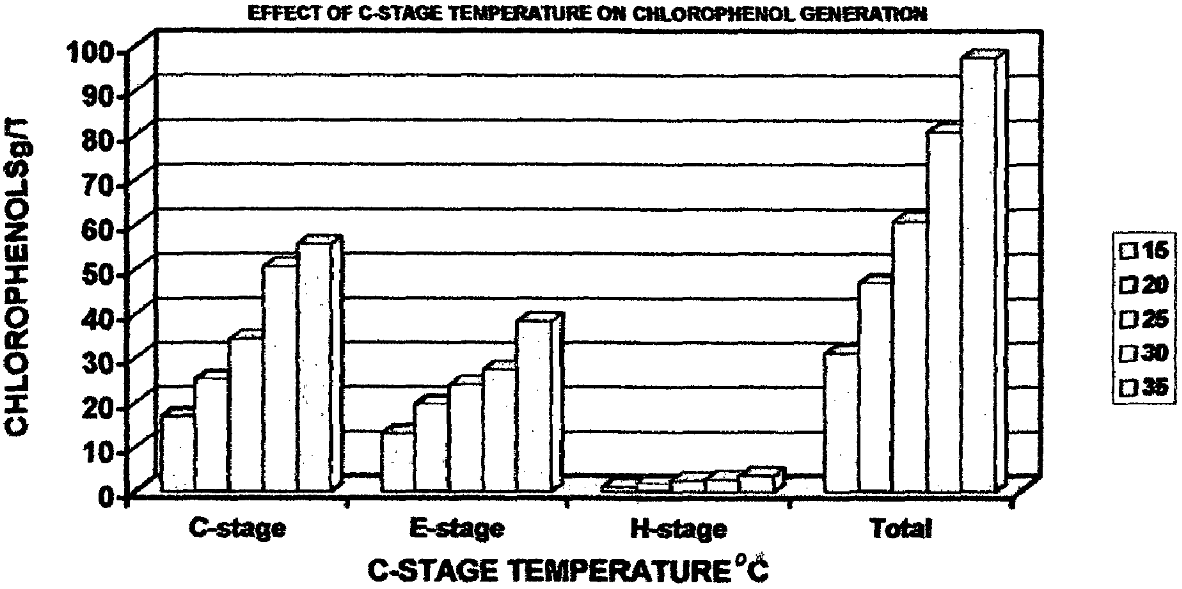


Fig. 4.218

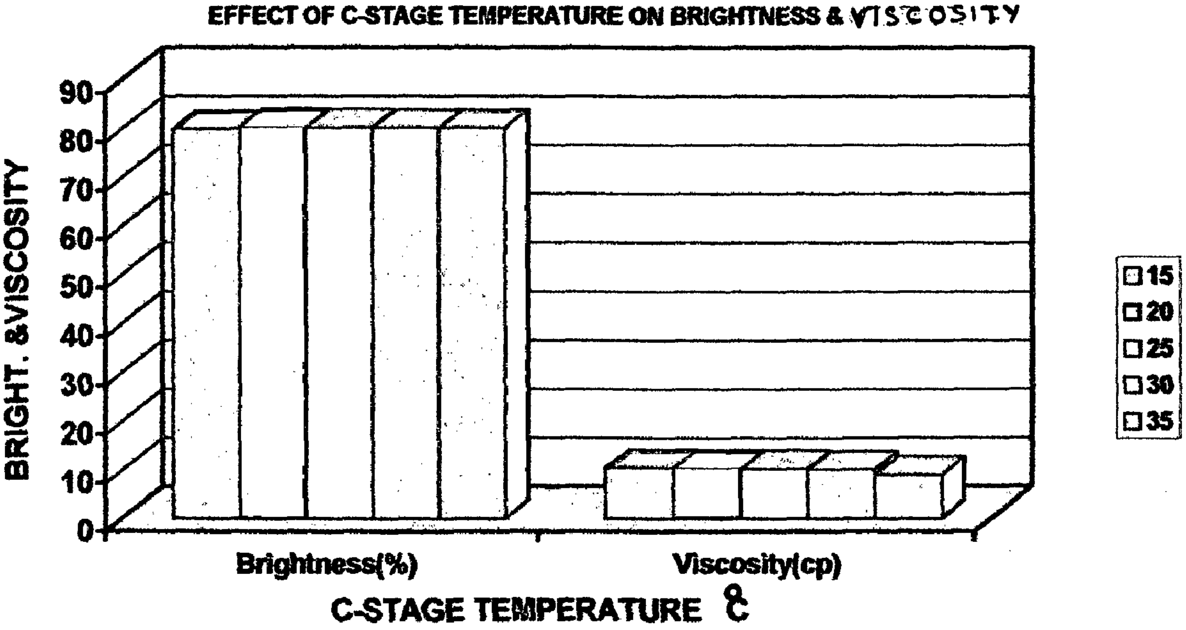


Table 4.121

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Consistency of 2.5%

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	1.97	0.04	1.64	0.06	-	-	3.61
2	3-chlorophenol	0.45	0.01	1.37	0.05	0.01	0.0004	1.83
3	4-chloroguaiacol	-	-	-	-	0.001	0.00004	0.001
4	5-chloroguaiacol	-	-	-	-	0.005	0.0002	0.005
5	2,3,5-trichlorophenol	0.04	0.001	-	-	-	-	0.04
6	2,4,6-trichlorophenol	1.97	0.04	3.14	0.12	0.19	0.01	5.3
7	3,6-dichloroguaiacol	0.04	0.001	0.05	0.002	-	-	0.09
8	3,4-dichlorocatechol	2.92	0.06	0.39	0.01	-	-	3.31
9	4,5-dichloroguaiacol	0.12	0.002	0.14	0.005	0.01	0.0004	0.27
10	5,6-dichloroguaiacol	1.26	0.02	0.19	0.01	0.04	0.002	1.49
11	2,3,4,6-tetrachlorophenol	0.72	0.01	0.01	0.0004	-	-	0.73
12	3,4,5-trichloroguaiacol	0.48	0.01	0.76	0.031	-	-	1.24
13	3,4,6-trichloroguaiacol	3.64	0.07	0.02	0.0001	-	-	3.66
14	3,5-dichlorosyringol	2.64	0.05	0.11	0.004	0.02	0.001	2.77
15	3,6-dichlorocatechol	-	-	0.46	0.02	-	-	0.46
16	4,5,6-trichloroguaiacol	0.22	0.004	0.01	0.0004	-	-	0.23
17	tetrachloroguaiacol	1.42	0.03	0.18	0.01	0.03	0.001	1.63
18	3,4,6-trichlorocatechol	0.92	0.02	0.16	0.01	-	-	1.08
19	2,6-dichlorosyringaldehyde	1.24	0.02	1.35	0.05	-	-	2.59
20	5,6-dichlorovanillin	0.97	0.02	0.31	0.01	-	-	1.28
21	tetrachlorocatechol	3.96	0.08	2.76	0.11	0.25	0.01	6.97
22	2,3,4-trichlorophenol	-	-	-	-	0.06	0.002	0.06
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	24.98	0.49	13.05	0.50	0.62	0.03	38.65

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C

Table 4.122

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Consistency of 3%

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	3.97	0.08	2.34	0.09	-	0.01	6.31
2	3-chlorophenol	2.21	0.04	2.04	0.08	0.09	0.02	4.34
3	4-chloroguaiacol	-	-	-	-	0.04	0.004	0.04
4	5-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01
5	2,3,5-trichlorophenol	0.10	0.002	0.72	0.03	-	0.03	0.82
6	2,4,6-trichlorophenol	9.74	0.19	5.01	0.2	0.78	-	15.53
7	3,6-dichloroguaiacol	0.09	0.002	0.14	0.006	-	-	0.23
8	3,4-dichlorocatechol	2.87	0.06	0.97	0.04	-	0.01	3.84
9	4,5-dichloroguaiacol	0.25	0.005	0.76	0.03	0.28	0.003	1.29
10	5,6-dichloroguaiacol	1.31	0.03	0.57	0.02	0.07	-	1.95
11	2,3,4,6-tetrachlorophenol	0.84	0.02	0.06	0.002	-	-	0.90
12	3,4,5-trichloroguaiacol	1.08	0.02	0.89	0.03	-	-	1.97
13	3,4,6-trichloroguaiacol	3.53	0.07	0.21	0.01	-	0.007	3.74
14	3,5-dichlorosyringol	2.58	0.05	1.12	0.04	0.17	-	3.87
15	3,6-dichlorocatechol	-		0.87	0.03	-	-	0.87
16	4,5,6-trichloroguaiacol	2.12	0.04	2.12	0.08	-	-	4.24
17	tetrachloroguaiacol	3.10	0.06	0.77	0.03	0.27	0.01	4.14
18	3,4,6-trichlorocatechol	2.36	0.05	1.74	0.07	0.10	0.004	4.20
19	2,6-dichlorosyringaldehyde	4.95	0.1	1.74	0.07	-	-	6.69
20	5,6-dichlorovanillin	1.16	0.02	2.23	0.09	0.35	0.01	3.74
21	tetrachlorocatechol	8.32	0.17	3.15	0.13	0.54	0.02	12.01
22	2,3,4-trichlorophenol	-		-	-	0.11	0.004	0.11
23	4,5-dichlorocatechol	-		-	-	-	-	-
	TOTAL	50.58	1.01	27.45	1.08	2.81	0.10	80.84

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C

Table 4.123

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Consistency of 3.5%

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	4.95	0.10	3.15	0.13	-	-	8.10
2	3-chlorophenol	2.87	0.06	2.34	0.09	0.44	0.02	5.65
3	4-chloroguaiacol	-	-	-	-	0.05	0.002	0.05
4	5-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01
5	2,3,5-trichlorophenol	0.13	0.003	0.86	0.03	-	-	0.99
.6	2,4,6-trichlorophenol	10.19	0.20	5.48	0.22	0.83	0.03	16.5
7	3,6-dichloroguaiacol	0.18	0.004	0.29	0.01	-	-	0.47
8	3,4-dichlorocatechol	0.69	0.01	1.74	0.07	-	-	2.43
9	4,5-dichloroguaiacol	1.46	0.03	1.13	0.04	0.35	0.01	2.94
10	5,6-dichloroguaiacol	1.44	0.03	0.64	0.02	0.16	0.01	2.24
11	2,3,4,6-tetrachlorophenol	0.97	0.02	0.17	0.01	-	-	1.14
12	3,4,5-trichloroguaiacol	1.64	0.03	1.04	0.04	-	-	2.68
13	3,4,6-trichloroguaiacol	1.44	0.03	0.53	0.02	-	-	1.97
14	3,5-dichlorosyringol	1.12	0.02	1.62	0.06	0.25	0.01	2.99
15	3,6-dichlorocatechol	-	-	0.81	0.03	-	-	0.81
16	4,5,6-trichloroguaiacol	2.49	0.05	2.49	0.10	-	-	4.98
17	tetrachloroguaiacol	3.51	0.07	1.35	0.05	0.30	0.01	5.16
18	3,4,6-trichlorocatechol	2.44	0.05	1.96	0.08	0.19	0.01	4.59
19	2,6-dichlorosyringaldehyde	5.03	0.10	1.84	0.07	-	-	6.87
20	5,6-dichlorovanillin	1.21	0.02	2.86	0.11	0.72	0.03	4.79
21	tetrachlorocatechol	9.88	0.20	4.36	0.17	0.75	0.03	14.99
22	2,3,4-trichlorophenol	-	-	-	-	0.13	0.005	0.13
23	4,5-dichlorocatechol	-	-	-	-	-	-	
	TOTAL	51.64	1.03	34.66	1.35	4.18	0.17	90.48

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C

Table 4.124

Formation of different chlorophenolic compounds in various effluents by bleaching at C Stage Consistency of 4%

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	5.56	0.11	3.45	0.14	-	-	9.01
2	3-chlorophenol	3.91	0.08	4.06	0.16	0.83	0.03	8.80
3	4-chloroguaiacol	-	-	-	-	0.08	0.003	0.08
4	5-chloroguaiacol	-	-	-	-	0.43	0.02	0.43
5	2,3,5-trichlorophenol	0.17	0.003	0.95	0.04	-	-	1.12
6	2,4,6-trichlorophenol	11.42	0.23	6.41	0.26	0.82	0.03	18.65
7	3,6-dichloroguaiacol	0.27	0.005	0.32	0.01	-	-	0.59
8	3,4-dichlorocatechol	0.40	0.01	2.24	0.09	-	-	2.64
9	4,5-dichloroguaiacol	1.68	0.03	2.18	0.09	0.54	0.02	4.40
10	5,6-dichloroguaiacol	1.56	0.03	0.81	0.03	0.21	0.01	2.58
11	2,3,4,6-tetrachlorophenol	1.13	0.02	0.35	0.01	-	-	1.48
12	3,4,5-trichloroguaiacol	2.42	0.05	2.12	0.08	-	-	4.54
13	3,4,6-trichloroguaiacol	1.07	0.02	0.82	0.03	-	-	1.89
14	3,5-dichlorosyringol	0.74	0.01	2.30	0.09	0.27	0.01	3.31
15	3,6-dichlorocatechol	-	-	1.62	0.06	-	-	1.62
16	4,5,6-trichloroguaiacol	2.67	0.05	3.04	0.12	-	-	5.71
17	tetrachloroguaiacol	3.76	0.07	2.71	0.11	0.49	0.02	6.96
18	3,4,6-trichlorocatechol	2.59	0.05	3.32	0.13	0.23	0.01	6.14
19	2,6-dichlorosyringaldehyde	5.49	0.11	2.15	0.09	-	-	7.64
20	5,6-dichlorovanillin	1.33	0.03	3.21	0.13	0.84	0.03	5.38
21	tetrachlorocatechol	11.27	0.22	5.10	0.20	0.81	0.03	17.18
22	2,3,4-trichlorophenol	-	-	-	-	0.15	0.01	0.15
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	57.44	1.13	47.16	1.87	5.70	0.22	110.3

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C

Table 4.233 Effect of change in C Stage consistency on the generation of Chlorophenolic compounds

Chlorophenolic compounds (kg/t)				
Consistency (%)	C-stage	E-stage	H-stage	TOTAL
2.5	24.98	13.05	0.62	38.65
3.0	50.58	27.45	2.81	80.84
3.5	51.64	34.66	4.18	90.48
4.0	57.44	47.16	5.70	110.3

Table 4.234 Effect of change in C Stage consistency on the generation of effluent COD

COD (kg/t)				
Consistency (%)	C-stage	E-stage	H-stage	TOTAL
2.5	29.7	21.6	17.6	68.9
3.0	34.2	29.4	19.4	83.0
3.5	35.7	31.3	20.4	87.4
4.0	37.2	33.7	21.9	92.8

Table 4.235 Effect of change in C Stage consistency on the generation of effluent Colour

Colour (kg/t)				
Consistency (%)	C-stage	E-stage	H-stage	TOTAL
2.5	27.5	60.8	1.0	89.3
3.0	35.3	67.3	1.7	104.3
3.5	40.3	71.6	1.8	113.7
4.0	42.6	75.2	2.0	119.8

Table 4.236 Effect of change in C Stage consistency on Brightness and Viscosity of bleached pulps obtained by CEH bleaching

Consistency (%)	Brightness (%)	Viscosity (cp)
2.5	79.9	10.4
3.0	80.1	10.1
3.5	80.3	9.6
4.0	80.6	9.3

Table 4.237 Monochlorophenolic compounds present in different effluents formed by bleaching at various C Stage consistency

Monochlorophenolic compounds (g/t)				
Consistency (%)	C-stage	E-stage	H-stage	TOTAL
15	0.45	1.37	0.02	1.84
20	2.21	2.04	0.14	4.39
25	2.87	2.34	0.50	5.71
30	3.91	4.06	1.34	9.31
35	0.45	1.37	0.02	1.84

Table 4.238 Dichlorophenolic compounds present in different effluents formed by bleaching at various C Stage consistency

Dichlorophenolic compounds (g/t)				
Consistency (%))	C-stage	E-stage	H-stage	TOTAL
2.5	11.16	4.64	0.02	15.82
3.0	17.18	10.74	0.14	28.06
3.5	16.08	14.08	0.50	30.66
4.0	17.03	18.28	1.34	36.65

Table 4.239 Trichlorophenolic compounds present in different effluents formed by bleaching at various C Stage consistency

Trichlorophenolic compounds (g/t)				
Consistency (%)	C-stage	E-stage	H-stage	TOTAL
2.5	7.27	4.09	0.25	11.61
3.0	18.93	10.69	0.99	30.61
3.5	18.33	12.36	1.15	31.84
4.0	20.34	16.66	1.20	38.20

Table 4.240 Tetrachlorophenolic compounds present in different effluents formed by bleaching at various C Stage consistency

Tetrachlorophenolic compounds (g/t)				
Consistency (%)	C-stage	E-stage	H-stage	TOTAL
2.5	6.10	2.95	0.28	9.33
3.0	12.26	3.98	0.81	17.05
3.5	14.36	5.88	1.05	21.29
4.0	16.16	8.16	1.30	25.62

Table 4.241 Category wise load of chlorophenols in different effluents formed by bleaching at various C Stage consistency

Chlorophenols (g/t)				
Consistency (%)	C-stage	E-stage	H-stage	TOTAL
2.5	5.15	6.16	0.26	11.57
3.0	16.86	10.17	0.98	28.01
3.5	19.11	12.00	1.40	32.51
4.0	22.19	15.22	1.80	39.21

Table 4.242 Category wise load of chloroguaiacols in different effluents formed by bleaching at various C Stage consistency

Chloroguaiacols (g/t)				
Consistency (%)	C-stage	E-stage	H-stage	TOTAL
2.5	7.18	1.35	0.09	8.62
3.0	11.48	5.46	0.67	17.61
3.5	12.16	7.47	0.87	20.50
4.0	13.43	12.00	1.75	27.18

Table 4.243 Category wise load of chlorocatechols in different effluents formed by bleaching at various C Stage consistency

Chlorocatechols (g/t)				
Consistency (%)	C-stage	E-stage	H-stage	TOTAL
2.5	7.80	3.77	0.25	11.82
3.0	13.55	6.73	0.64	20.92
3.5	13.01	8.87	0.94	22.82
4.0	14.26	12.28	1.04	27.58

Table 4.244 Category wise load of other chlorophenolic compounds in different effluents formed by bleaching at various C Stage consistency

Other Chlorophenolic compounds (g/t)				
Consistency (%)	C-stage	E-stage	H-stage	TOTAL
2.5	4.85	1.77	0.02	6.64
3.0	8.69	5.09	0.52	14.30
3.5	7.36	6.32	0.97	14.65
4.0	7.56	7.66	1.11	16.33

Table 4.319 Different chlorophenolic compounds formed in C stage at various consistency

C stage Consistency(%)					
S.No.	Chlorophenolic compounds(g/T)	**2.5**	**3.0**	**3.5**	**4.0**
1	2,4-dichlorophenol	1.97	3.97	4.95	5.56
2	3-chlorophenol	0.45	2.21	2.87	3.91
3	4-chloroguaiacol	-	-	-	-
4	5-chloroguaiacol	-	-	-	-
5	2,3,5-trichlorophenol	0.04	0.10	0.13	0.17
6	2,4,6-trichlorophenol	1.97	9.74	10.19	11.42
7	3,6-dichloroguaiacol	0.04	0.09	0.18	0.27
8	3,4dichlorocatechol	2.92	2.87	0.69	0.4
9	4,5-dichloroguaiacol	0.12	0.25	1.46	1.68
10	5,6-dichloroguaiacol	1.26	1.31	1.44	1.56
11	2,3,4,6-tetrachlorophenol	0.72	0.84	0.97	1.13
12	3,4,5-trichloroguaiacol	0.48	1.08	1.64	2.42
13	3,4,6-trichloroguaiacol	3.64	3.53	1.44	1.07
14	3,5-dichlorosyringol	2.64	2.58	1.12	0.74
15	3,6-dichlorocatechol	-	-	-	-
16	4,5,6-trichloroguaiacol	0.22	2.12	2.49	2.67
17	tetrachloroguaiacol	1.42	3.1	3.51	3.76
18	3,4,6-trichlorocatechol	0.92	2.36	2.44	2.59
19	2,6-dichlorosyringaldehyde	1.24	4.95	5.03	5.49
20	5,6-dichlorovanillin	0.97	1.16	1.21	1.33
21	tetrachlorocatechol	3.96	8.32	9.88	11.27
22	2,3,4-trichlorophenol	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-
	TOTAL	24.98	50.58	51.64	57.44

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C

Table 4.320 Different chlorophenolic compounds formed in E stage at various consistency

C stage Consistency(%)					
S.No.	Chlorophenolic compounds(g/T)	2.5	3.0	3.5	4.0
1	2,4-dichlorophenol	1.64	2.34	3.15	3.45
2	3-chlorophenol	1.37	2.04	2.34	4.06
3	4-chloroguaiacol	-	-	-	-
4	5-chloroguaiacol	-	-	-	-
5	2,3,5-trichlorophenol	-	0.72	0.86	0.95
6	2,4,6-trichlorophenol	3.14	5.01	5.48	6.41
7	3,6-dichloroguaiacol	0.05	0.14	0.29	0.32
8	3,4dichlorocatechol	0.39	0.97	1.74	2.24
9	4,5-dichloroguaiacol	0.14	0.76	1.13	2.18
10	5,6-dichloroguaiacol	0.19	0.57	0.64	0.81
11	2,3,4,6-tetrachlorophenol	0.01	0.06	0.17	0.35
12	3,4,5-trichloroguaiacol	0.76	0.89	1.04	2.12
13	3,4,6-trichloroguaiacol	0.02	0.21	0.53	0.82
14	3,5-dichlorosyringol	0.11	1.12	1.62	2.3
15	3,6-dichlorocatechol	0.46	0.87	0.81	1.62
16	4,5,6-trichloroguaiacol	0.01	2.12	2.49	3.04
17	tetrachloroguaiacol	0.18	0.77	1.35	2.71
18	3,4,6-trichlorocatechol	0.16	1.74	1.96	3.32
19	2,6-dichlorosyringaldehyde	1.35	1.74	1.84	2.15
20	5,6-dichlorovanillin	0.31	2.23	2.86	3.21
21	tetrachlorocatechol	2.76	3.15	4.36	5.10
22	2,3,4-trichlorophenol	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-
	TOTAL	13.05	27.45	34.66	47.16

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.321 Different chlorophenolic compounds formed in H stage at various consistency

		C stage Consistency(%)			
S.No.	Chlorophenolic compounds(g/T)	2.5	3.0	3.5	4.0
1	2,4-dichlorophenol	-	-	-	-
2	3-chlorophenol	0.01	0.09	0.44	0.83
3	4-chloroguaiacol	0.001	0.04	0.05	0.08
4	5-chloroguaiacol	0.005	0.01	0.01	0.43
5	2,3,5-trichlorophenol	-	-	-	-
6	2,4,6-trichlorophenol	0.19	0.78	0.83	0.82
7	3,6-dichloroguaiacol	-	-	-	-
8	3,4dichlorocatechol	-	-	-	-
9	4,5-dichloroguaiacol	0.01	0.28	0.35	0.54
10	5,6-dichloroguaiacol	0.04	0.07	0.16	0.21
11	2,3,4,6-tetrachlorophenol	-	-	-	-
12	3,4,5-trichloroguaiacol	-	-	-	-
13	3,4,6-trichloroguaiacol	-	-	-	-
14	3,5-dichlorosyringol	0.02	0.17	0.25	0.27
15	3,6-dichlorocatechol	-	-	-	-
16	4,5,6-trichloroguaiacol	-	-	-	-
17	tetrachloroguaiacol	0.03	0.27	0.3	0.49
18	3,4,6-trichlorocatechol	-	0.10	0.19	0.23
19	2,6-dichlorosyringaldehyde	-	-	-	-
20	5,6-dichlorovanillin	-	0.35	0.72	0.84
21	tetrachlorocatechol	0.25	0.54	0.75	0.81
22	2,3,4-trichlorophenol	0.06	0.11	0.13	0.15
23	4,5-dichlorocatechol	-	-	-	-
	TOTAL	0.62	2.81	4.18	5.70

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.322 Total chlorophenolic compounds formed in CEH bleaching at various consistency

C stage Consistency(%)					
S.No.	Chlorophenolic compounds(g/T)	**2.5**	**3.0**	**3.5**	**4.0**
1	2,4-dichlorophenol	3.61	6.31	8.10	9.01
2	3-chlorophenol	1.83	4.34	5.65	8.80
3	4-chloroguaiacol	0.001	0.04	0.05	0.08
4	5-chloroguaiacol	0.005	0.01	0.01	0.43
5	2,3,5-trichlorophenol	0.04	0.82	0.99	1.12
6	2,4,6-trichlorophenol	5.30	15.53	16.50	18.65
7	3,6-dichloroguaiacol	0.09	0.23	0.47	0.59
8	3,4dichlorocatechol	3.31	3.84	2.43	2.64
9	4,5-dichloroguaiacol	0.27	1.29	2.94	4.4
10	5,6-dichloroguaiacol	1.49	1.95	2.24	2.58
11	2,3,4,6-tetrachlorophenol	0.73	0.90	1.14	1.48
12	3,4,5-trichloroguaiacol	1.24	1.97	2.68	4.54
13	3,4,6-trichloroguaiacol	3.66	3.74	1.97	1.89
14	3,5-dichlorosyringol	2.77	3.87	2.99	3.31
15	3,6-dichlorocatechol	0.46	0.87	0.81	1.62
16	4,5,6-trichloroguaiacol	0.23	4.24	4.98	5.71
17	tetrachloroguaiacol	1.63	4.14	5.16	6.96
18	3,4,6-trichlorocatechol	1.08	4.20	4.59	6.14
19	2,6-dichlorosyringaldehyde	2.59	6.69	6.87	7.64
20	5,6-dichlorovanillin	1.28	3.74	4.79	5.38
21	tetrachlorocatechol	6.97	12.01	14.99	17.18
22	2,3,4-trichlorophenol	0.06	0.11	0.13	0.15
23	4,5-dichlorocatechol				
	TOTAL	38.646	80.84	90.48	110.3

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Fig. 4.219

EFFECT OF C-STAGE CONSISTENCY ON C.O.D. GENERATION

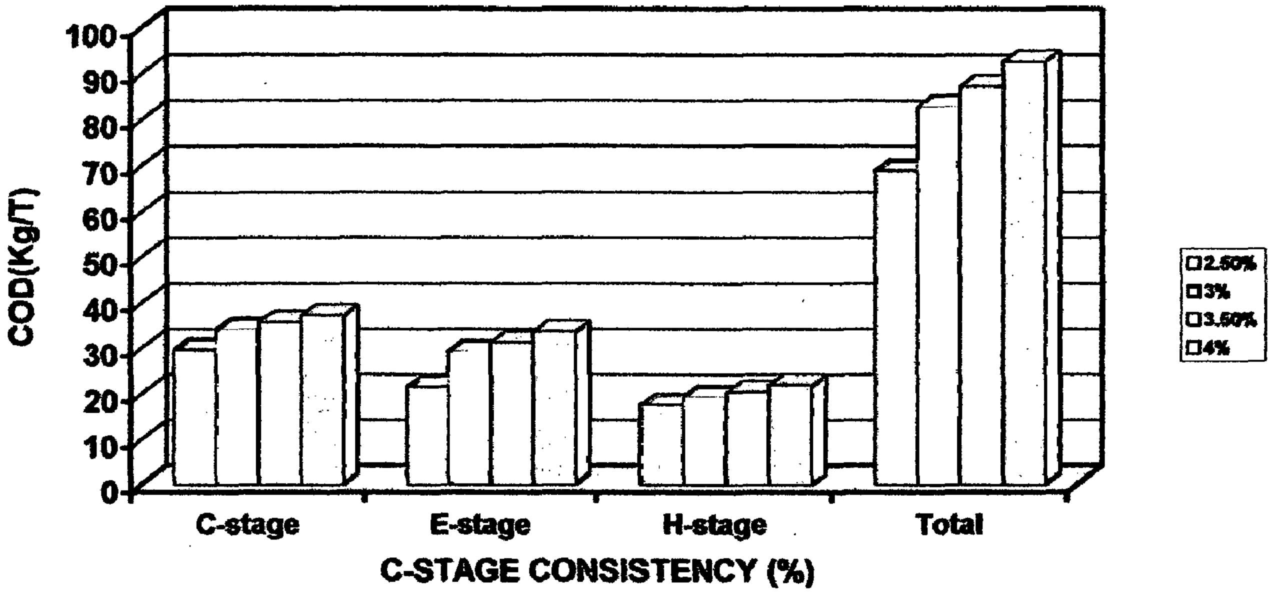


Fig. 4.220

EFFECT OF C-STAGE CONSISTENCY ON COLOR GENERATION

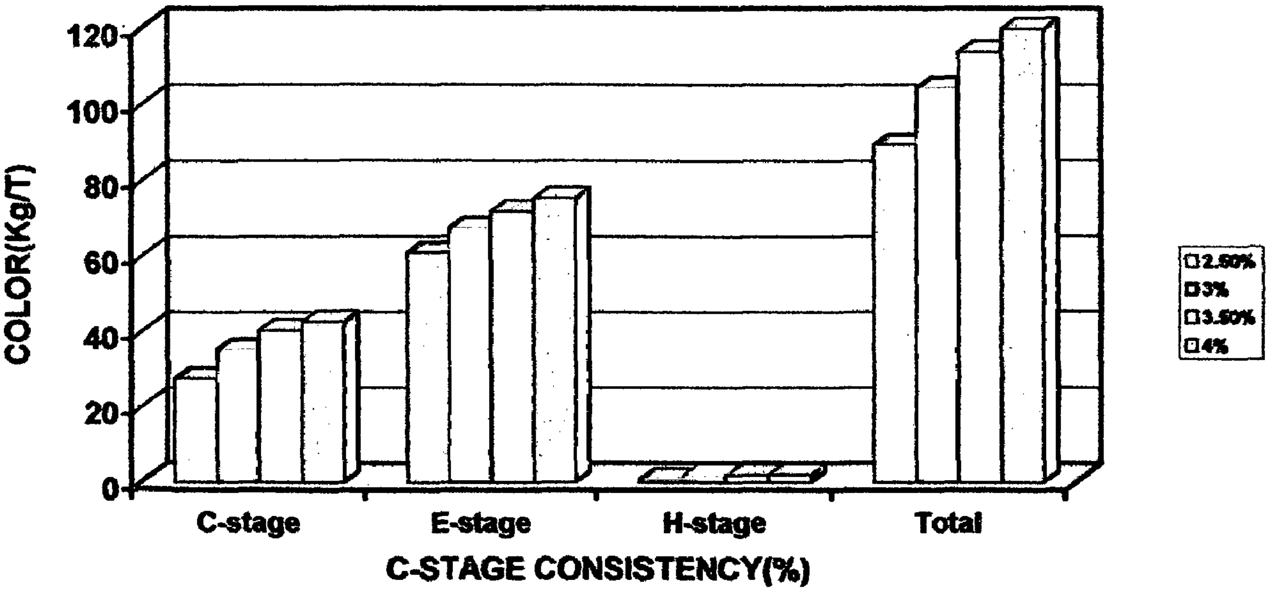


Fig. 4.221

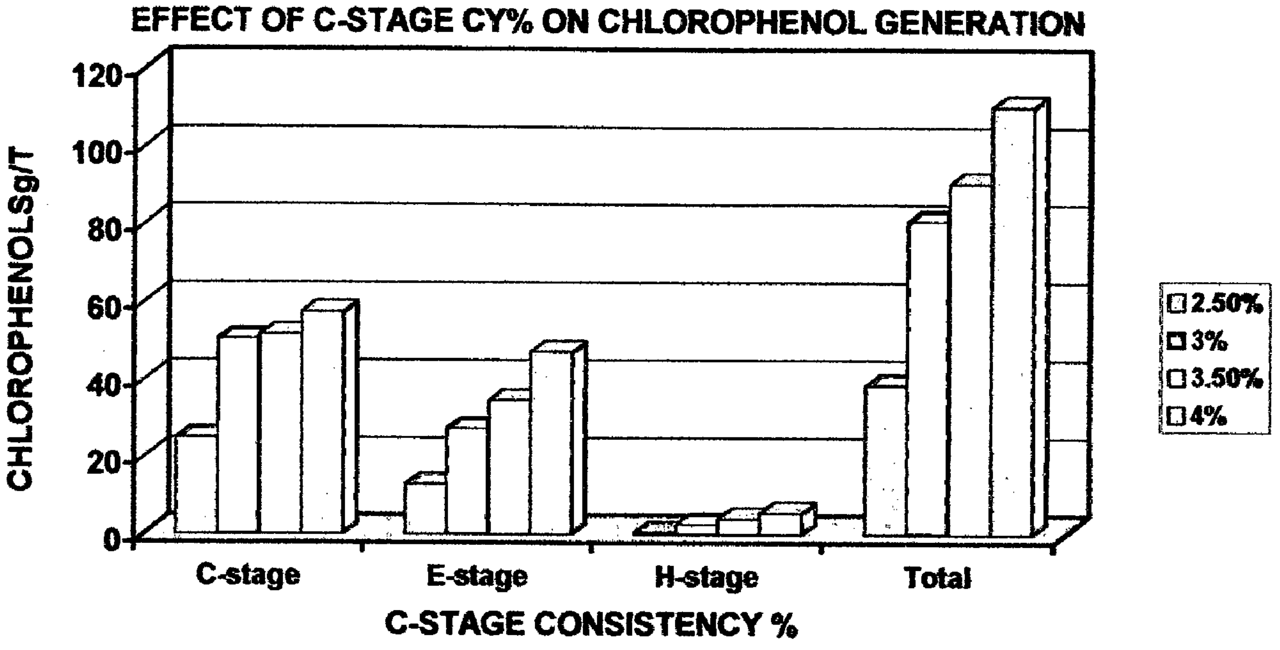


Fig.4.222

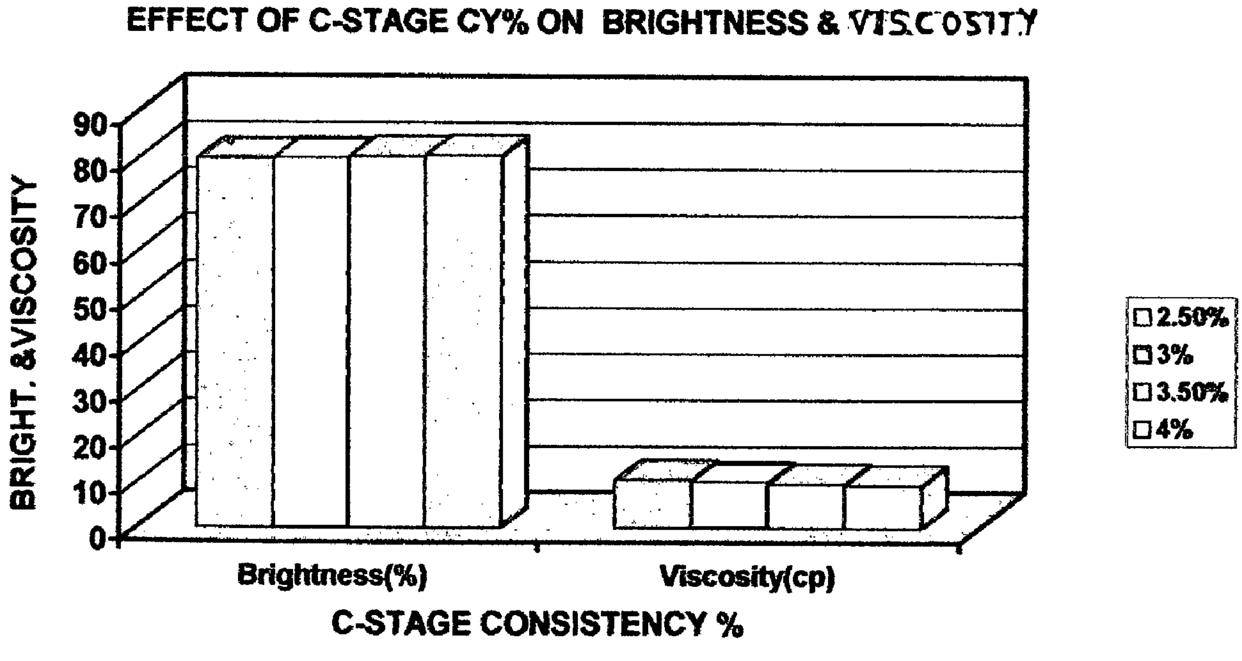


Table 4.125

Formation of different chlorophenolic compounds in various effluents by bleaching at 10% replacement of Chlorine by Chlorine dioxide

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	4.13	0.08	2.54	0.10	-	-	6.67
2	3-chlorophenol	2.97	0.06	2.21	0.09	-	-	5.18
3	4-chloroguaiacol	-	-	-	-	0.04	0.002	0.04
4	5-chloroguaiacol	-	-	-	-	0.004	0.0002	0.004
5	2,3,5-trichlorophenol	0.11	0.002	0.47	0.02	-	-	0.58
6	2,4,6-trichlorophenol	10.15	0.20	2.42	0.10	0.37	0.01	12.94
7	3,6-dichloroguaiacol	0.05	0.001	0.05	0.002	-	-	0.10
8	3,4-dichlorocatechol	2.09	0.04	1.04	0.04	-	-	3.13
9	4,5-dichloroguaiacol	0.19	0.004	0.35	0.01	0.23	0.01	0.77
10	5,6-dichloroguaiacol	1.36	0.03	-	-	0.08	0.003	1.44
11	2,3,4,6-tetrachlorophenol	0.07	0.001	0.04	0.002	-	-	0.11
12	3,4,5-trichloroguaiacol	1.93	0.04	0.45	0.02	-	-	2.38
13	3,4,6-trichloroguaiacol	3.61	0.07	0.20	0.01	0.01	0.0004	3.82
14	3,5-dichlorosyringol	0.21	0.004	0.05	0.002	0.16	0.01	0.42
15	3,6-dichlorocatechol	-	-	-	-	-	-	-
16	4,5,6-trichloroguaiacol	2.35	0.05	0.53	0.02	-	-	2.88
17	tetrachloroguaiacol	1.78	0.03	0.48	0.02	0.21	0.01	2.47
18	3,4,6-trichlorocatechol	1.54	0.03	0.82	0.03	0.10	0.004	2.46
19	2,6-dichlorosyringaldehyde	3.84	0.08	0.67	0.03	-	-	4.51
20	5,6-dichlorovanillin	1.07	0.02	1.72	0.07	0.31	0.01	3.10
21	tetrachlorocatechol	4.97	0.10	1.14	0.04	0.42	0.02	6.53
22	2,3,4-trichlorophenol	-	-	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	2.15	0.09	-	-	2.15
	TOTAL	42.42	0.84	17.33	0.70	1.93	0.08	61.68

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.126

Formation of different chlorophenolic compounds in various effluents by bleaching at 30% replacement of Chlorine by Chlorine dioxide

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	5.46	0.11	2.01	0.08	0.003	0.0001	7.47
2	3-chlorophenol	3.18	0.06	-	-	-	-	3.18
3	4-chloroguaiacol	-	-	-	-	0.02	0.001	0.02
4	5-chloroguaiacol	-	-	-	-	-	-	-
5	2,3,5-trichlorophenol	0.19	0.004	0.44	0.02	-	-	0.63
6	2,4,6-trichlorophenol	10.78	0.21	0.8	0.03	0.29	0.01	11.87
7	3,6-dichloroguaiacol	-	-	0.01	0.0004	-	-	0.01
8	3,4-dichlorocatechol	1.61	0.03	0.95	0.04	-	-	2.56
9	4,5-dichloroguaiacol	0.07	0.001	0.32	0.01	0.18	0.01	0.57
10	5,6-dichloroguaiacol	1.42	0.03	-	-	0.09	0.004	1.51
11	2,3,4,6-tetrachlorophenol	0.13	0.003	0.02	0.001	-	-	0.15
12	3,4,5-trichloroguaiacol	1.26	0.02	0.34	0.01	-	-	1.60
13	3,4,6-trichloroguaiacol	3.69	0.07	0.14	0.006	0.02	0.001	3.85
14	3,5-dichlorosyringol	0.09	0.002	-	-	0.11	0.004	0.20
15	3,6-dichlorocatechol	-	-	-	-	-	-	-
16	4,5,6-trichloroguaiacol	2.45	0.05	0.42	0.02	-	-	2.87
17	tetrachloroguaiacol	1.23	0.02	0.37	0.01	0.14	0.006	1.74
18	3,4,6-trichlorocatechol	0.87	0.02	0.54	0.02	0.08	0.003	1.49
19	2,6-dichlorosyringaldehyde	2.54	0.05	0.31	0.01	-	-	2.85
20	5,6-dichlorovanillin	0.84	0.02	1.54	0.06	0.16	0.01	2.54
21	tetrachlorocatechol	4.52	0.09	0.83	0.03	0.26	0.01	5.61
22	2,3,4-trichlorophenol	-	-	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	1.85	0.07	-	-	1.85
	TOTAL	40.33	0.79	10.89	0.42	1.35	0.06	52.57

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C, Consistency 3%

Table 4.127

Formation of different chlorophenolic compounds in various effluents by bleaching at 50% replacement of Chlorine by Chlorine dioxide								
S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	6.59	0.13	0.17	0.01	0.01	0.0004	6.77
2	3-chlorophenol	3.32	0.07	1.46	0.06	-	-	4.78
3	4-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01
4	5-chloroguaiacol	-	-	-	-	-	-	-
5	2,3,5-trichlorophenol	0.24	0.005	0.04	0.002	-	-	0.28
6	2,4,6-trichlorophenol	11.17	0.22	0.35	0.01	0.19	0.01	11.71
7	3,6-dichloroguaiacol	-	-	-	-	-	-	-
8	3,4-dichlorocatechol	0.54	0.01	0.27	0.01	-	-	0.81
9	4,5-dichloroguaiacol	0.01	0.0002	0.18	0.01	0.11	0.004	0.30
10	5,6-dichloroguaiacol	1.47	0.03	-	-	0.11	0.004	1.58
11	2,3,4,6-tetrachlorophenol	0.21	0.004	-	-	-	-	0.21
12	3,4,5-trichloroguaiacol	1.32	0.03	2.26	0.09	-	-	3.58
13	3,4,6-trichloroguaiacol	3.76	0.07	0.08	0.003	0.03	0.001	3.87
14	3,5-dichlorosyringol	0.05	0.001	-	-	0.04	0.002	0.09
15	3,6-dichlorocatechol	-	-	-	-	-	-	-
16	4,5,6-trichloroguaiacol	2.56	0.05	0.16	0.01	-	-	2.72
17	tetrachloroguaiacol	0.94	0.02	0.28	0.01	0.09	0.004	1.31
18	3,4,6-trichlorocatechol	0.35	0.01	0.36	0.01	0.06	0.002	0.77
19	2,6-dichlorosyringaldehyde	1.18	0.02	0.24	0.01	-	-	1.42
20	5,6-dichlorovanillin	0.78	0.01	0.49	0.02	0.14	0.006	1.41
21	tetrachlorocatechol	3.63	0.07	0.37	0.01	0.22	0.01	4.22
22	2,3,4-trichlorophenol	-	-	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	1.74	0.07	-	-	1.74
	TOTAL	38.12	0.75	8.45	0.33	1.01	0.04	47.58

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.128

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	0.23	0.005	0.14	0.01	0.04	0.002	0.41
2	3-chlorophenol	0.36	0.01	-	-	-	-	0.36
3	4-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01
4	5-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01
5	2,3,5-trichlorophenol	-	-	-	-	-	-	-
6	2,4,6-trichlorophenol	1.13	0.02	0.27	0.01	0.11	0.004	1.51
7	3,6-dichloroguaiacol	-	-	-	-	-	-	-
8	3,4-dichlorocatechol	0.37	0.01	0.05	0.002	-	-	0.42
9	4,5-dichloroguaiacol	-	-	0.03	0.001	0.06	0.002	0.09
10	5,6-dichloroguaiacol	0.04	0.001	-	-	0.05	0.002	0.09
11	2,3,4,6-tetrachlorophenol	-	-	-	-	-	-	-
12	3,4,5-trichloroguaiacol	0.31	0.01	0.13	0.005	-	-	0.44
13	3,4,6-trichloroguaiacol	0.19	0.004	0.02	0.001	0.004	0.0002	0.214
14	3,5-dichlorosyringol	0.01	0.0002	-	-	0.02	0.001	0.03
15	3,6-dichlorocatechol	-	-	-	-	-	-	-
16	4,5,6-trichloroguaiacol	0.04	0.001	0.09	0.004	-	-	0.13
17	tetrachloroguaiacol	0.27	0.005	0.14	0.01	0.06	0.002	0.47
18	3,4,6-trichlorocatechol	0.21	0.004	0.06	0.002	0.04	0.002	0.31
19	2,6-dichlorosyringaldehyde	0.76	0.01	0.09	0.004	-	-	0.85
20	5,6-dichlorovanillin	0.33	0.01	0.09	0.004	0.12	0.005	0.54
21	tetrachlorocatechol	2.76	0.05	0.15	0.01	0.08	0.003	2.99
22	2,3,4-trichlorophenol	-	-	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	1.62	0.06	-	-	1.62
	TOTAL	7.01	0.14	2.88	0.12	0.60	0.02	10.49

Formation of different chlorophenolic compounds in various effluents by bleaching at 75% replacement of Chlorine by Chlorine dioxide

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.245 Effect of partial substitution of chlorine by chlorine dioxide in C stage on the generation of Chlorophenolic compounds

Chlorophenolic compounds (kg/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0%	50.58	27.45	2.81	80.84
10%	42.42	17.33	1.93	61.68
30%	40.33	10.89	1.35	52.57
50%	38.12	8.45	1.01	47.58
75%	7.01	2.88	0.60	10.49

Table 4.246 Effect of partial substitution of chlorine by chlorine dioxide in C stage on the generation of effluent COD

COD (kg/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0%	34.2	29.4	19.4	83.0
10%	29.2	26.2	17.2	72.6
30%	26.5	24.7	16.1	67.3
50%	24.3	23.1	14.9	62.3
75%	20.2	17.5	13.2	50.9

Table 4.247 Effect of partial substitution of chlorine by chlorine dioxide in C stage on the generation of effluent Colour

Colour (kg/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0%	35.3	67.3	1.7	104.3
10%	28.4	64.2	1.0	93.6
30%	26.7	57.5	0.9	85.1
50%	22.9	40.7	0.4	64.0
75%	10.7	12.6	0.1	23.4

Table 4.248 Effect of partial substitution of chlorine by chlorine dioxide in C stage on Brightness and Viscosity of bleached pulps obtained by CEH bleaching

Substitution by D	Brightness (%)	Viscosity (cp)
0%	80.1	10.1
10%	80.7	12.7
30%	81.2	14.1
50%	81.7	15.6
75%	82.0	17.3

Table 4.249 Monochlorophenolic compounds present in different effluents formed by partial substitution of chlorine by chlorine dioxide in C stage

Monochlorophenolic compounds (g/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0% D	2.21	2.04	0.14	4.39
10% D	2.97	2.21	0.04	5.22
30% D	3.18	-	0.02	3.20
50% D	3.32	1.46	0.01	4.79
75% D	0.36	-	0.02	0.38

Table 4.250 Dichlorophenolic compounds present in different effluents formed by partial substitution of chlorine by chlorine dioxide in C stage

Dichlorophenolic compounds (g/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0% D	17.18	10.74	0.14	28.06
10% D	12.94	8.57	0.04	21.55
30% D	12.03	6.99	0.02	19.04
50% D	10.62	3.09	0.01	13.72
75% D	1.74	2.02	0.02	3.78

Table 4.251 Trichlorophenolic compounds present in different effluents formed by partial substitution of chlorine by chlorine dioxide in C stage

Trichlorophenolic compounds (g/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0% D	18.93	10.69	0.99	30.61
10% D	19.69	4.89	0.48	25.06
30% D	19.24	2.68	0.39	22.31
50% D	19.40	3.25	0.28	22.93
75% D	1.88	0.57	0.15	2.60

Table 4.252 Tetrachlorophenolic compounds present in different effluents formed by partial substitution of chlorine by chlorine dioxide in C stage

Tetrachlorophenolic compounds (g/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0% D	12.26	3.98	0.81	17.05
10% D	6.82	1.66	0.63	9.11
30% D	5.88	3.90	0.40	10.18
50% D	4.78	0.05	0.31	5.14
75% D	3.03	0.29	0.14	3.46

Table 4.253 Category wise load of chlorophenols in different effluents formed by partial substitution of chlorine by chlorine dioxide in C stage

Chlorophenols (g/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0% D	16.86	10.17	0.98	28.01
10% D	17.43	7.68	0.37	25.48
30% D	19.74	3.27	0.29	23.30
50% D	21.53	2.02	0.20	23.75
75% D	1.72	0.41	0.15	2.28

Table 4.254 Category wise load of chloroguaiacols in different effluents formed by partial substitution of chlorine by chlorine dioxide in C stage

Chloroguaiacols (g/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0% D	11.48	5.46	0.67	17.61
10% D	11.27	2.06	0.57	13.90
30% D	10.12	1.6	0.45	12.17
50% D	10.06	2.96	0.35	13.37
75% D	0.85	0.41	0.19	1.45

Table 4.255 Category wise load of chlorocatechols in different effluents formed by partial substitution of chlorine by chlorine dioxide in C stage

Chlorocatechols (g/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0% D	13.55	6.73	0.64	20.92
10% D	8.6	5.15	0.52	14.27
30% D	7.00	4.17	0.34	11.51
50% D	4.52	2.74	0.28	7.54
75% D	3.34	1.88	0.12	5.34

Table 4.256 Category wise load of other chlorophenolic compounds in different effluents formed by partial substitution of chlorine by chlorine dioxide in C stage

Other Chlorophenolic compounds (g/t)				
Substitution by D	C-stage	E-stage	H-stage	TOTAL
0% D	8.69	5.09	0.52	14.30
10% D	5.12	2.44	0.47	8.03
30% D	3.47	1.85	0.27	5.59
50% D	2.01	0.73	0.18	2.92
75% D	1.10	0.18	0.14	1.42

Table 4.323 Different chlorophenolic compounds formed in C stage by partial substitution of chlorine by chlorine dioxide

Partial substitution of chlorine by chlorine dioxide						
S.No.	Chlorophenolic compounds(g/T)	0% D	10% D	30% D	50% D	75% D
1	2,4-dichlorophenol	3.97	4.13	5.46	6.59	0.23
2	3-chlorophenol	2.21	2.97	3.18	3.32	0.36
3	4-chloroguaiacol	-	-	-	-	-
4	5-chloroguaiacol	-	-	-	-	-
5	2,3,5-trichlorophenol	0.10	0.11	0.19	0.24	-
6	2,4,6-trichlorophenol	9.74	10.15	10.78	11.17	1.13
7	3,6-dichloroguaiacol	0.09	0.05	-	-	-
8	3,4dichlorocatechol	2.87	2.09	1.61	0.54	0.37
9	4,5-dichloroguaiacol	0.25	0.19	0.07	0.01	-
10	5,6-dichloroguaiacol	1.31	1.36	1.42	1.47	0.04
11	2,3,4,6-tetrachlorophenol	0.84	0.07	0.13	0.21	-
12	3,4,5-trichloroguaiacol	1.08	1.93	1.26	1.32	0.31
13	3,4,6-trichloroguaiacol	3.53	3.61	3.69	3.76	0.19
14	3,5-dichlorosyringol	2.58	0.21	0.09	0.05	0.01
15	3,6-dichlorocatechol	-	-	-	-	-
16	4,5,6-trichloroguaiacol	2.12	2.35	2.45	2.56	0.04
17	tetrachloroguaiacol	3.10	1.78	1.23	0.94	0.27
18	3,4,6-trichlorocatechol	2.36	1.54	0.87	0.35	0.21
19	2,6-dichlorosyringaldehyde	4.95	3.84	2.54	1.18	0.76
20	5,6-dichlorovanillin	1.16	1.07	0.84	0.78	0.33
21	tetrachlorocatechol	8.32	4.97	4.52	3.63	2.76
22	2,3,4-trichlorophenol	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	50.58	42.42	40.33	38.12	7.01

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.324 Different chlorophenolic compounds formed in E stage by partial substitution of chlorine by chlorine dioxide

Partial substitution of chlorine by chlorine dioxide						
S.No.	Chlorophenolic compounds(g/T)	0% D	10% D	30% D	50% D	75% D
1	2,4-dichlorophenol	2.34	2.54	2.01	0.17	0.14
2	3-chlorophenol	2.04	2.21	-	1.46	-
3	4-chloroguaiacol	-	-	-	-	-
4	5-chloroguaiacol	-	-	-	-	-
5	2,3,5-trichlorophenol	0.72	0.47	0.44	0.04	-
6	2,4,6-trichlorophenol	5.01	2.42	0.8	0.35	0.27
7	3,6-dichloroguaiacol	0.14	0.05	0.01	-	-
8	3,4dichlorocatechol	0.97	1.04	0.95	0.27	0.05
9	4,5-dichloroguaiacol	0.76	0.35	0.32	0.18	0.03
10	5,6-dichloroguaiacol	0.57	-	-	-	-
11	2,3,4,6-tetrachlorophenol	0.06	0.04	0.02	-	-
12	3,4,5-trichloroguaiacol	0.89	0.45	0.34	2.26	0.13
13	3,4,6-trichloroguaiacol	0.21	0.2	0.14	0.08	0.02
14	3,5-dichlorosyringol	1.12	0.05	-	-	-
15	3,6-dichlorocatechol	0.87	-	-	-	-
16	4,5,6-trichloroguaiacol	2.12	0.53	0.42	0.16	0.09
17	tetrachloroguaiacol	0.77	0.48	0.37	0.28	0.14
18	3,4,6-trichlorocatechol	1.74	0.82	0.54	0.36	0.06
19	2,6-dichlorosyringaldehyde	1.74	0.67	0.31	0.24	0.09
20	5,6-dichlorovanillin	2.23	1.72	1.54	0.49	0.09
21	tetrachlorocatechol	3.15	1.14	0.83	0.37	0.15
22	2,3,4-trichlorophenol	-	-	-	-	-
23	4,5-dichlorocatechol	-	2.15	1.85	1.74	1.62
	TOTAL	27.45	17.33	10.89	8.45	2.88

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.325 Different chlorophenolic compounds formed in H stage by partial substitution of chlorine by chlorine dioxide

Partial substitution of chlorine by chlorine dioxide						
S.No.	Chlorophenolic compounds(g/T)	0% D	10% D	30% D	50% D	75% D
1	2,4-dichlorophenol	-	-	0.003	0.01	0.04
2	3-chlorophenol	0.09	-	-	-	-
3	4-chloroguaiacol	0.04	0.04	0.02	0.01	0.01
4	5-chloroguaiacol	0.01	0.004	-	-	0.01
5	2,3,5-trichlorophenol	-	-	-	-	-
6	2,4,6-trichlorophenol	0.78	0.37	0.29	0.19	0.11
7	3,6-dichloroguaiacol	-	-	-	-	-
8	3,4dichlorocatechol	-	-	-	-	-
9	4,5-dichloroguaiacol	0.28	0.23	0.18	0.11	0.06
10	5,6-dichloroguaiacol	0.07	0.08	0.09	0.11	0.05
11	2,3,4,6-tetrachlorophenol	-	-	-	-	-
12	3,4,5-trichloroguaiacol	-	-	-		-
13	3,4,6-trichloroguaiacol	-	0.01	0.02	0.03	0.004
14	3,5-dichlorosyringol	0.17	0.16	0.11	0.04	0.02
15	3,6-dichlorocatechol	-	-	-	-	-
16	4,5,6-trichloroguaiacol	-	-	-	-	-
17	tetrachloroguaiacol	0.27	0.21	0.14	0.09	0.06
18	3,4,6-trichlorocatechol	0.10	0.10	0.08	0.06	0.04
19	2,6-dichlorosyringaldehyde	-	-	-	-	-
20	5,6-dichlorovanillin	0.35	0.31	0.16	0.14	0.12
21	tetrachlorocatechol	0.54	0.42	0.26	0.22	0.08
22	2,3,4-trichlorophenol	0.11	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	2.81	1.93	1.35	1.01	0.60

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C, Consistency 3%

Table 4.326 Total chlorophenolic compounds formed in CEH bleaching by partial substitution of chlorine by chlorine dioxide

Partial substitution of chlorine by chlorine dioxide						
S.No.	Chlorophenolic compounds(g/T)	0% D	10% D	30% D	50% D	75% D
1	2,4-dichlorophenol	6.31	6.67	7.473	6.77	0.41
2	3-chlorophenol	4.34	5.18	3.18	4.78	0.36
3	4-chloroguaiacol	0.04	0.04	0.02	0.01	0.01
4	5-chloroguaiacol	0.01	0.004	-	-	0.01
5	2,3,5-trichlorophenol	0.82	0.58	0.63	0.28	-
6	2,4,6-trichlorophenol	15.53	12.94	11.87	11.71	1.51
7	3,6-dichloroguaiacol	0.23	0.10	0.01	-	-
8	3,4dichlorocatechol	3.84	3.13	2.56	0.81	0.42
9	4,5-dichloroguaiacol	1.29	0.77	0.57	0.30	0.09
10	5,6-dichloroguaiacol	1.95	1.44	1.51	1.58	0.09
11	2,3,4,6-tetrachlorophenol	0.90	0.11	0.15	0.21	-
12	3,4,5-trichloroguaiacol	1.97	2.38	1.60	3.58	0.44
13	3,4,6-trichloroguaiacol	3.74	3.82	3.85	3.87	0.214
14	3,5-dichlorosyringol	3.87	0.42	0.20	0.09	0.03
15	3,6-dichlorocatechol	0.87	-	-	-	-
16	4,5,6-trichloroguaiacol	4.24	2.88	2.87	2.72	0.13
17	tetrachloroguaiacol	4.14	2.47	1.74	1.31	0.47
18	3,4,6-trichlorocatechol	4.2	2.46	1.49	0.77	0.31
19	2,6-dichlorosyringaldehyde	6.69	4.51	2.85	1.42	0.85
20	5,6-dichlorovanillin	3.74	3.10	2.54	1.41	0.54
21	tetrachlorocatechol	12.01	6.53	5.61	4.22	2.99
22	2,3,4-trichlorophenol	0.11	-	-	-	-
23	4,5-dichlorocatechol	-	2.15	1.85	1.74	1.62
	TOTAL	80.84	61.68	52.57	47.58	10.49

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Fig. 4.223

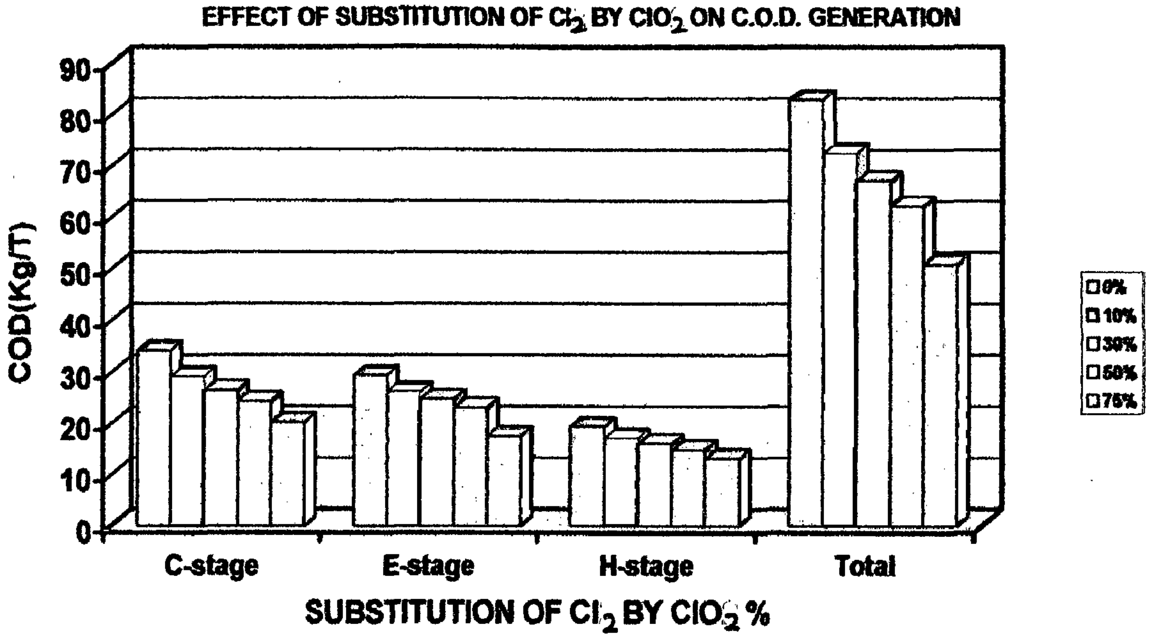


Fig. 4.224

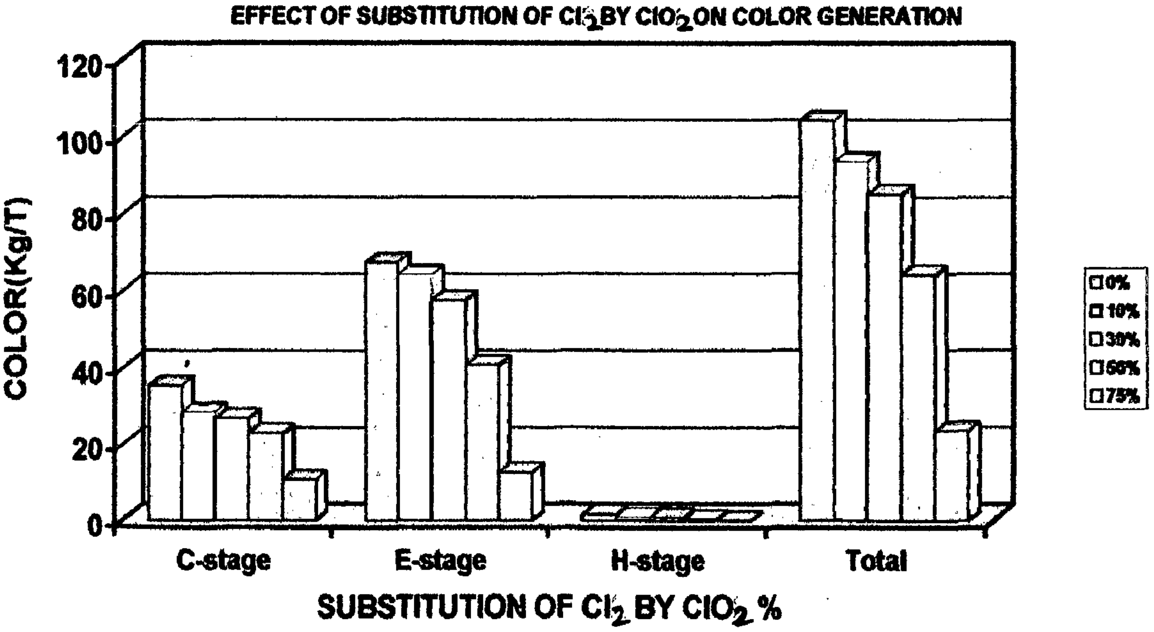


Fig. 4.225

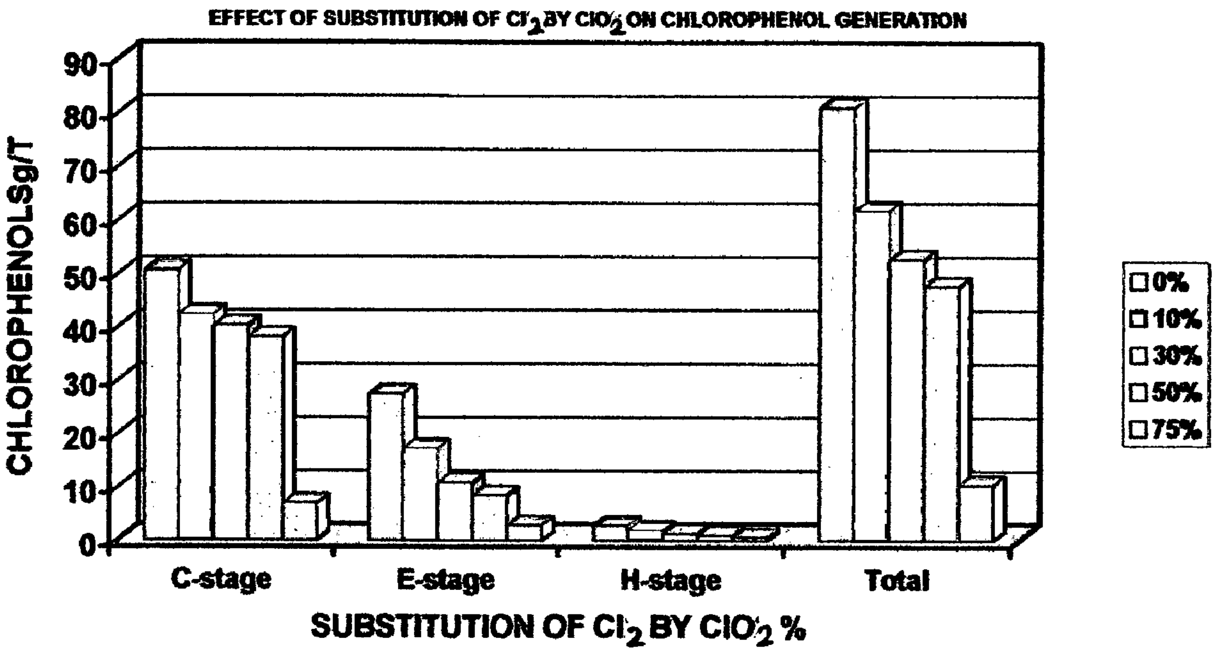


Fig. 4.226

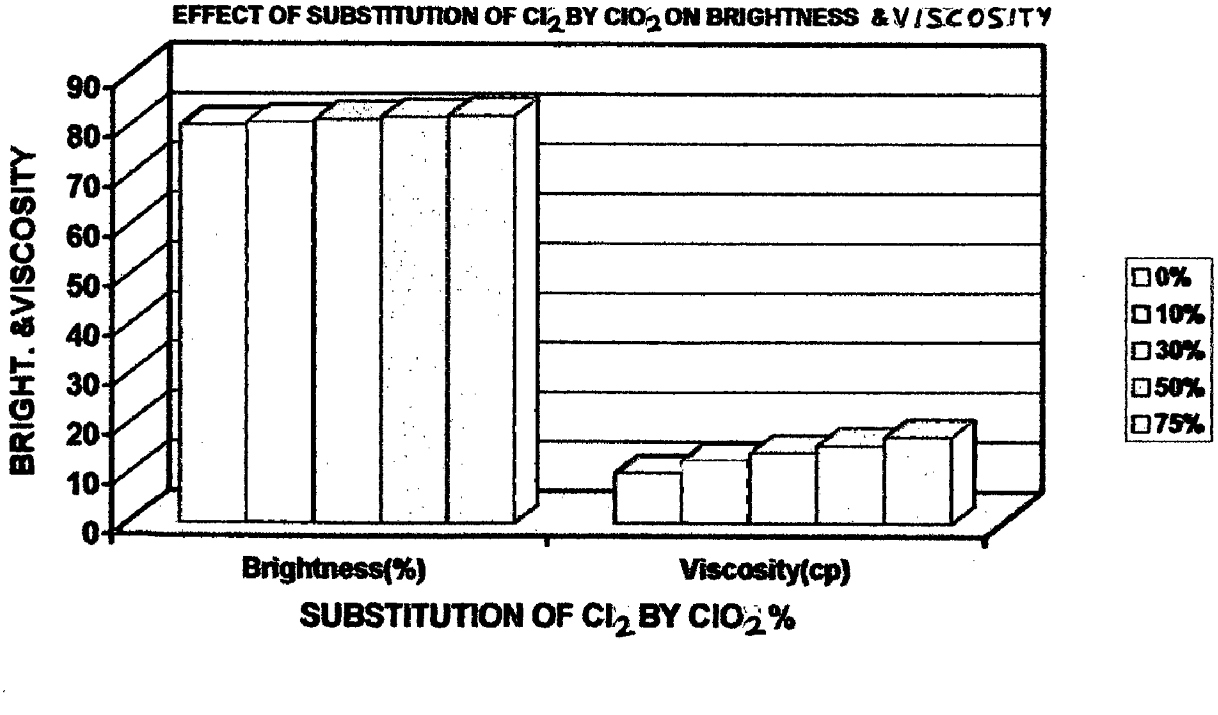


Table 4.129

Formation of different chlorophenolic compounds in various effluents by bleaching at 40:60 Chlorine charge distribution

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	1.47	0.03	-	-	-	-	1.47
2	3-chlorophenol	0.75	0.01	0.05	0.002	0.16	0.01	0.96
3	4-chloroguaiacol	-	-	-	-	0.10	0.004	0.10
4	5-chloroguaiacol	-	-	-	-	0.08	0.003	0.08
5	2,3,5-trichlorophenol	0.01	0.0001	0.03	0.001	-	-	0.04
6	2,4,6-trichlorophenol	7.21	0.14	1.74	0.07	0.94	0.04	9.89
7	3,6-dichloroguaiacol	0.01	0.0002	-	-	-	-	0.01
8	3,4-dichlorocatechol	0.52	0.01	0.36	0.01	-	-	0.88
9	4,5-dichloroguaiacol	0.06	0.001	0.10	0.004	0.16	0.01	0.32
10	5,6-dichloroguaiacol	-	-	-	-	0.16	0.01	0.16
11	2,3,4,6-tetrachlorophenol	0.01	0.0002	-	-	-	-	0.01
12	3,4,5-trichloroguaiacol	0.09	0.002	0.44	0.02	-	-	0.53
13	3,4,6-trichloroguaiacol	1.26	0.02	0.01	0.0004	-	-	1.27
14	3,5-dichlorosyringol	0.95	0.02	-	-	0.07	0.003	1.02
15	3,6-dichlorocatechol	-	-	0.11	0.004	-	-	0.11
16	4,5,6-trichloroguaiacol'	0.62	0.01	0.37	0.01	-	-	0.99
17	tetrachloroguaiacol	1.41	0.03	0.39	0.01	0.51	0.02	2.31
18	3,4,6-trichlorocatechol	1.36	0.03	1.43	0.06	0.37	0.01	3.16
19	2,6-dichlorosyringaldehyde	2.41	0.05	0.66	0.03	-	-	3.07
20	5,6-dichlorovanillin	1.34	0.03	2.46	0.10	0.21	0.01	4.01
21	tetrachlorocatechol	4.74	0.09	1.31	0.05	0.82	0.03	6.87
22	2,3,4-trichlorophenol	-	-	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	0.64	-	-	-	0.64
	TOTAL	24.22	0.47	9.46	0.38	3.58	0.15	37.26

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.130

Formation of different chlorophenolic compounds in various effluents by bleaching at 50:50 Chlorine charge distribution								
S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	2.35	0.05	-	-	-	-	2.35
2	3-chlorophenol	1.03	0.02	1.65	0.07	0.15	0.01	2.83
3	4-chloroguaiacol	-	-	-	-	0.08	0.003	0.08
4	5-chloroguaiacol	-	-	-	-	0.07	0.003	0.07
5	2,3,5-trichlorophenol	0.02	0.0004	0.34	0.01	-	-	0.36
6	2,4,6-trichlorophenol	7.67	0.15	3.43	0.14	0.86	0.03	11.96
7	3,6-dichloroguaiacol	0.02	0.0004	0.01	0.0004	-	-	0.03
8	3,4-dichlorocatechol	1.18	0.02	0.51	0.02	-	-	1.69
9	4,5-dichloroguaiacol	0.11	0.002	0.14	0.01	0.24	0.01	0.49
10	5,6-dichloroguaiacol	-	-	-	-	0.11	0.004	0.11
11	2,3,4,6-tetrachlorophenol	0.01	0.0002	0.01	0.0004	-	-	0.02
12	3,4,5-trichloroguaiacol	0.18	0.004	0.76	0.03	-	-	0.94
13	3,4,6-trichloroguaiacol	2.04	0.04	0.06	0.002	-	-	2.10
14	3,5-dichlorosyringol	1.84	0.04	0.02	0.001	0.11	0.004	1.97
15	3,6-dichlorocatechol	-	-	0.28	0.01	-	-	0.28
16	4,5,6-trichloroguaiacol	0.72	0.01	0.65	0.03	-	-	1.37
17	tetrachloroguaiacol	2.27	0.04	0.49	0.02	0.47	0.02	3.23
18	3,4,6-trichlorocatechol	1.77	0.03	1.51	0.06	0.31	0.01	3.59
19	2,6-dichlorosyringaldehyde	2.67	0.05	1.48	0.06	-	-	4.15
20	5,6-dichlorovanillin	1.27	0.02	2.35	0.09	0.25	0.01	3.87
21	tetrachlorocatechol	5.56	0.11	2.65	0.11	0.76	0.03	8.97
22	2,3,4-trichlorophenol	-	-	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-	-	-
	TOTAL	30.71	0.59	16.30	0.66	3.41	0.13	50.46

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C, Consistency 3%

Table 4.131

Formation of different chlorophenolic compounds in various effluents by bleaching at 60:40 Chlorine charge distribution

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	3.26	0.06	-	-	-	-	3.26
2	3-chlorophenol	1.48	0.03	1.96	0.08	0.13	0.005	3.57
3	4-chloroguaiacol	-	-	-	-	0.07	0.003	0.07
4	5-chloroguaiacol	-	-	-	-	0.04	0.002	0.04
5	2,3,5-trichlorophenol	0.05	0.001	0.54	0.02	-	-	0.59
6	2,4,6-trichlorophenol	9.15	0.18	4.87	0.19	0.83	0.03	14.85
7	3,6-dichloroguaiacol	0.05	0.001	0.04	0.002	-	-	0.09
8	3,4-dichlorocatechol	1.83	0.04	0.94	0.04	-	-	2.77
9	4,5-dichloroguaiacol	0.16	0.003	0.46	0.02	0.22	0.01	0.84
10	5,6-dichloroguaiacol	-	-	-	-	0.09	0.004	0.09
11	2,3,4,6-tetrachlorophenol	0.03	0.001	0.03	0.001	-	-	0.06
12	3,4,5-trichloroguaiacol	0.37	0.01	0.8	0.03	-	-	1.17
13	3,4,6-trichloroguaiacol	2.87	0.06	0.15	0.01	-	-	3.02
14	3,5-dichlorosyringol	2.44	0.05	0.04	0.002	0.15	0.01	2.63
15	3,6-dichlorocatechol	-	-	0.32	0.01	-	-	0.32
16	4,5,6-trichloroguaiacol	1.03	0.02	1.44	0.06	-	-	2.47
17	tetrachloroguaiacol	2.85	0.06	0.67	0.03	0.41	0.02	3.93
18	3,4,6-trichlorocatechol	2.01	0.04	1.66	0.07	0.16	0.01	3.83
19	2,6-dichlorosyringaldehyde	3.97	0.08	1.53	0.06	-	-	5.5
20	5,6-dichlorovanillin	1.21	0.02	2.21	0.09	0.29	0.01	3.71
21	tetrachlorocatechol	8.25	0.16	3.01	0.12	0.66	0.03	11.92
22	2,3,4-trichlorophenol	-	-	-	-	-	-	
23	4,5-dichlorocatechol	-	-	-	-	-	-	
	TOTAL	41.01	0.82	20.67	0.83	3.05	0.13	64.73

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.132

Formation of different chlorophenolic compounds in various effluents by bleaching at 70:30 Chlorine charge distribution

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	3.97	0.08	2.34	0.09	-	0.01	6.31
2	3-chlorophenol	2.21	0.04	2.04	0.08	0.09	0.02	4.34
3	4-chloroguaiacol	-	-	-	-	0.04	0.004	0.04
4	5-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01
5	2,3,5-trichlorophenol	0.10	0.002	0.72	0.03	-	0.03	0.82
6	2,4,6-trichlorophenol	9.74	0.19	5.01	0.2	0.78	-	15.53
7	3,6-dichloroguaiacol	0.09	0.002	0.14	0.006	-	-	0.23
8	3,4-dichlorocatechol	2.87	0.06	0.97	0.04	-	0.01	3.84
9	4,5-dichloroguaiacol	0.25	0.005	0.76	0.03	0.28	0.003	1.29
10	5,6-dichloroguaiacol	1.31	0.03	0.57	0.02	0.07	-	1.95
11	2,3,4,6-tetrachlorophenol	0.84	0.02	0.06	0.002	-	-	0.90
12	3,4,5-trichloroguaiacol	1.08	0.02	0.89	0.03	-	-	1.97
13	3,4,6-trichloroguaiacol	3.53	0.07	0.21	0.01	-	0.007	3.74
14	3,5-dichlorosyringol	2.58	0.05	1.12	0.04	0.17	-	3.87
15	3,6-dichlorocatechol	-		0.87	0.03	-	-	0.87
16	4,5,6-trichloroguaiacol	2.12	0.04	2.12	0.08	-	-	4.24
17	tetrachloroguaiacol	3.10	0.06	0.77	0.03	0.27	0.01	4.14
18	3,4,6-trichlorocatechol	2.36	0.05	1.74	0.07	0.10	0.004	4.20
19	2,6-dichlorosyringaldehyde	4.95	0.1	1.74	0.07	-	-	6.69
20	5,6-dichlorovanillin	1.16	0.02	2.23	0.09	0.35	0.01	3.74
21	tetrachlorocatechol	8.32	0.17	3.15	0.13	0.54	0.02	12.01
22	2,3,4-trichlorophenol	-		-	-	0.11	0.004	0.11
23	4,5-dichlorocatechol	-		-	-	-	-	-
	TOTAL	50.58	1.01	27.45	1.08	2.81	0.10	80.84

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.133

Formation of different chlorophenolic compounds in various effluents by bleaching at 80:20 Chlorine charge distribution

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	4.37	0.09	2.74	0.11	-	-	7.11
2	3-chlorophenol	2.84	0.06	2.24	0.09	0.06	0.002	5.14
3	4-chloroguaiacol	-	-	-	-	0.02	0.001	0.02
4	5-chloroguaiacol	-	-	-	-	0.004	0.0002	0.004
5	2,3,5-trichlorophenol	0.19	0.004	0.93	0.04	-	-	1.12
6	2,4,6-trichlorophenol	9.94	0.20	5.22	0.21	0.15	0.01	15.31
7	3,6-dichloroguaiacol	0.12	0.002	1.18	0.05	-	-	1.30
8	3,4-dichlorocatechol	3.31	0.07	1.31	0.05	-	-	4.62
9	4,5-dichloroguaiacol	0.56	0.01	0.98	0.04	0.31	0.01	1.85
10	5,6-dichloroguaiacol	-	-	-	-	0.03	0.001	0.03
11	2,3,4,6-tetrachlorophenol	0.01	0.0002	0.01	0.0004	-	-	0.02
12	3,4,5-trichloroguaiacol	1.46	0.03	1.21	0.05	-	-	2.67
13	3,4,6-trichloroguaiacol	3.92	0.08	1.28	0.05	-	-	5.20
14	3,5-dichlorosyringol	2.99	0.06	1.44	0.06	0.23	0.01	4.66
15	3,6-dichlorocatechol	-	-	0.25	0.01	-	-	0.25
16	4,5,6-trichloroguaiacol	2.21	0.04	3.26	0.13	-	-	5.47
17	tetrachloroguaiacol	3.43	0.07	2.88	0.11	0.02	0.001	6.33
18	3,4,6-trichlorocatechol	3.12	0.06	0.45	0.02	0.05	0.002	3.62
19	2,6-dichlorosyringaldehyde	5.56	0.11	1.94	0.08	-	-	7.50
20	5,6-dichlorovanillin	0.92	0.02	2.14	0.08	0.43	0.02	3.49
21	tetrachlorocatechol	8.64	0.17	3.12	0.12	0.11	0.004	11.87
22	2,3,4-trichlorophenol	-	-	-	-	-	-	
23	4,5-dichlorocatechol	-	-	-	-	-	-	
	TOTAL	53.59	1.08	32.58	1.30	1.414	0.06	87.58

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.257 Effect of chlorine charge distribution between C and H stages on the generation of Chlorophenolic compounds

Chlorophenolic compounds (kg/t)				
% Distribution between C & H	C-stage	E-stage	H-stage	TOTAL
40:60	24.22	9.46	3.58	37.26
50:50	30.71	16.34	3.41	50.46
60:40	41.01	20.67	3.05	64.73
70:30	50.58	27.45	2.81	80.84
80:20	53.59	32.58	1.41	87.58

Table 4.258 Effect of chlorine charge distribution between C and H stages on the generation of effluent COD

COD (kg/t)				
% Distribution between C & H	C-stage	E-stage	H-stage	TOTAL
40:60	17.6	19.4	24.8	61.8
50:50	27.3	23.2	22.4	72.9
60:40	30.1	27.6	21.1	78.8
70:30	34.2	29.4	19.4	83.0
80:20	38.7	31.5	18.2	88.4

Table 4.259 Effect of chlorine charge distribution between C and H stages on the generation of effluent Colour

Colour (kg/t)				
% Distribution between C & H	C-stage	E-stage	H-stage	TOTAL
40:60	19.7	20.1	0.4	40.2
50:50	22.4	48.5	0.6	71.5
60:40	30.2	61.6	1.1	92.9
70:30	35.3	67.3	1.7	104.3
80:20	39.4	75.8	1.9	117.1

Table 4.260 Effect of chlorine charge distribution between C and H stages on Brightness and Viscosity of bleached pulps obtained by CEH bleaching

% Distribution between C & H	Brightness (%)	Viscosity (cp)
40:60	80.9	9.4
50:50	80.7	9.5
60:40	80.5	9.8
70:30	80.1	10.1
80:20	80.4	10.3

Table 4.261 Monochlorophenolic compounds present in different effluents formed by distributing chlorine charge between C and H stages

Monochlorophenolic compounds (g/t)				
% Distribution between C:H	C-stage	E-stage	H-stage	TOTAL
40:60	0.75	0.05	0.34	1.14
50:50	1.03	1.65	0.30	2.98
60:40	1.48	1.96	0.24	3.68
70:30	2.21	2.04	0.14	4.39
80:20	2.84	2.24	0.08	5.16

Table 4.262 Dichlorophenolic compounds present in different effluents formed by distributing chlorine charge between C and H stages

Dichlorophenolic compounds (g/t)				
% Distribution between C:H	C-stage	E-stage	H-stage	TOTAL
40:60	6.76	3.69	0.34	10.79
50:50	9.44	4.79	0.03	14.26
60:40	12.92	5.54	0.24	18.70
70:30	17.18	10.74	0.14	28.06
80:20	17.83	11.98	0.08	29.89

Table 4.263 Trichlorophenolic compounds present in different effluents formed by distributing chlorine charge between C and H stages

Trichlorophenolic compounds (g/t)				
% Distribution between C:H	C-stage	E-stage	H-stage	TOTAL
40:60	10.55	4.02	1.31	15.88
50:50	12.40	6.75	1.17	20.32
60:40	15.48	9.46	0.99	25.93
70:30	18.93	10.69	0.99	30.61
80:20	20.84	12.35	0.20	33.39

Table 4.264 Tetrachlorophenolic compounds present in different effluents formed by distributing chlorine charge between C and H stages

Tetrachlorophenolic compounds (g/t)				
% Distribution between C:H	C-stage	E-stage	H-stage	TOTAL
40:60	6.16	1.7	1.33	9.19
50:50	7.84	3.15	1.23	12.22
60:40	11.13	3.71	1.07	15.91
70:30	12.26	3.98	0.81	17.05
80:20	12.08	6.01	0.13	18.22

Table 4.265 Category wise load of chlorophenols in different effluents formed by distributing chlorine charge between C and H stages

Chlorophenols (g/t)				
% Distribution between C:H	C-stage	E-stage	H-stage	TOTAL
40:60	9.44	1.82	1.10	12.36
50:50	11.08	5.43	1.01	17.52
60:40	13.97	7.40	0.96	22.33
70:30	16.86	10.17	0.98	28.01
80:20	17.35	11.14	0.21	28.70

Table 4.266 Category wise load of chloroguaiacols in different effluents formed by distributing chlorine charge between C and H stages

Chloroguaiacols (g/t)				
% Distribution between C:H	C-stage	E-stage	H-stage	TOTAL
40:60	3.45	1.31	1.01	5.77
50:50	5.34	2.11	1.98	9.43
60:40	7.33	3.56	0.83	11.72
70:30	11.48	5.46	0.67	17.61
80:20	11.70	10.79	0.38	22.87

Table 4.267 Category wise load of chlorocatechols in different effluents formed by distributing chlorine charge between C and H stages

Chlorocatechols (g/t)				
% Distribution between C:H	C-stage	E-stage	H-stage	TOTAL
40:60	6.62	3.21	1.19	11.02
50:50	8.51	4.95	1.07	14.53
60:40	12.09	5.93	0.82	18.84
70:30	13.55	6.73	0.64	20.92
80:20	15.07	5.13	0.16	20.36

Table 4.268 Category wise load of other chlorophenolic compounds in different effluents formed by distributing chlorine charge between C and H stages

Other Chlorophenolic compounds (g/t)				
% Distribution between C:H	C-stage	E-stage	H-stage	TOTAL
40:60	4.70	3.12	0.28	8.10
50:50	5.78	3.85	0.36	9.99
60:40	7.62	3.78	0.44	11.84
70:30	8.69	5.09	0.52	14.30
80:20	9.47	5.52	0.66	15.65

Table 4.327 Different chlorophenolic compounds formed in C stage by distributing chlorine charge between C & H stages

		Distributing chlorine charge C:H				
S.No.	Chlorophenolic compounds(g/T)	40:60	50:50	60:40	70:30	80:20
1	2,4-dichlorophenol	1.47	2.35	3.26	3.97	4.37
2	3-chlorophenol	0.75	1.03	1.48	2.21	2.84
3	4-chloroguaiacol	-	-	-	-	-
4	5-chloroguaiacol	-	-	-	-	-
5	2,3,5-trichlorophenol	0.01	0.02	0.05	0.10	0.19
6	2,4,6-trichlorophenol	7.21	7.67	9.15	9.74	9.94
7	3,6-dichloroguaiacol	0.01	0.02	0.05	0.09	0.12
8	3,4dichlorocatechol	0.52	1.18	1.83	2.87	3.31
9	4,5-dichloroguaiacol	0.06	0.11	0.16	0.25	0.56
10	5,6-dichloroguaiacol	-	-	-	1.31	-
11	2,3,4,6-tetrachlorophenol	0.01	0.01	0.03	0.84	0.01
12	3,4,5-trichloroguaiacol	0.09	0.18	0.37	1.08	1.46
13	3,4,6-trichloroguaiacol	1.26	2.04	2.87	3.53	3.92
14	3,5-dichlorosyringol	0.95	1.84	2.44	2.58	2.99
15	3,6-dichlorocatechol	-	-	-	-	-
16	4,5,6-trichloroguaiacol	0.62	0.72	1.03	2.12	2.21
17	tetrachloroguaiacol	1.41	2.27	2.85	3.10	3.43
18	3,4,6-trichlorocatechol	1.36	1.77	2.01	2.36	3.12
19	2,6-dichlorosyringaldehyde	2.41	2.67	3.97	4.95	5.56
20	5,6-dichlorovanillin	1.34	1.27	1.21	1.16	0.92
21	tetrachlorocatechol	4.74	5.56	8.25	8.32	8.64
22	2,3,4-trichlorophenol	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	24.22	30.71	41.01	50.58	53.59

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.328 Different chlorophenolic compounds formed in E stage by distributing chlorine charge between C & H stages

Distributing chlorine charge C:H						
S.No.	Chlorophenolic compounds(g/T)	40:60	50:50	60:40	70:30	80:20
1	2,4-dichlorophenol	-	-	-	2.34	2.74
2	3-chlorophenol	0.05	1.65	1.96	2.04	2.24
3	4-chloroguaiacol	-	-	-	-	-
4	5-chloroguaiacol	-	-	-	-	-
5	2,3,5-trichlorophenol	0.03	0.34	0.54	0.72	0.93
6	2,4,6-trichlorophenol	1.74	3.43	4.87	5.01	5.22
7	3,6-dichloroguaiacol	-	0.01	0.04	0.14	1.18
8	3,4dichlorocatechol	0.36	0.51	0.94	0.97	1.31
9	4,5-dichloroguaiacol	0.1	0.14	0.46	0.76	0.98
10	5,6-dichloroguaiacol	-	-	-	0.57	-
11	2,3,4,6-tetrachlorophenol	-	0.01	0.03	0.06	0.01
12	3,4,5-trichloroguaiacol	0.44	0.76	0.8	0.89	1.21
13	3,4,6-trichloroguaiacol	0.01	0.06	0.15	0.21	1.28
14	3,5-dichlorosyringol	-	0.02	0.04	1.12	1.44
15	3,6-dichlorocatechol	0.11	0.28	0.32	0.87	0.25
16	4,5,6-trichloroguaiacol	0.37	0.65	1.44	2.12	3.26
17	tetrachloroguaiacol	0.39	0.49	0.67	0.77	2.88
18	3,4,6-trichlorocatechol	1.43	1.51	1.66	1.74	0.45
19	2,6-dichlorosyringaldehyde	0.66	1.48	1.53	1.74	1.94
20	5,6-dichlorovanillin	2.46	2.35	2.21	2.23	2.14
21	tetrachlorocatechol	1.31	2.65	3.01	3.15	3.12
22	2,3,4-trichlorophenol	-	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	9.46	16.34	20.67	27.45	32.58

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.329 Different chlorophenolic compounds formed in H stage by distributing chlorine charge between C & H stages

		Distributing chlorine charge C:H				
S.No.	Chlorophenolic compounds(g/T)	40:60	50:50	60:40	70:30	80:20
1	2,4-dichlorophenol	-	-	-	-	-
2	3-chlorophenol	0.16	0.15	0.13	0.09	0.06
3	4-chloroguaiacol	0.10	0.08	0.07	0.04	0.02
4	5-chloroguaiacol	0.08	0.07	0.04	0.01	0.004
5	2,3,5-trichlorophenol	-	-	-	-	-
6	2,4,6-trichlorophenol	0.94	0.86	0.83	0.78	0.15
7	3,6-dichloroguaiacol	-	-	-	-	-
8	3,4dichlorocatechol	-	-	-	-	-
9	4,5-dichloroguaiacol	0.16	0.24	0.22	0.28	0.31
10	5,6-dichloroguaiacol	0.16	0.11	0.09	0.07	0.03
11	2,3,4,6-tetrachlorophenol	-	-	-	-	-
12	3,4,5-trichloroguaiacol	-	-	-	-	-
13	3,4,6-trichloroguaiacol	-	-	-	-	-
14	3,5-dichlorosyringol	0.07	0.11	0.15	0.17	0.23
15	3,6-dichlorocatechol	-	-	-	-	-
16	4,5,6-trichloroguaiacol	-	-	-	-	-
17	tetrachloroguaiacol	0.51	0.47	0.41	0.27	0.02
18	3,4,6-trichlorocatechol	0.37	0.31	0.16	0.10	0.05
19	2,6-dichlorosyringaldehyde	-	-	-	-	
20	5,6-dichlorovanillin	0.21	0.25	0.29	0.35	0.43
21	tetrachlorocatechol	0.82	0.76	0.66	0.54	0.11
22	2,3,4-trichlorophenol	-	-	-	0.11	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	3.58	3.41	3.05	2.81	1.414

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.330 Total chlorophenolic compounds formed in CEH bleaching by distributing chlorine charge between C & H stages

Distributing chlorine charge C:H						
S.No.	Chlorophenolic compounds(g/T)	**40:60**	**50:50**	**60:40**	**70:30**	**80:20**
1	2,4-dichlorophenol	1.47	2.35	3.26	6.31	7.11
2	3-chlorophenol	0.96	2.83	3.57	4.34	5.14
3	4-chloroguaiacol	0.1	0.08	0.07	0.04	0.02
4	5-chloroguaiacol	0.08	0.07	0.04	0.01	0.004
5	2,3,5-trichlorophenol	0.04	0.36	0.59	0.82	1.12
6	2,4,6-trichlorophenol	9.89	11.96	14.85	15.53	15.31
7	3,6-dichloroguaiacol	0.01	0.03	0.09	0.23	1.3
8	3,4dichlorocatechol	0.88	1.69	2.77	3.84	4.62
9	4,5-dichloroguaiacol	0.32	0.49	0.84	1.29	1.85
10	5,6-dichloroguaiacol	0.16	0.11	0.09	1.95	0.03
11	2,3,4,6-tetrachlorophenol	0.01	0.02	0.06	0.9	0.02
12	3,4,5-trichloroguaiacol	0.53	0.94	1.17	1.97	2.67
13	3,4,6-trichloroguaiacol	1.27	2.10	3.02	3.74	5.20
14	3,5-dichlorosyringol	1.02	1.97	2.63	3.87	4.66
15	3,6-dichlorocatechol	0.11	0.28	0.32	0.87	0.25
16	4,5,6-trichloroguaiacol	0.99	1.37	2.47	4.24	5.47
17	tetrachloroguaiacol	2.31	3.23	3.93	4.14	6.33
18	3,4,6-trichlorocatechol	3.16	3.59	3.83	4.2	3.62
19	2,6-dichlorosyringaldehyde	3.07	4.15	5.50	6.69	7.50
20	5,6-dichlorovanillin	4.01	3.87	3.71	3.74	3.49
21	tetrachlorocatechol	6.87	8.97	11.92	12.01	11.87
22	2,3,4-trichlorophenol	-	-	-	0.11	-
23	4,5-dichlorocatechol	-	-	-	-	-
	TOTAL	37.26	50.46	64.73	80.84	87.58

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Fig. 4.227

EFFECT OF DISTRIBUTION OF Cl_2CHARGE ON C.O.D. GENERATION

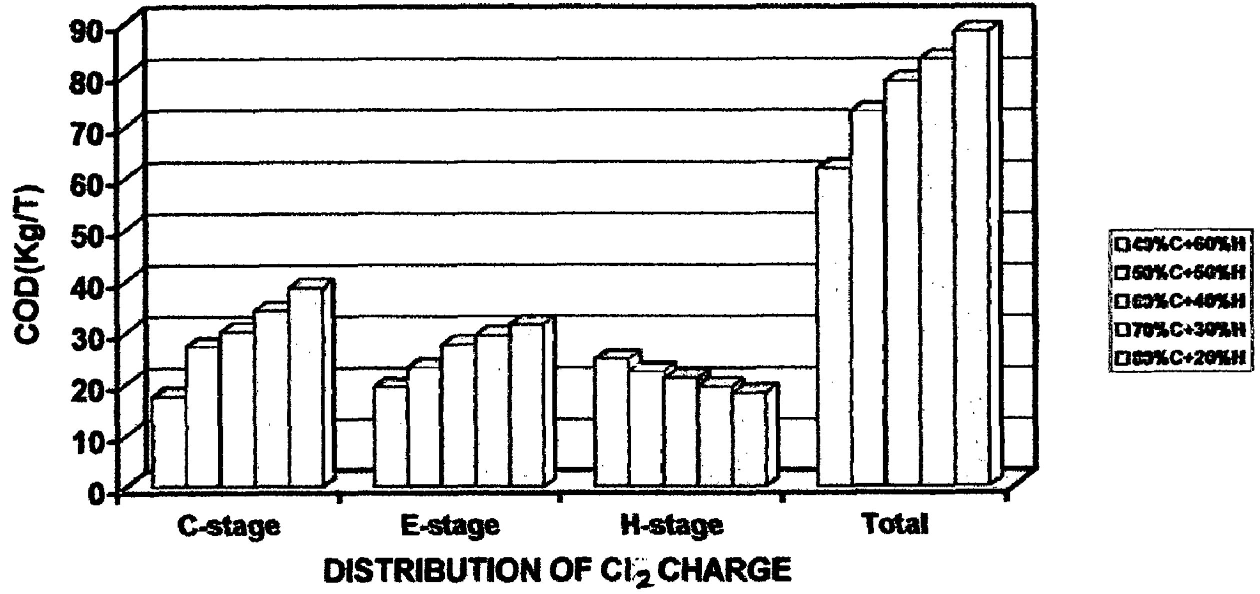


Fig. 4.228

EFFECT OF DISTRIBUTION OF Cl_2 CHARGE ON COLOR GENERATION

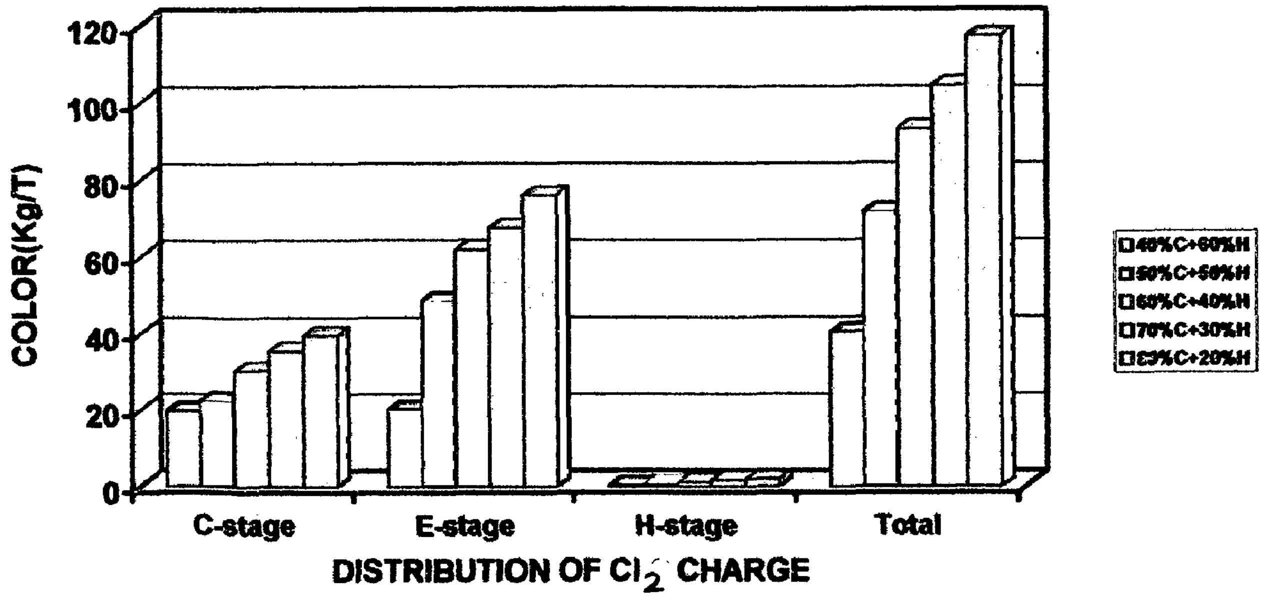


Fig. 4.229

EFFECT OF DISTRIBUTION OF Cl_2 CHARGE ON CHLOROPHENOL GENERATION

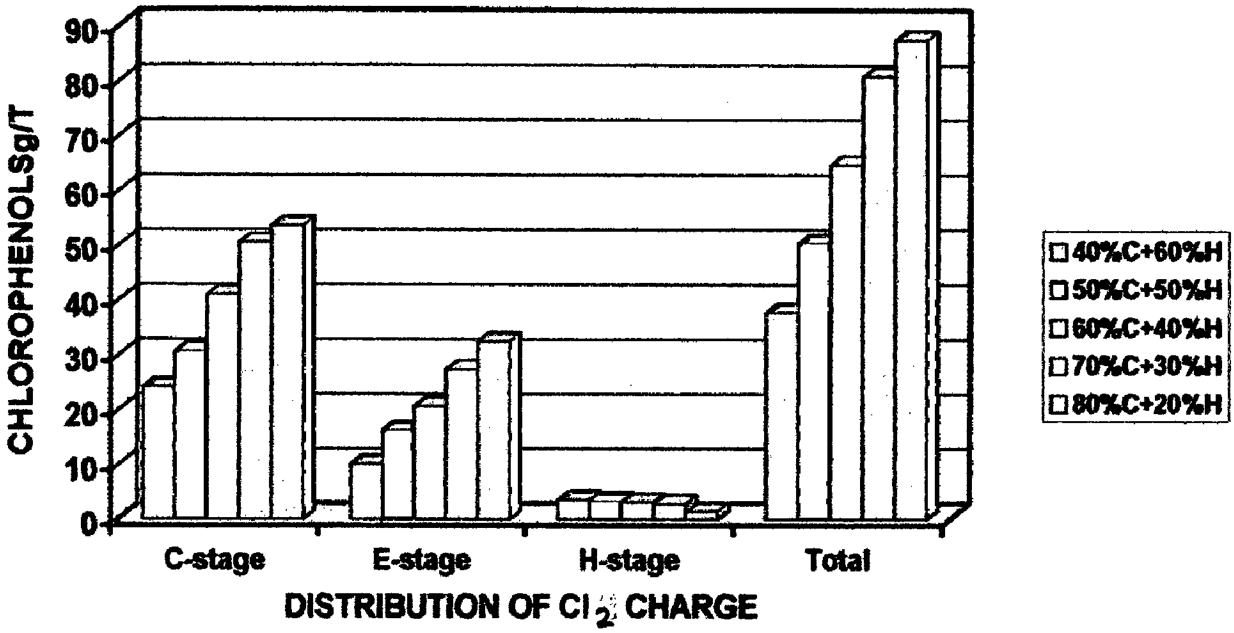


Fig. 4.230

EFFECT OF DISTRIBUTION OF Cl_2 CHARGE ON BRIGHTNESS & VISCOSITY

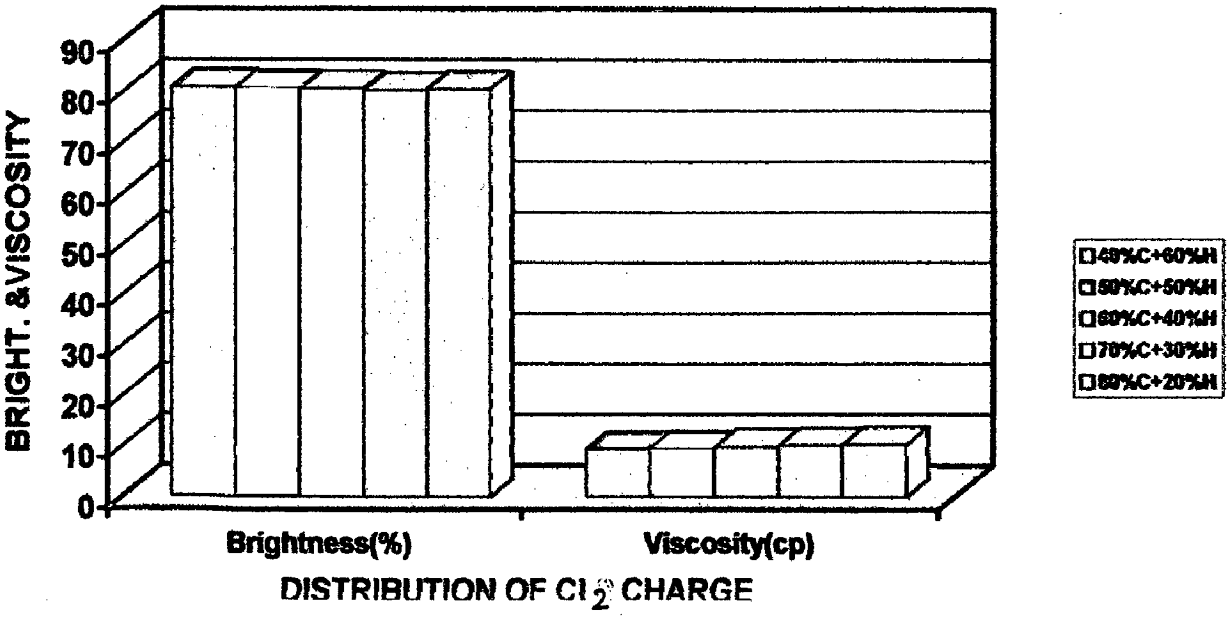


Table 4.134

Formation of different chlorophenolic compounds in various effluents by splitting Chlorine dose in two equal parts in C-stage								
S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	0.32	0.01	0.47	0.02	-	-	0.79
2	3-chlorophenol	2.01	0.04	1.43	0.06	-	-	3.44
3	4-chloroguaiacol	-	-	-	-	0.05	0.002	0.05
4	5-chloroguaiacol	-	-	-	-	0.005	0.0002	0.005
5	2,3,5-trichlorophenol	0.37	0.01	0.34	0.01	-	-	0.71
6	2,4,6-trichlorophenol	2.85	0.06	0.08	0.003	-	-	2.93
7	3,6-dichloroguaiacol	0.02	0.0004	0.09	0.004	-	-	0.11
8	3,4-dichlorocatechol	2.56	0.05	0.64	0.02	-	-	3.20
9	4,5-dichloroguaiacol	0.23	0.005	0.06	0.002	0.22	0.01	0.51
10	5,6-dichloroguaiacol	0.31	0.01	-	-	0.01	0.0004	0.32
11	2,3,4,6-tetrachlorophenol	0.16	0.003	0.01	0.0004	-	-	0.17
12	3,4,5-trichloroguaiacol	0.07	0.001	0.62	0.02	-	-	0.69
13	3,4,6-trichloroguaiacol	-	-	0.13	0.005	-	-	0.13
14	3,5-dichlorosyringol	1.24	0.02	1.02	0.04	0.07	0.003	2.33
15	3,6-dichlorocatechol	-	-	0.84	0.03	-	-	0.84
16	4,5,6-trichloroguaiacol	1.27	0.02	1.16	0.05	-	-	2.43
17	tetrachloroguaiacol	1.83	0.04	0.66	0.03	0.18	0.01	2.67
18	3,4,6-trichlorocatechol	2.54	0.05	1.26	0.05	0.05	0.002	3.85
19	2,6-dichlorosyringaldehyde	2.11	0.04	0.99	0.04	-	-	3.10
20	5,6-dichlorovanillin	0.85	0.02	1.12	0.04	0.22	0.01	2.19
21	tetrachlorocatechol	6.17	0.12	2.76	0.11	0.47	0.02	9.40
22	2,3,4-trichlorophenol	-	-	-	-	0.04	0.002	0.04
23	4,5-dichlorocatechol	-	-	-	-	-	-	
	TOTAL	24.91	0.50	13.68	0.53	1.31	0.06	39.90

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.269 Effect of splitting of chlorine dose in C stage, replacement of H stage by D stage and using an oxygen deliginification stage prior to CEH sequence on the generation of Chlorophenolic compounds

Chlorophenolic compounds (kg/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	50.58	27.45	2.81	80.84
Split Cl_2 dose	24.91	13.68	1.31	39.90
H replaced by D	50.58	27.45	0.46	78.49
O_2 delignification	11.04	8.21	0.70	19.95

Table 4.270 Effect of splitting of chlorine dose in C stage, replacement of H stage by D stage and using an oxygen deliginification stage prior to CEH sequence on the generation of effluent COD

COD (kg/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	34.2	29.4	19.4	83.0
Split Cl_2 dose	28.6	25.3	16.5	70.4
H replaced by D	34.2	29.4	17.3	80.9
O_2 delignification	25.4	22.7	13.4	61.5

Table 4.271 Effect of splitting of chlorine dose in C stage, replacement of H stage by D stage and using an oxygen deliginification stage prior to CEH sequence on the generation of effluent Colour

Colour (kg/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	35.3	67.3	1.7	104.3
Split Cl_2 dose	31.4	58.2	0.1	89.7
H replaced by D	35.3	67.3	0.001	102.6
O_2 delignification	25.3	40.2	0.1	65.6

Table 4.272 Effect of splitting of chlorine dose in C stage, replacement of H stage by D stage and using an oxygen deliginification stage prior to CEH sequence on Brightness and Viscosity of bleached pulps obtained by CEH bleaching

	Brightness (%)	Viscosity (cp)
Normal CEH	80.1	10.1
Split Cl_2 dose	80.9	12.8
H replaced by D	81.5	17.5
O_2 delignification	80.3	9.9

Table 4.134

Formation of different chlorophenolic compounds in various effluents by splitting Chlorine dose in two equal parts in C-stage

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	0.32	0.01	0.47	0.02	-	-	0.79
2	3-chlorophenol	2.01	0.04	1.43	0.06	-	-	3.44
3	4-chloroguaiacol	-	-	-	-	0.05	0.002	0.05
4	5-chloroguaiacol	-	-	-	-	0.005	0.0002	0.005
5	2,3,5-trichlorophenol	0.37	0.01	0.34	0.01	-	-	0.71
6	2,4,6-trichlorophenol	2.85	0.06	0.08	0.003	-	-	2.93
7	3,6-dichloroguaiacol	0.02	0.0004	0.09	0.004	-	-	0.11
8	3,4-dichlorocatechol	2.56	0.05	0.64	0.02	-	-	3.20
9	4,5-dichloroguaiacol	0.23	0.005	0.06	0.002	0.22	0.01	0.51
10	5,6-dichloroguaiacol	0.31	0.01	-	-	0.01	0.0004	0.32
11	2,3,4,6-tetrachlorophenol	0.16	0.003	0.01	0.0004	-	-	0.17
12	3,4,5-trichloroguaiacol	0.07	0.001	0.62	0.02	-	-	0.69
13	3,4,6-trichloroguaiacol	-	-	0.13	0.005	-	-	0.13
14	3,5-dichlorosyringol	1.24	0.02	1.02	0.04	0.07	0.003	2.33
15	3,6-dichlorocatechol	-	-	0.84	0.03	-	-	0.84
16	4,5,6-trichloroguaiacol	1.27	0.02	1.16	0.05	-	-	2.43
17	tetrachloroguaiacol	1.83	0.04	0.66	0.03	0.18	0.01	2.67
18	3,4,6-trichlorocatechol	2.54	0.05	1.26	0.05	0.05	0.002	3.85
19	2,6-dichlorosyringaldehyde	2.11	0.04	0.99	0.04	-	-	3.10
20	5,6-dichlorovanillin	0.85	0.02	1.12	0.04	0.22	0.01	2.19
21	tetrachlorocatechol	6.17	0.12	2.76	0.11	0.47	0.02	9.40
22	2,3,4-trichlorophenol	-	-	-	-	0.04	0.002	0.04
23	4,5-dichlorocatechol	-	-	-	-	-	-	
	TOTAL	24.91	0.50	13.68	0.53	1.31	0.06	39.90

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.135

Formation of different chlorophenolic compounds in various effluents by complete replacement of Hypochlorite stage by Chlorine dioxide stage

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	3.97	0.08	2.34	0.09	0.01	0.0004	6.32
2	3-chlorophenol	2.21	0.04	2.04	0.08	0.03	0.001	4.28
3	4-chloroguaiacol	-	-	-	-	0.003	0.0001	0.003
4	5-chloroguaiacol	-	-	-	-	0.005	0.0002	0.005
5	2,3,5-trichlorophenol	0.10	0.002	0.72	0.03	-	-	0.82
6	2,4,6-trichlorophenol	9.74	0.19	5.01	0.2	0.01	0.0004	14.76
7	3,6-dichloroguaiacol	0.09	0.002	0.14	0.006	-	-	0.23
8	3,4-dichlorocatechol	2.87	0.06	0.97	0.04	-	-	3.84
9	4,5-dichloroguaiacol	0.25	0.005	0.76	0.03	0.06	0.002	1.07
10	5,6-dichloroguaiacol	1.31	0.03	0.57	0.02	0.04	0.002	1.92
11	2,3,4,6-tetrachlorophenol	0.84	0.02	0.06	0.002	-	-	0.90
12	3,4,5-trichloroguaiacol	1.08	0.02	0.89	0.03	-	-	1.97
13	3,4,6-trichloroguaiacol	3.53	0.07	0.21	0.01	0.01	0.0004	3.75
14	3,5-dichlorosyringol	2.58	0.05	1.12	0.04	0.11	0.004	3.81
15	3,6-dichlorocatechol	-		0.87	0.03	-	-	0.87
16	4,5,6-trichloroguaiacol	2.12	0.04	2.12	0.08	-	-	4.24
17	tetrachloroguaiacol	3.10	0.06	0.77	0.03	0.02	0.001	3.89
18	3,4,6-trichlorocatechol	2.36	0.05	1.74	0.07	0.04	0.002	4.14
19	2,6-dichlorosyringaldehyde	4.95	0.1	1.74	0.07	-	-	6.69
20	5,6-dichlorovanillin	1.16	0.02	2.23	0.09	0.09	0.004	3.48
21	tetrachlorocatechol	8.32	0.17	3.15	0.13	0.03	0.001	11.5
22	2,3,4-trichlorophenol	-		-	-	-	-	
23	4,5-dichlorocatechol	-		-	-	-	-	
	TOTAL	50.58	1.01	27.45	1.08	0.46	0.02	78.49

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.136

Formation of different chlorophenolic compounds in various effluents by using an Oxygen delignification stage prior to CEH sequence

S.No.	Chlorophenolic compound	C stage		E stage		H stage		Total
		g\T	mg\l	g\T	mg\l	g\T	mg\l	g\T
1	2,4-dichlorophenol	0.07	0.001	0.29	0.01	-	-	0.36
2	3-chlorophenol	0.21	0.004	0.89	0.03	-	-	1.10
3	4-chloroguaiacol	-	-	-	-	0.01	0.0004	0.01
4	5-chloroguaiacol	-	-	-	-		-	
5	2,3,5-trichlorophenol	0.01	0.0002	0.18	0.01	-	-	0.19
6	2,4,6-trichlorophenol	1.85	0.04	0.02	0.001	0.33	0.01	2.20
7	3,6-dichloroguaiacol	0.004	0.0001	0.01	0.0004	-	-	0.014
8	3,4-dichlorocatechol	0.37	0.01	0.14	0.01	-	-	0.51
9	4,5-dichloroguaiacol	0.04	0.001	0.01	0.0004	0.05	0.002	0.10
10	5,6-dichloroguaiacol	-	-	-	-	0.005	0.0002	0.005
11	2,3,4,6-tetrachlorophenol	-	-	0.01	0.0004	-	-	0.01
12	3,4,5-trichloroguaiacol	0.05	0.001	0.37	0.01	-	-	0.42
13	3,4,6-trichloroguaiacol	1.22	0.02	0.06	0.002	-	-	1.28
14	3,5-dichlorosyringol	0.39	0.01	0.76	0.03	0.003	0.0001	1.153
15	3,6-dichlorocatechol	-	-	0.40	0.02	-	-	0.40
16	4,5,6-trichloroguaiacol	0.54	0.01	0.91	0.04	-	-	1.45
17	tetrachloroguaiacol	1.08	0.02	0.46	0.02	0.09	0.004	1.63
18	3,4,6-trichlorocatechol	0.45	0.01	0.88	0.03	0.02	0.001	1.35
19	2,6-dichlorosyringaldehyde	2.17	0.04	0.78	0.03	-	-	2.95
20	5,6-dichlorovanillin	0.48	0.01	1.03	0.04	0.04	0.002	1.55
21	tetrachlorocatechol	2.11	0.04	1.01	0.04	0.14	0.01	3.26
22	2,3,4-trichlorophenol	-	-	-	-	0.01	0.0004	0.01
23	4,5-dichlorocatechol	-	-	-	-	-	-	
	TOTAL	11.04	0.22	8.21	0.32	0.70	0.03	19.95

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C, Consistency 3%

Table 4.269 Effect of splitting of chlorine dose in C stage, replacement of H stage by D stage and using an oxygen deliginification stage prior to CEH sequence on the generation of Chlorophenolic compounds

Chlorophenolic compounds (kg/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	50.58	27.45	2.81	80.84
Split Cl_2 dose	24.91	13.68	1.31	39.90
H replaced by D	50.58	27.45	0.46	78.49
O_2 delignification	11.04	8.21	0.70	19.95

Table 4.270 Effect of splitting of chlorine dose in C stage, replacement of H stage by D stage and using an oxygen deliginification stage prior to CEH sequence on the generation of effluent COD

COD (kg/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	34.2	29.4	19.4	83.0
Split Cl_2 dose	28.6	25.3	16.5	70.4
H replaced by D	34.2	29.4	17.3	80.9
O_2 delignification	25.4	22.7	13.4	61.5

Table 4.271 Effect of splitting of chlorine dose in C stage, replacement of H stage by D stage and using an oxygen deliginification stage prior to CEH sequence on the generation of effluent Colour

Colour (kg/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	35.3	67.3	1.7	104.3
Split Cl_2 dose	31.4	58.2	0.1	89.7
H replaced by D	35.3	67.3	0.001	102.6
O_2 delignification	25.3	40.2	0.1	65.6

Table 4.272 Effect of splitting of chlorine dose in C stage, replacement of H stage by D stage and using an oxygen deliginification stage prior to CEH sequence on Brightness and Viscosity of bleached pulps obtained by CEH bleaching

	Brightness (%)	Viscosity (cp)
Normal CEH	80.1	10.1
Split Cl_2 dose	80.9	12.8
H replaced by D	81.5	17.5
O_2 delignification	80.3	9.9

Table 4.273 Monochlorophenolic compounds present in different effluents formed by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

Monochlorophenolic compounds (g/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	2.21	2.04	0.14	4.39
Split Cl_2 dose	2.01	1.43	0.05	3.49
H replaced by D	2.21	2.04	0.04	4.29
O_2 delignification	0.21	0.89	0.01	1.11

Table 4.274 Dichlorophenolic compounds present in different effluents formed by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

Dichlorophenolic compounds (g/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	17.18	10.74	0.14	28.06
Split Cl_2 dose	7.64	5.23	0.52	13.39
H replaced by D	17.18	10.74	0.31	28.23
O_2 delignification	3.52	3.42	0.10	7.04

Table 4.275 Trichlorophenolic compounds present in different effluents formed by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

Trichlorophenolic compounds (g/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	18.93	10.69	0.99	30.61
Split Cl_2 dose	7.10	3.59	0.09	10.78
H replaced by D	18.93	10.69	0.05	29.67
O_2 delignification	4.12	2.42	0.36	6.90

Table 4.276 Tetrachlorophenolic compounds present in different effluents formed by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

Tetrachlorophenolic compounds (g/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	12.26	3.98	0.81	17.05
Split Cl_2 dose	8.16	3.43	0.65	12.24
H replaced by D	12.26	3.98	0.05	16.29
O_2 delignification	3.19	1.48	0.23	4.90

Table 4.277 Category wise load of chlorophenols in different effluents formed by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

Chlorophenols (g/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	16.86	10.17	0.98	28.01
Split Cl_2 dose	5.71	2.33	0.04	8.08
H replaced by D	16.86	10.17	0.05	27.08
O_2 delignification	2.14	1.39	0.34	3.87

Table 4.278 Category wise load of chloroguaiacols in different effluents formed by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

Chloroguaiacols (g/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	11.48	5.46	0.67	17.61
Split Cl_2 dose	3.73	2.72	0.46	6.91
H replaced by D	11.48	5.46	0.14	17.08
O_2 delignification	2.93	1.82	0.15	4.90

Table 4.279 Category wise load of chlorocatechols in different effluents formed by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

Chlorocatechols (g/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	13.55	6.73	0.64	20.92
Split Cl_2 dose	11.27	5.5	0.52	17.29
H replaced by D	13.55	6.73	0.07	20.35
O_2 delignification	2.93	2.43	0.16	5.52

Table 4.280 Category wise load of other chlorophenolic compounds in different effluents formed by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

Other Chlorophenolic compounds (g/t)				
	C-stage	E-stage	H-stage	TOTAL
Normal CEH	8.69	5.09	0.52	14.30
Split Cl_2 dose	4.20	3.13	0.29	7.62
H replaced by D	8.69	5.09	0.20	13.98
O_2 delignification	3.04	2.57	0.04	5.65

Table 4.331 Different chlorophenolic compounds formed in C stage by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEII sequence

splitting of chlorine dose, replacing II by D and using O_2 delignification stage prior to CEH sequence					
S.No.	Chlorophenolic compounds(g/T)	Normal CEH	Split Cl_2 dose	II replaced by D	O_2delignific -ation
1	2,4-dichlorophenol	3.97	0.32	3.97	0.07
2	3-chlorophenol	2.21	2.01	2.21	0.21
3	4-chloroguaiacol	-	-	-	-
4	5-chloroguaiacol	-	-	-	-
5	2,3,5-trichlorophenol	0.10	0.37	0.10	0.01
6	2,4,6-trichlorophenol	9.74	2.85	9.74	1.85
7	3,6-dichloroguaiacol	0.09	0.02	0.09	0.004
8	3,4dichlorocatechol	2.87	2.56	2.87	0.37
9	4,5-dichloroguaiacol	0.25	0.23	0.25	0.04
10	5,6-dichloroguaiacol	1.31	0.31	1.31	-
11	2,3,4,6-tetrachlorophenol	0.84	0.16	0.84	-
12	3,4,5-trichloroguaiacol	1.08	0.07	1.08	0.05
13	3,4,6-trichloroguaiacol	3.53	-	3.53	1.22
14	3,5-dichlorosyringol	2.58	1.24	2.58	0.39
15	3,6-dichlorocatechol	-	-	-	-
16	4,5,6-trichloroguaiacol	2.12	1.27	2.12	0.54
17	tetrachloroguaiacol	3.10	1.83	3.10	1.08
18	3,4,6-trichlorocatechol	2.36	2.54	2.36	0.45
19	2,6-dichlorosyringaldehyde	4.95	2.11	4.95	2.17
20	5,6-dichlorovanillin	1.16	0.85	1.16	0.48
21	tetrachlorocatechol	8.32	6.17	8.32	2.11
22	2,3,4-trichlorophenol	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-
	TOTAL	50.58	24.91	50.58	11.04

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30°C

Table 4.332 Different chlorophenolic compounds formed in E stage by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence					
S.No.	Chlorophenolic compounds(g/T)	Normal CEH	Split Cl_2 dose	H replaced by D	O_2deligni fic-ation
1	2,4-dichlorophenol	2.34	0.47	2.34	0.29
2	3-chlorophenol	2.04	1.43	2.04	0.89
3	4-chloroguaiacol	-	-	-	-
4	5-chloroguaiacol	-	-	-	-
5	2,3,5-trichlorophenol	0.72	0.34	0.72	0.18
6	2,4,6-trichlorophenol	5.01	0.08	5.01	0.02
7	3,6-dichloroguaiacol	0.14	0.09	0.14	0.01
8	3,4dichlorocatechol	0.97	0.64	0.97	0.14
9	4,5-dichloroguaiacol	0.76	0.06	0.76	0.01
10	5,6-dichloroguaiacol	0.57	-	0.57	-
11	2,3,4,6-tetrachlorophenol	0.06	0.01	0.06	0.01
12	3,4,5-trichloroguaiacol	0.89	0.62	0.89	0.37
13	3,4,6-trichloroguaiacol	0.21	0.13	0.21	0.06
14	3,5-dichlorosyringol	1.12	1.02	1.12	0.76
15	3,6-dichlorocatechol	0.87	0.84	0.87	0.40
16	4,5,6-trichloroguaiacol	2.12	1.16	2.12	0.91
17	tetrachloroguaiacol	0.77	0.66	0.77	0.46
18	3,4,6-trichlorocatechol	1.74	1.26	1.74	0.88
19	2,6-dichlorosyringaldehyde	1.74	0.99	1.74	0.78
20	5,6-dichlorovanillin	2.23	1.12	2.23	1.03
21	tetrachlorocatechol	3.15	2.76	3.15	1.01
22	2,3,4-trichlorophenol	-	-	-	-
23	4,5-dichlorocatechol	-	-	-	-
	TOTAL	27.45	13.68	27.45	8.21

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C

Table 4.333 Different chlorophenolic compounds formed in H stage by splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence					
S.No.	Chlorophenolic compounds(g/T)	Normal CEH	Split Cl_2 dose	H replaced by D	O_2delignifi c-ation
1	2,4-dichlorophenol	-	-	0.01	-
2	3-chlorophenol	0.09	-	0.03	-
3	4-chloroguaiacol	0.04	0.05	0.003	0.01
4	5-chloroguaiacol	0.01	0.005	0.005	-
5	2,3,5-trichlorophenol	-	-	-	-
6	2,4,6-trichlorophenol	0.78	-	0.01	0.33
7	3,6-dichloroguaiacol	-	-	-	-
8	3,4dichlorocatechol	-	-	-	-
9	4,5-dichloroguaiacol	0.28	0.22	0.06	0.05
10	5,6-dichloroguaiacol	0.07	0.01	0.04	0.005
11	2,3,4,6-tetrachlorophenol	-	-	-	-
12	3,4,5-trichloroguaiacol	-	-	-	-
13	3,4,6-trichloroguaiacol	-	-	0.01	-
14	3,5-dichlorosyringol	0.17	0.07	0.11	0.003
15	3,6-dichlorocatechol	-	-	-	-
16	4,5,6-trichloroguaiacol	-	-	-	-
17	tetrachloroguaiacol	0.27	0.18	0.02	0.09
18	3,4,6-trichlorocatechol	0.10	0.05	0.04	0.02
19	2,6-dichlorosyringaldehyde	-	-	-	-
20	5,6-dichlorovanillin	0.35	0.22	0.09	0.04
21	tetrachlorocatechol	0.54	0.47	0.03	0.14
22	2,3,4-trichlorophenol	0.11	0.04	-	0.01
23	4,5-dichlorocatechol	-	-	-	-
	TOTAL	2.81	1.31	0.46	0.70

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^0C

Table 4.334 Total chlorophenolic compounds formed in CEH bleaching by splitting of chlorine dose, replacing II by D and using O_2 delignification stage prior to CEH sequence

splitting of chlorine dose, replacing H by D and using O_2 delignification stage prior to CEH sequence

S.No.	Chlorophenolic compounds(g/T)	Normal CEH	Split Cl_2 dose	H replaced by D	O_2delignific -ation
1	2,4-dichlorophenol	6.31	0.79	6.32	0.36
2	3-chlorophenol	4.34	3.44	4.28	1.10
3	4-chloroguaiacol	0.04	0.05	0.003	0.01
4	5-chloroguaiacol	0.01	0.005	0.005	-
5	2,3,5-trichlorophenol	0.82	0.71	0.82	0.19
6	2,4,6-trichlorophenol	15.53	2.93	14.76	2.20
7	3,6-dichloroguaiacol	0.23	0.11	0.23	0.014
8	3,4dichlorocatechol	3.84	3.2	3.84	0.51
9	4,5-dichloroguaiacol	1.29	0.51	1.07	0.10
10	5,6-dichloroguaiacol	1.95	0.32	1.92	0.005
11	2,3,4,6-tetrachlorophenol	0.9	0.17	0.90	0.01
12	3,4,5-trichloroguaiacol	1.97	0.69	1.97	0.42
13	3,4,6-trichloroguaiacol	3.74	0.13	3.75	1.28
14	3,5-dichlorosyringol	3.87	2.33	3.81	1.153
15	3,6-dichlorocatechol	0.87	0.84	0.87	0.40
16	4,5,6-trichloroguaiacol	4.24	2.43	4.24	1.45
17	tetrachloroguaiacol	4.14	2.67	3.89	1.63
18	3,4,6-trichlorocatechol	4.2	3.85	4.14	1.35
19	2,6-dichlorosyringaldehyde	6.69	3.10	6.69	2.95
20	5,6-dichlorovanillin	3.74	2.19	3.48	1.55
21	tetrachlorocatechol	12.01	9.40	11.50	3.26
22	2,3,4-trichlorophenol	0.11	0.04	-	0.01
23	4,5-dichlorocatechol	-	-	-	-
	TOTAL	80.84	39.90	78.49	19.95

C Stage bleaching conditions: Charge 5.1%, pH 2, Temperature 30^{0}C

Fig. 4.231

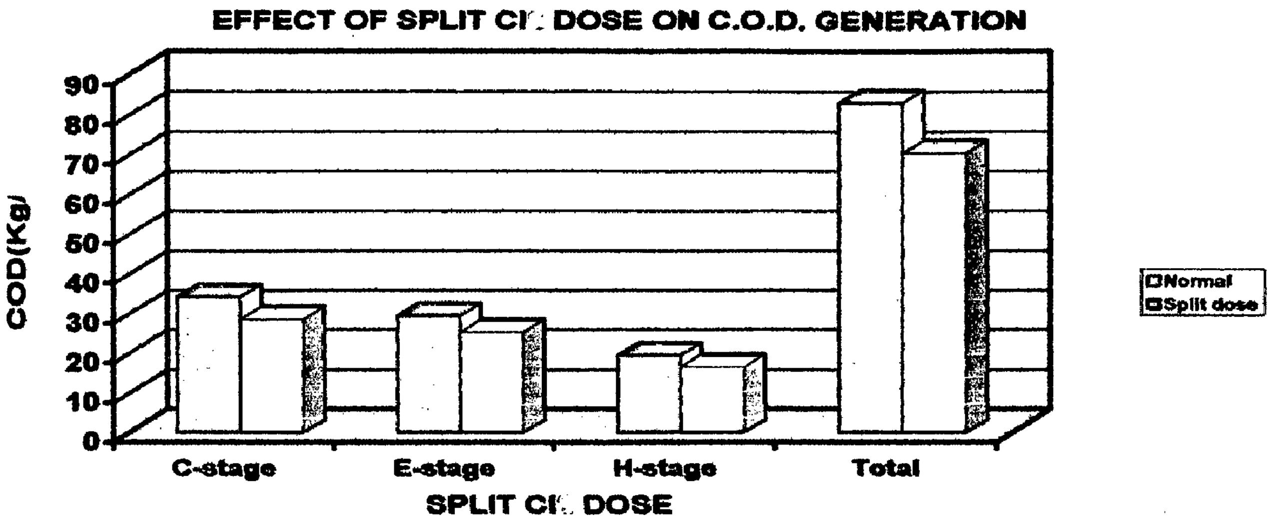
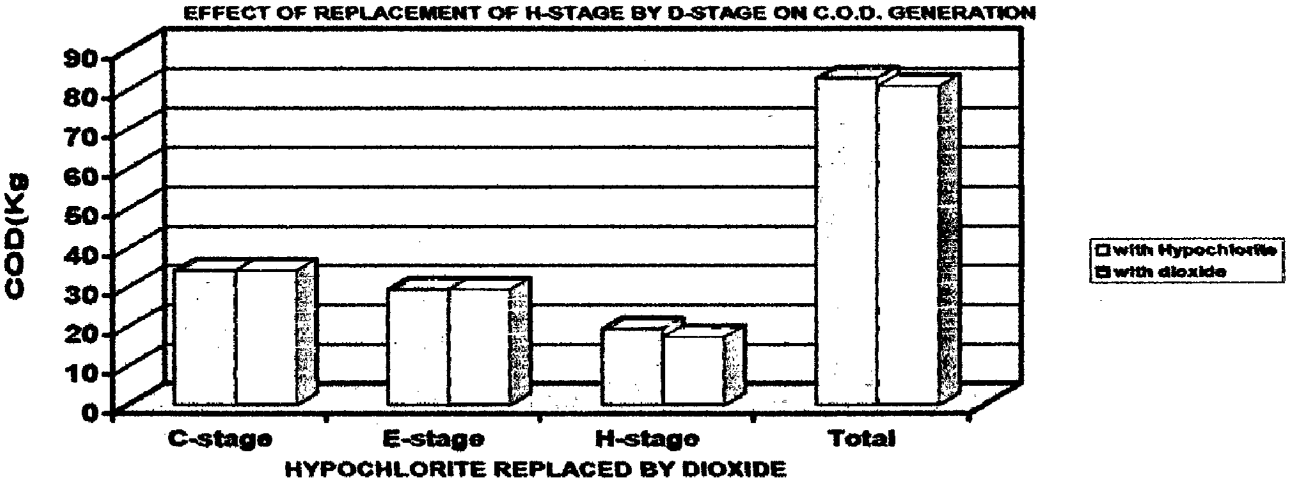


Fig. 4.232



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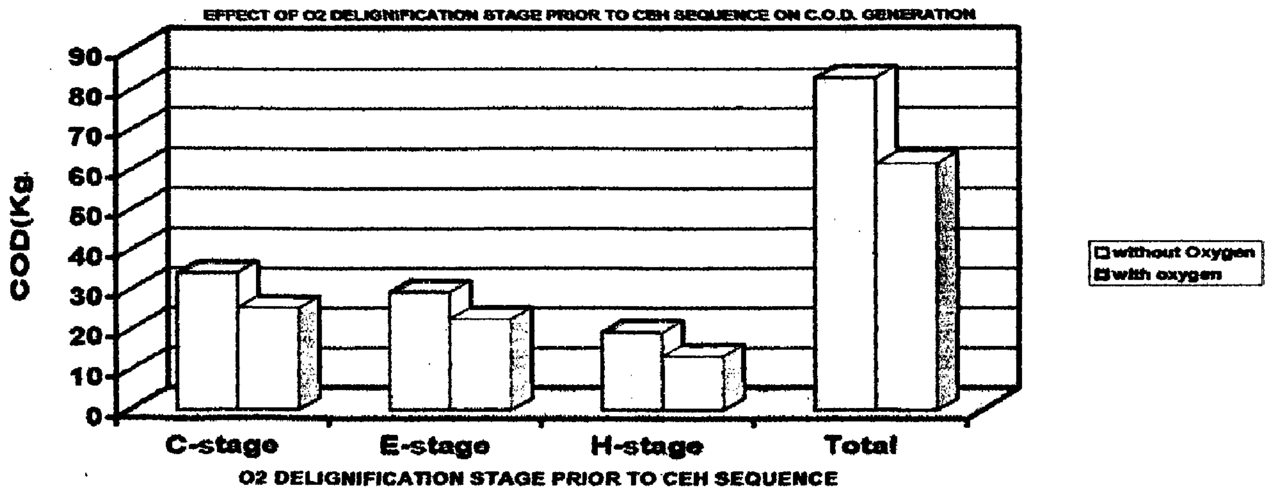

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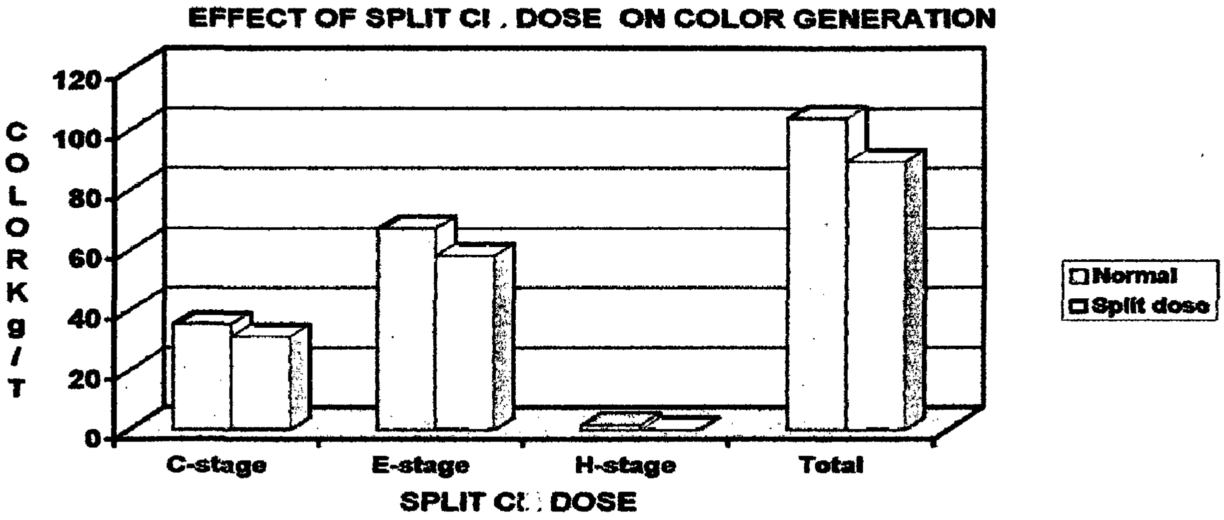
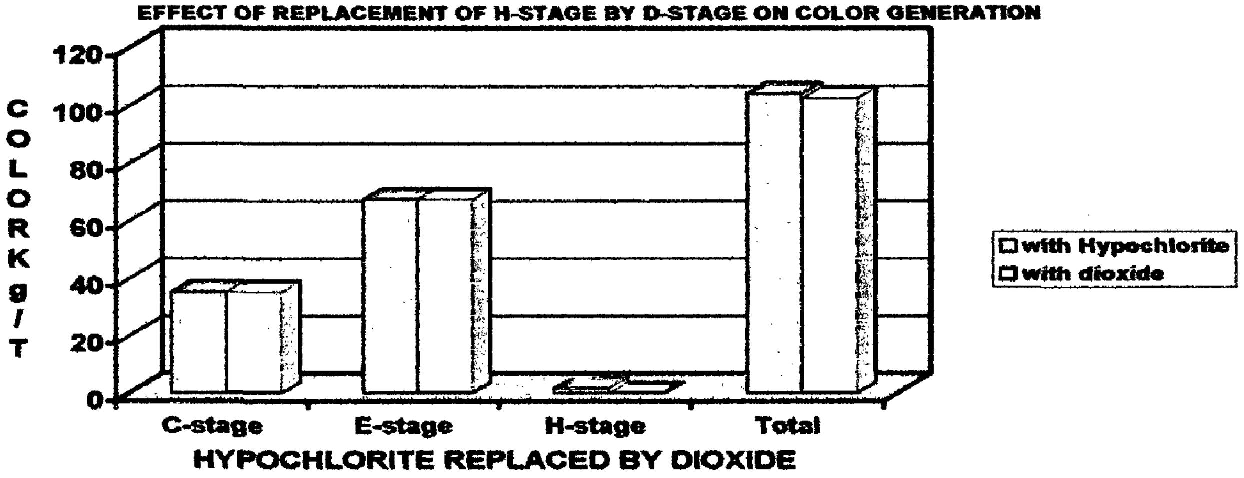


Fig. 4.235



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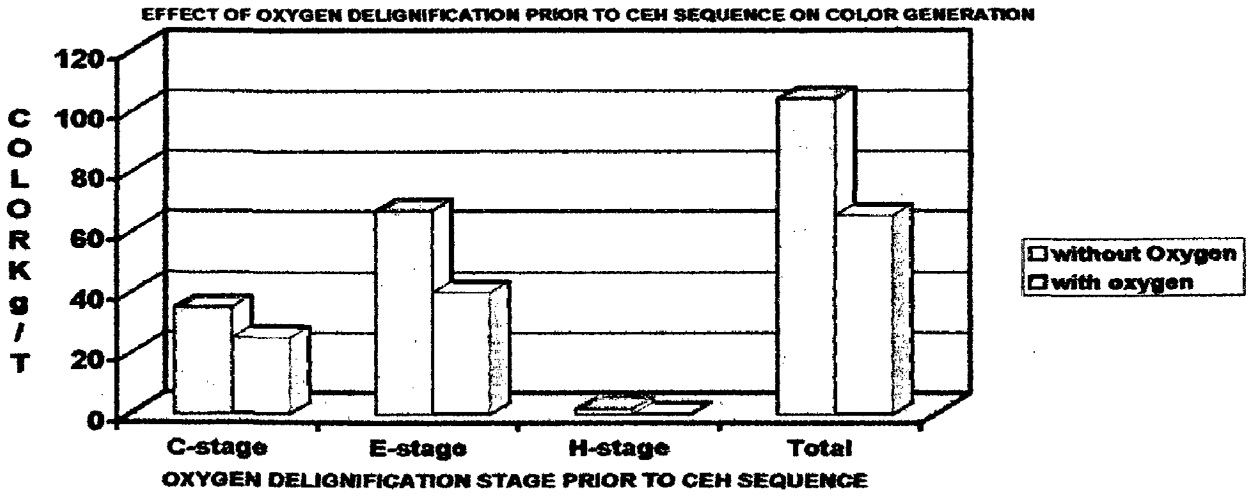

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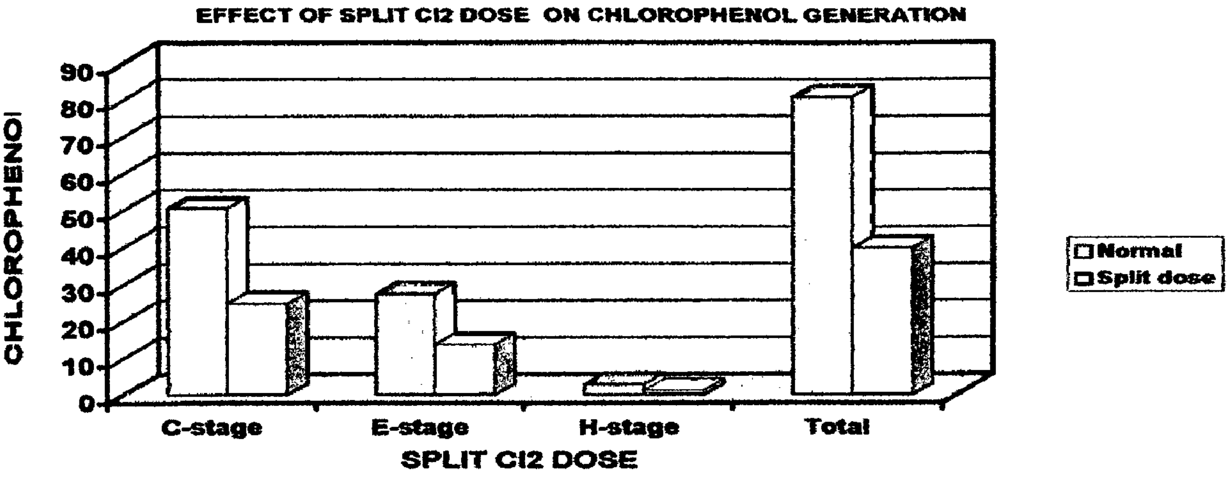

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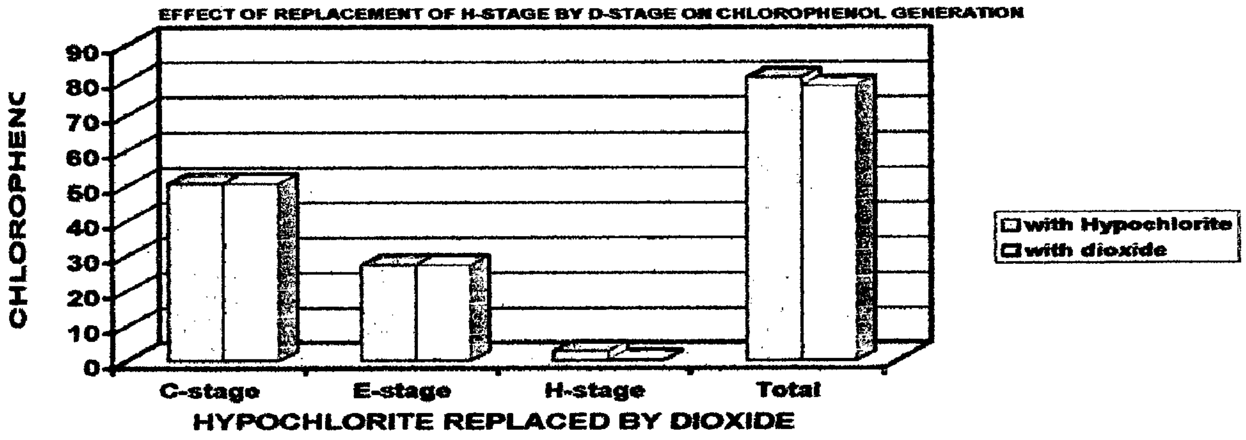


Fig. 4.239

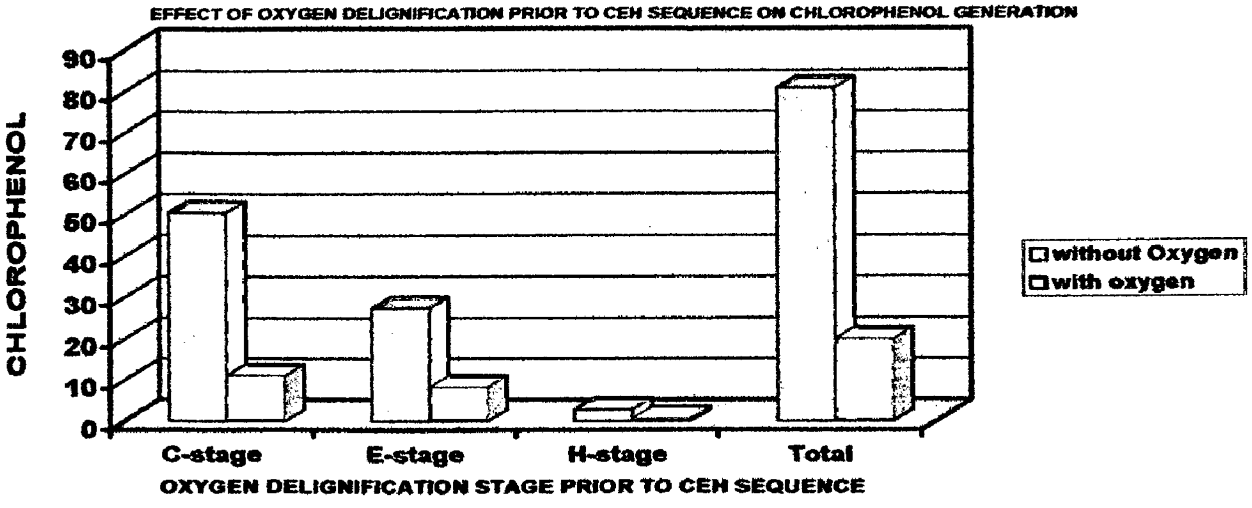


Fig. 4.240

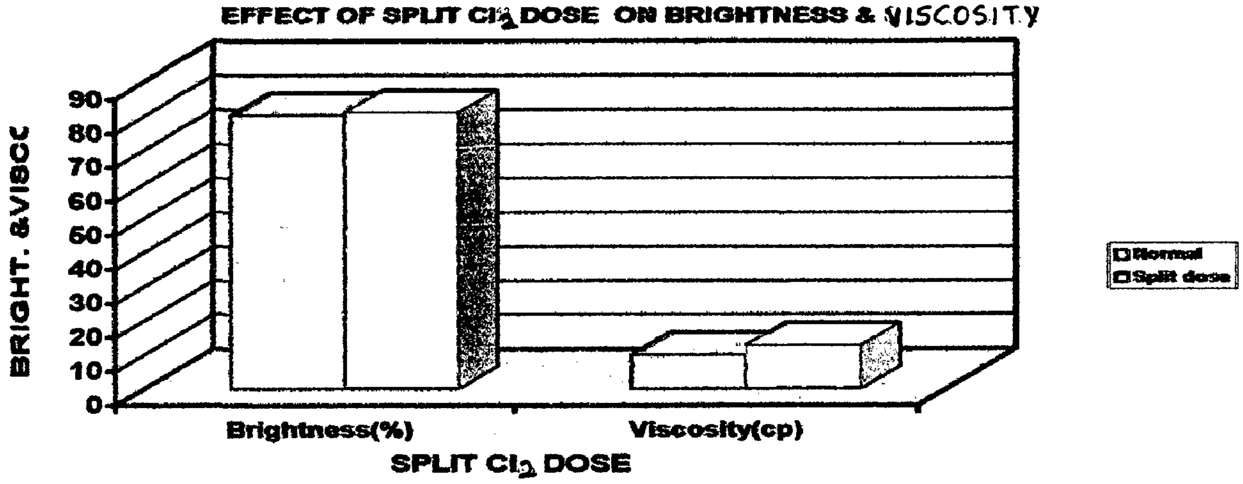


Fig. 4.241

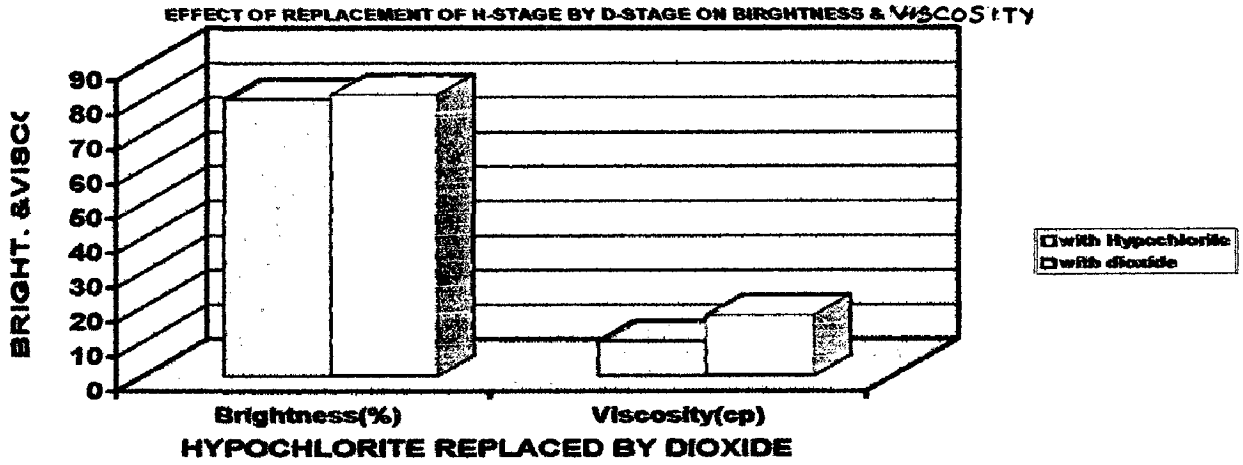
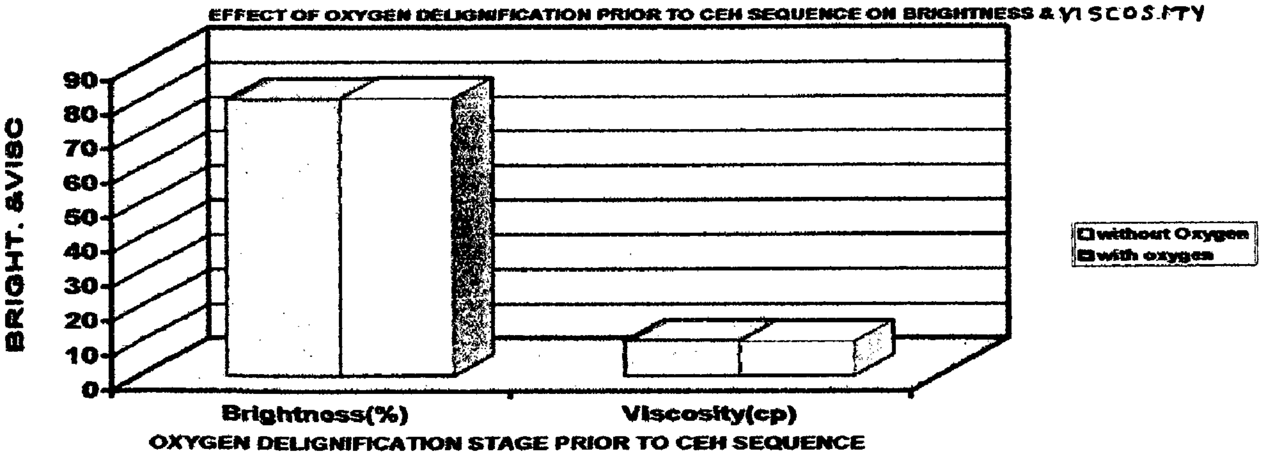


Fig. 4.242



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CHAPTER 5

CONCLUSIONS

From the present study the following conclusions are drawn:

1) A target brightness of 80% ISO is achievable for both wheat straw and sarkanda pulps using CEH, CED and OCEH sequences.

2) The possibility exists in reducing the generation of chlorophenolics by altering the C stage bleaching conditions for both wheat straw and sarkanda soda pulps.

3) The total chlorophenolics generated with sarkanda pulp were less when compared with wheat straw pulp. This is due to low kappa number and lower chlorine charged in sarkanda pulp.

4) Increase in C stage pH decreases the formation of various chlorophenols in C, E, H stage effluents and combined CEH effluent, with certain amount of reduction in effluent COD and colour and drop in pulp viscosity.

5) Raising C stage temperature increases the quantity of chlorophenolics formed, with a marginal increase in COD and colour and drop in pulp viscosity.

6) The total chlorophenolic compounds generated in C, E, H stage effluents and combined CEH effluent increase with increase in C stage pulp consistency. The effluent COD and colour increases with drop in viscosity.

7) The partial substitution of chlorine by chlorine dioxide reduces the formation of chlorophenolic compounds, effluent COD and colour, but increases pulp viscosity and brightness appreciably.

8) The quantity of chlorinated phenolic compounds formed in C, E, H stage effluents and combined CEH effluent increase with increase in proportion of chlorine in C stage from 40% to 80% and decrease with decrease in proportion of hypochlorite from 60% to 20% in H stage, with a drop in pulp viscosity.

9) Splitting of chlorine dose in C stage in two equal half, decreases the generation of chlorophenols considerably in both wheat straw and sarkanda pulps. The effluent COD and colour formation also decrease with improvement in the pulp brightness and viscosity, indicating that splitting of chlorine dose reduces the pollution load and gives a stronger and brighter pulp.

10) Replacing the hypochlorite stage by dioxide in wheat straw and sarkanda pulps, the formation of various chlorophenolics was found to decrease. The effluent COD and colour decrease but there is immense improvement in brightness and viscosity of these pulps as hypochlorite is strongly pulp degrading where as chlorine dioxide is inert to pulp, thus giving a stronger pulp.

11) By introducing oxygen pre-bleaching stage, the kappa number of the pulp was lowered which reduces the active chlorine multiple in conventional CEH bleaching and consequently lowers formation of chlorinated organic compounds with a reduction in effluent COD and colour.

ABBREVIATIONS

AOX	:	Adsorbable Organic Halides
AQ	:	Anthraquinone
ASB	:	Aerated Stablization Basin
ASP	:	Activated Sludge Process
BCRC	:	British Columbia Research Canada
BOD	:	Biochemical Oxygen Demand
CED	:	Cupriethylenediamine
COD	:	Chemical Oxygen Demand
Cy	:	Consistency
ECD	:	Electron Capture Detector
EMCC	:	Extended Modified Continuous Cooking
EOX	:	Extractable Organic Halides
ETP	:	End of Pipe Treatment
FID	:	Flame Ionization Detector
GC	:	Gas Chromatograph
HPLC	:	High Performance Liquid Chromatography
LC	:	Lethal Concentration
LR	:	Laboratory Reagent
MCC	:	Modified Continuous Cooking
OD	:	Oven Dry
PC No.	:	Post Colour number
PCDF	:	Poly-Chlorinated Dibenzofuran
PCPD	:	Poly-Chlorinated Dibenzodioxin
POX	:	Purgable Organic Halides
RDH	:	Rapid Displacement Heating
RPM	:	Rotation Per Minute
TCDD	:	2,3,7,8-Tetra Chlorodibenzo-p-dioxin
TOCL	:	Total Organic Chlorides