LABORATORY EVALUATION OF WASHING CHARACTERISTICS OF BROWN STOCK

A DISSERTATION

Submitted in partial fulfilment of the
requirements for the award of the degree
Of
MASTER OF ENGINEERING
In
PULP AND PAPER TECHNOLOGY

By
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CANDIDATE'S DECELARATION

I hereby declare that the work which is being presented in this dissertation entitled "LABORATORY EVALUATION OF WASHING CHARACTERISTICS OF BROWN STOCK" in partial fulfilment of the requirements for the award of the degree of Master of Engineering in Pulp and Paper Technology, University of Roorkee, is an authentic record of my own work carried out from July 1994 to March 1995, under the supervision Dr. A.K. Ray and Dr. N.J. Rao, Institute of Paper Technology (University of Roorkee) Saharanpur.

The matter embodied in this disseratation has not been submitted by me for the award of any other degree.

Dated : March 31st, 1995

Place : Saharanpur

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This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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ABSTRACT

A brown stock washing is the most important operation in the pulp mill controlling on one hand, the cleanliness of the pulp for bleaching and reducing bleach demand and on the other hand going black liquors of acceptable concentration on for further processing in recovery plant. To control and to optimize the various process variables of a washer in the industry one can study the parameters on laboratory vacuum filters continently industry filters are not amenable for experimentation and cannot provide data for rational analysis so easily.

Institute of Paper Technology has an EMICO-KCP vacuum drum washer of size 18" x 12" (45cm x 30 cm). The system was not in running condition. The system has to be installed after making the modification in the setup as some of the components are missing/not supplied originally. Therefore the installation and commissioning of the equipment was the first major step of the work. The installation required modification of some components and assembly of various sections. The modification includes wash liquor shower system, vacuum gauge setting, seal water arrangement in vacuum pump, exhaust snubber arrangement to vacuum pump, receiving line installation to vacuum receiver, filter cloth installation on drum, feed pump connection and electrical connection. The system was commissioned and trails are taken with the water and lime sludge. All these activities took the major part of the time.

Experiments were planned for conducting washing trials with brown stock obtained from a nearby paper mill. The experiments includes variation of wash water flow rate, drum speed, vat consistency and drum submergence. Only limited data could be taken due to paucity of time.

The experimental data is analyzed. Simultaneously the operating data of brown stock system of a nearby mill (3- stage counter current brown stock washing on rotary vacuum drum filter) is taken and analyzed. Using the Perkin's method, Equivalent displacement ratio method. Norden factor method and the fundamental methods. The comparison are presented in the report.

CONTENTS

CHAPTER - 1

INTRODUCTION:

The primary reason for washing the cooked pulp is to produce clean pulp with least amount of carry over solids. Pulp is also washed to recover (a) expensive cooking chemicals and (b) organic matters, which are recovered for their heating value. The strict pollution laws forbid the sewering of cooking liquors demanding a very high degree of chemical recovery with improved washing operation.

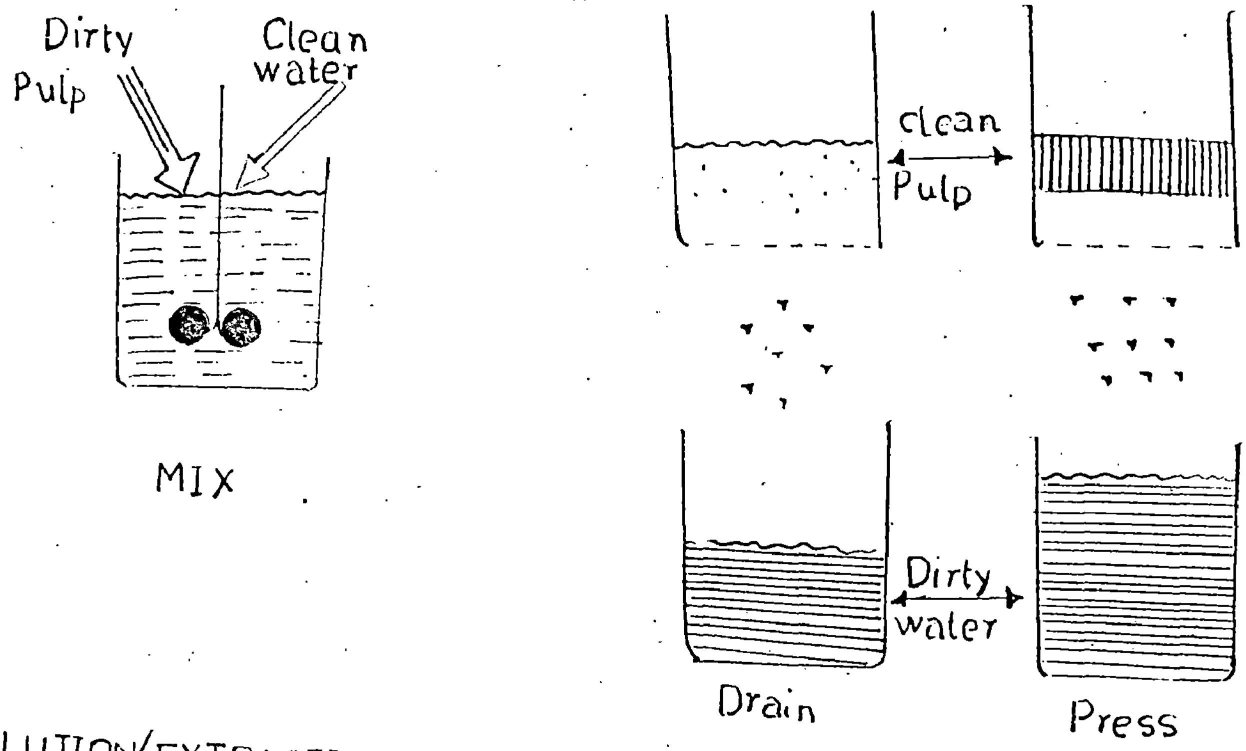
The performance of brown stock washing is conventionally expressed in terms of make up inorganic chemicals as a soda loss (kg sodium sulfate/tonne pulp). In the present day with greater environmental stress, the performance of a brown stock washing system is expressed in terms of COD/BOD values of the pulp. A better method of expressing the performance would be in terms of total dissolved solids/tonne of pulp which includes both organic and inorganic compounds. This should be balanced in terms of various other input parameters to the process. The parameters are dilution factor and washed liquor ratio, in addition to usual parameters like pulp consistency, black liquor concentration, temperature of wash water and vacuum applied to the system. A particular size of drum, drum vat, angle of submergence, degree of rotation in the vat, wash liquor distribution, zones for washing are the other parameters. Number of washers for counter current washing also play a vital role for optimizing the efficiency.

1.1 Basic pulp washing operations:

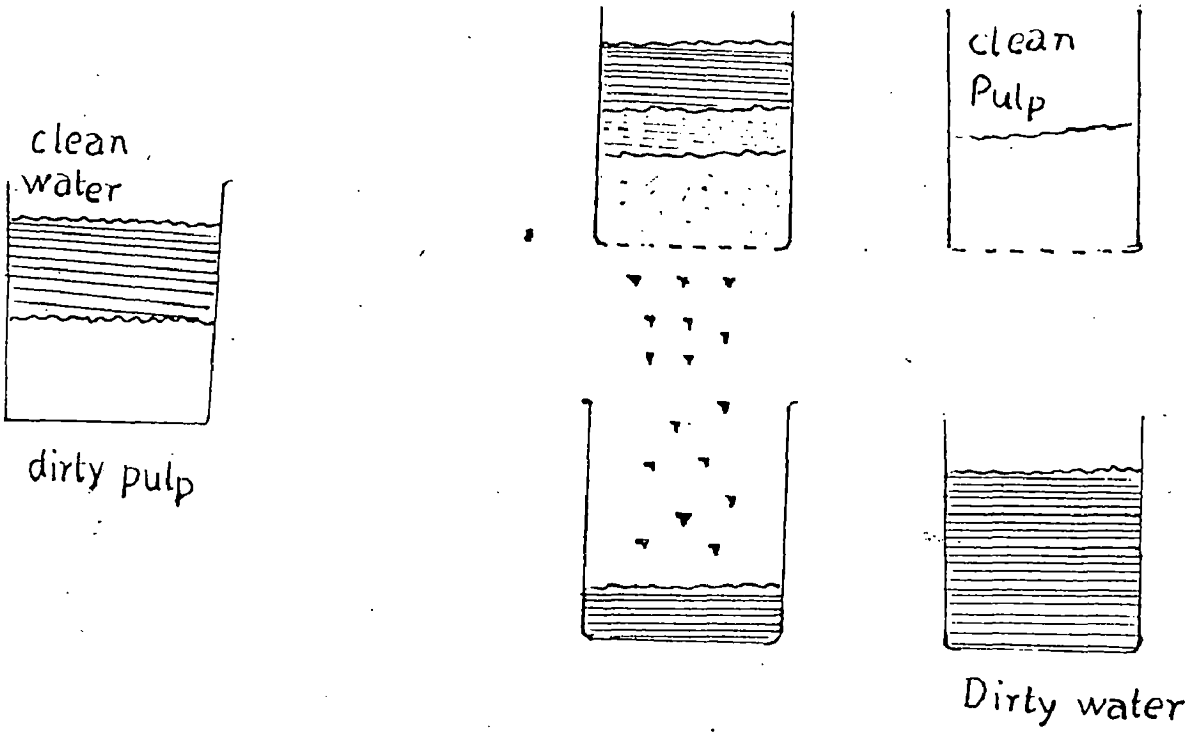
There are two basic pulp washing operations: Dilution/Extraction and Displacement washing. These two operations are shown in fig.(1) and (2). All pulp washing equipments perform on one or both of these basic operations.

In dilution/extraction washing, the pulp slurry is diluted and thoroughly mixed with weak liquor or clean water and then thickened by filtering (usually aided by pressure difference applied across the pulp pad) or by pressing. This process does not remove all solutes unless it is repeated many times using clean water. The efficiency of this operation depends primarily on the consistencies to which pulp is diluted and thickened. Efficiency also depends on the extent to which solute has been sorbed onto the fibers and the time required for the solute to diffuse out of the fibers.

In displacement washing, the liquor in the pulp pad is displaced with weak wash liquor or clean water. Mixing at the interface between the wash liquor and the liquor being displaced from the pulp should be minimized. Ideally, if no mixing takes place, it is possible to remove all of the solutes by displacing one volume of the liquor in the pulp pad. In real practice, however, through cleaning cannot be achieved. Mixing at the interface takes place and solute sorbed by fibers does not have sufficient time to diffuse out of the fibers.



DILUTION/EXTRACTION \ WASHING fig(1)



DISPLACEMENT WASHING fig(2)

1.2 Commercial Pulp Washer:

There is a large and growing variety of pulp washing equipments available today. The most commonly used washers are,

(1) Rotary Vacuum washer

(2) Horizontal Belt washer

(3) Pressure washer

(4) Wash press

(5) Kamyr diffuser washer

Out of these, the rotary vacuum washer is most widely used piece of equipment for brown stock washing and in bleach plants, especially in our country for washing of commercial pulps. Hence the present work is mostly concerned with rotary vacuum drum washer.

1.3 Principle of Operation of Vacuum Drum Washers :

Basically all vacuum drum washers operates under the cycle as shown in fig.(3). Stock at 0.75 to 2.5% O.D. consistency is fed to the inlet box of the washer and overflows the weir into the vat containing counter rotating cylinder or drum[8].

The drum has a filter media, generally a mesh cloth of plastic or metal between 25 and 40 mesh called the "face". The "face" is installed on the periphery of the drum, and is supported by a substructure which varies in design depending on the manufacturer of the washer drum.

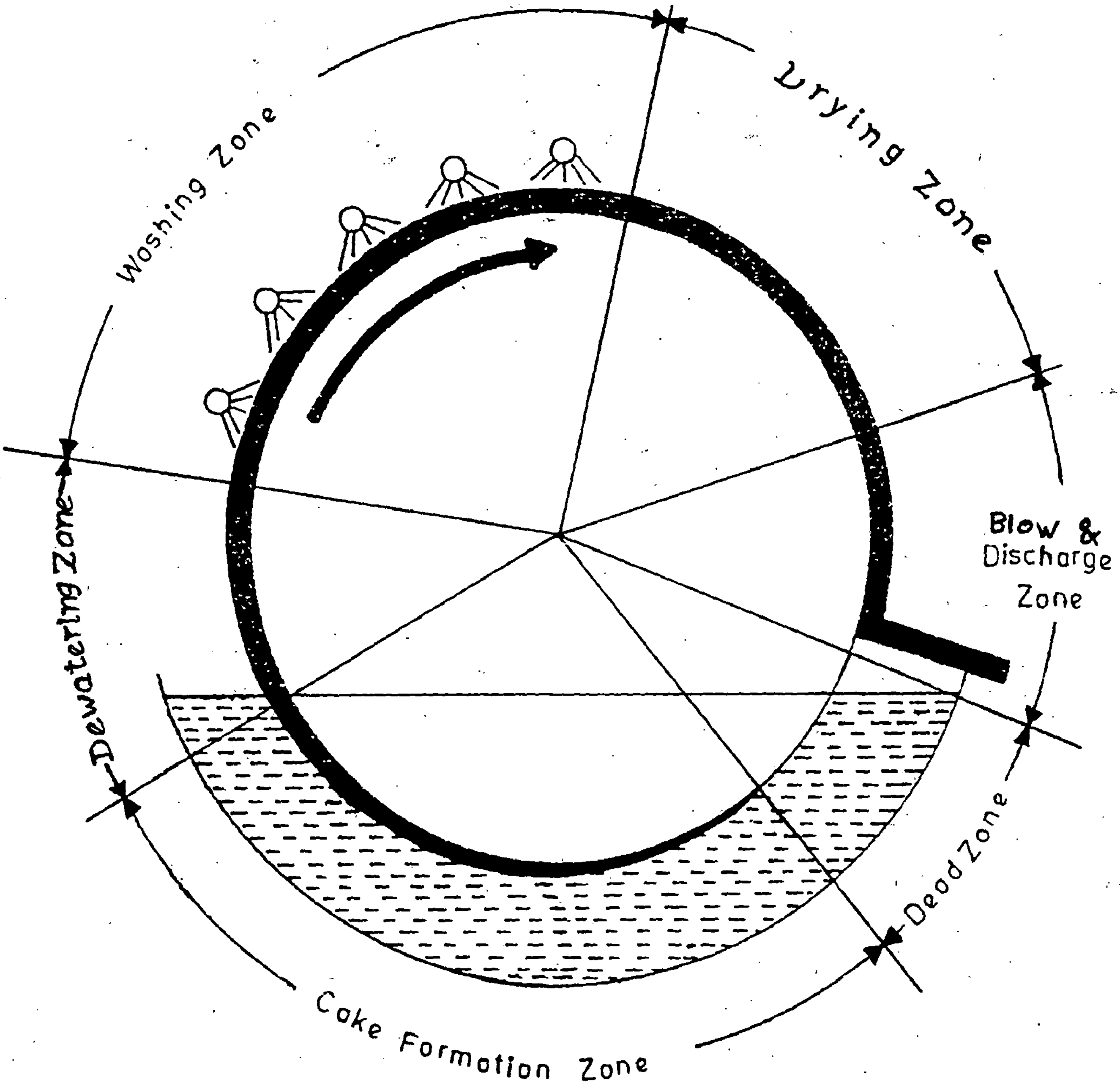


FIGURE 3 : A ROTARY VACUUM FILTER

A vacuum is drawn on the interior of the drum, generally developed by a drop leg or by vacuum pump, which forms the pulp slurry. This drainage of liquor results in the formation of a pulp mat on the drum in the sheet formation zone.

As the sheet emerges from the slurry in the vat, liquor is further extracted by the pressure differential as it moves into the displacement washing zone. Fresh water or recycled liquor is applied to the formed mat generally through distribution in multiple shower pipes. This liquor displaces the liquor in the sheet, after which additional liquor is extracted in the drying zone.

At the point where the pulp mat is removed from the drum, the pressure differential is eliminated so that the sheet can be continuously discharged from the drum. The mechanism for the elimination of the pressure differential varies widely depending upon the drum design used, but typically involves the use of a valve which cuts off the drum face from the vacuum.

Pulp is discharged from the washer drum at 8 to 18% O.D. consistency depending upon washer and auxiliary equipments design, as well as pulp drainage characteristics and operating procedures on the drum. Pressurized drum-washer also operates in accordance with these principles but include additional steps such as compaction of the formed pulp mat or multistage operation on a single drum.

1.4 Some important design and process parameters

To wash commercial pulp in industry there are certain design and process parameters which play dominant role for efficient operation. This must be considered in detail as it's efficiency is drastically influenced by these parameters. These are discussed in the following paragraphs.

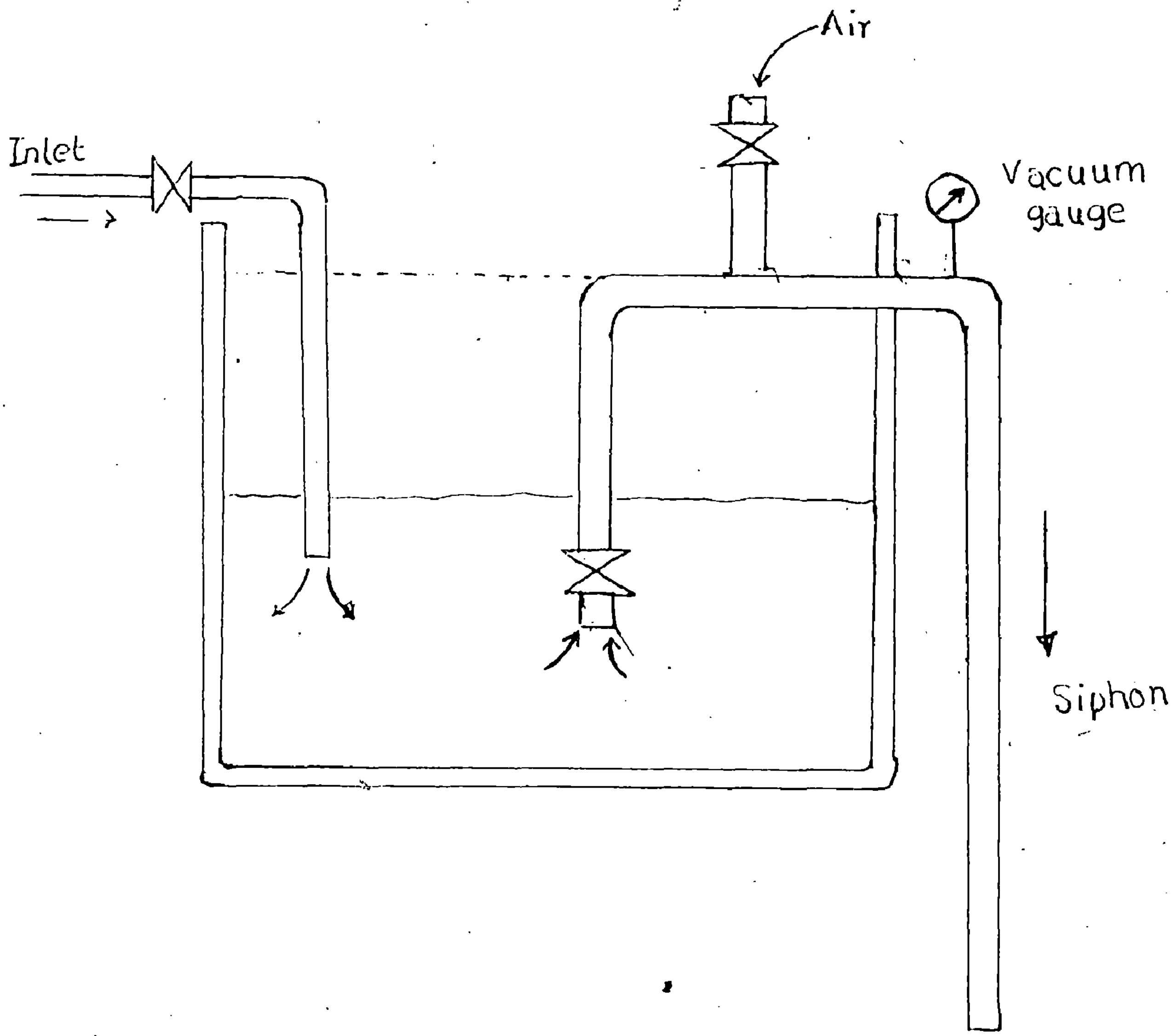
1.4.1 Design Parameters

(a). The Drop Leg:

Most vacuum washers operate economically by utilizing drop leg to generate the pressure differential required for formation and displacement. The proper design and operation of a drop leg is very important for the ease of start up, stable washer operation and acceptable discharge consistency.

The washer drop leg is often called barometric leg as it is used in early installations where the vacuum receiver required a barometric column in order that vacuum pump operates. The drop leg is actually a siphon that is removing the water or liquor out of the washer vat through the face of the filter. A fig.(4) shows its functioning.

If the liquid is filling the tank at steady rate, the air valves is closed, and the discharge valve open, the liquid will begin to flow through the siphon when the tank level reaches the full lines. The leg is then primed, and at this time, the level will drop until air is sucked into the discharge line and



PRINCIPLE OF VACUUM WASHER DROP LEG

Fig. [4]

the tank will again refill. This cycle will continue as long as the discharge line has a great capacity than the inlet line. Same siphon principle take place in the vacuum washer. The liquid is drawn into the drum, lifted up, extracted through the trunnion and flows down the drop leg. A pressure lower than atmospheric pressure is created as the liquor flows down the drop leg, and vacuum effect will be noted in the trunnion outlet from the washer.

(b). Drop leg diameter:

The drop leg diameter is based on washer type, the foaming tendency of the filtrate, but primarily the normal filtrate volume. The type of washer has a bearing on the amount of air present in the leg flow. Generally, the larger the volume between the face and valve, the more air is introduced in the leg and vice versa. This volume of air is exhausted on every revolution.

(c). Filtrate Volume:

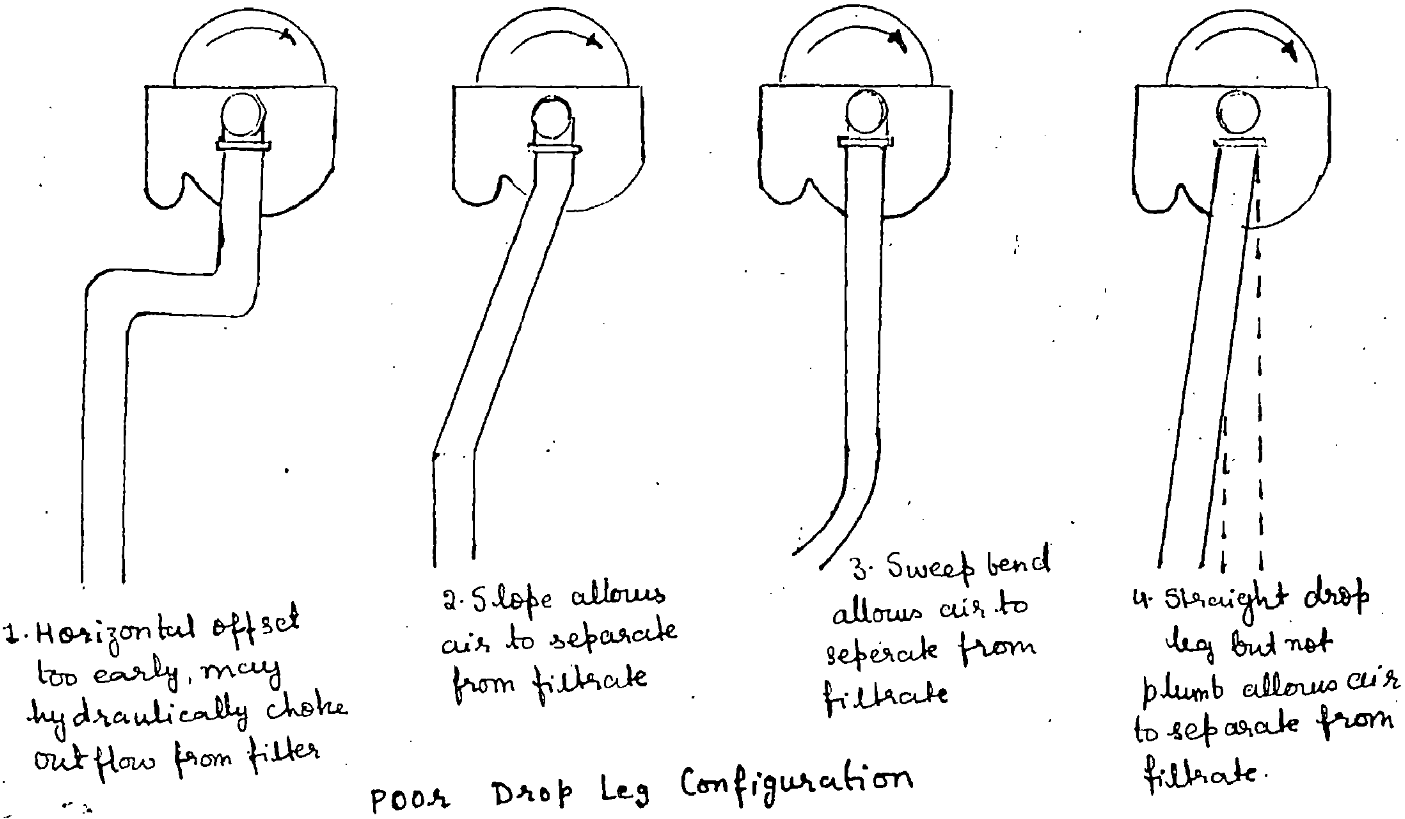
This is calculated from the feed to the washer at the vat consistency, plus the shower water flow, minus the filtrate leaving with cake. Using this normal flow of filtrate to be handled, the leg is sized based on velocity.

(d). Drop leg Configuration:

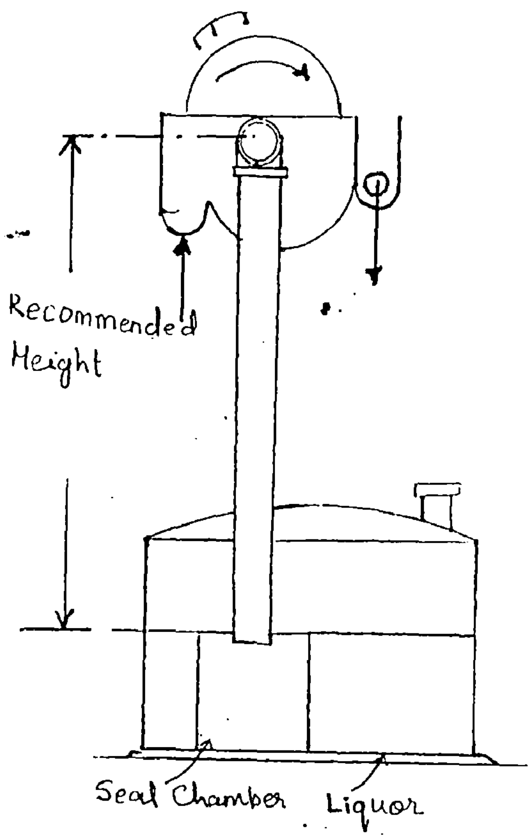
An ideal drop leg should be perfectly vertical for its full required drop into the filtrate tank. These are instances where it would be either very costly or absolutely impractical to install a leg with ideal configuration. Horizontal offsets are sometimes necessary but can compromise efficiency. A jog should be taken as low as possible in the vertical distance, or after at least a 4.5 m drop. The important consideration is to keep horizontal runs truly horizontal and vertical drop truly vertical. An angle run or a slope in the drop legs allows air to separate out of the filtrate and this air begins to flow back up the leg. Long horizontal runs are probably best installed on a slightly upward slope. If air does separate, it will be carried into the filtrate tank instead of trying to get back up the leg. fig.(5).

(e). Height of the Drop Leg:

The more air that is drawn down the leg, the lower the specific gravity of the air-liquid emulsion in the leg, the longer the leg must be to compensate. Drop leg height is basically the function of the washer type relating to air flow into drop leg.



Poor Drop Leg Configuration



Recommended Drop leg Configuration.

Fig: [5]

(f). The filtrate tank:

The main purpose of the washer filtrate tank is the elimination of air from the filtrate. The design fundamentals for washer filtrate tanks are [8] :

- -The drop leg pipe should be submerged no smaller than one half the diameter of the pipe below the filtrate level.

- -The receiving chambers in the filtrate tank should be no smaller than to allow 1-1/2 pipe diameter in every direction from the periphery of the leg. This volume is included in calculated retention time.

- -The receiving chamber should over flow at filtrate level in the tank.

- -The filtrate should be no more than 3 m deep.

- -Rectangular or round tanks can be used. Round tanks are generally the lest expensive, but rectangular tanks allows for more ground floor area for other equipment.

1.4.2 Process Parameters

Before discussing the effects of various process parameters on efficiency the parameters must be defined in terms of mathematical symbols.

The generalized washing model is given in fig.(A) which shows some of the variables of the washing process. This nomenclature was originally proposed by Norden[1].

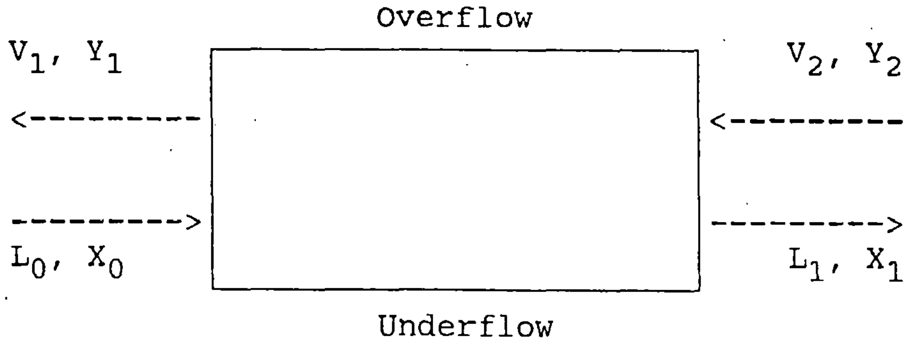


Figure A : A generalised washing system

where,

L_o = Unwashed pulp stream,
(tons of liquor / O.D. tons of washed pulp)

L_1 = Washed pulp stream,
(tons of liquor / O.D. tons of washed pulp)

V_1 = Filtrate stream
(tons of liquor / O.D. tons of washed pulp)

V_2 = Washed liquor stream,
(tons of liquor / O.D. tons of washed pulp)

X = Concentration of dissolved solids in pulp stream,
(kg dissolved solids / ton of liquor)

Y = Concentration of dissolved solids in liquor stream,
(kg dissolved solids / ton of liquor)

The model above shows two streams entering the washer, the unwashed pulp in the under flow, L and the wash liquor, V in the overflow. In the washing operation, solute is transferred from the under flow to the overflow. Hence the solute concentration in the pulp under flow decreases ($X_1 < X_0$), while the solute concentration in the wash liquor overflow increases ($Y_1 > Y_2$).

The process parameters used to describe the performance of pulp washer can be divided into three categories.

* The amount of wash liquor used .
* The amount of solute removed .
* The efficiency of pulp washer operating under standardized inlet and discharged consistencies.

The various performance parameters are listed in Table 1 & 2 [1,2,6]. The symbols defined in fig.(A) are used for parameters listed in Table 1, where as for Table 2 the nomenclature is given in page 73

TABLE - 1 : WASHER PERFORMANCE PARAMETERS

SN	Parameters	Formula	Description
			Wash liquor usage parameters
1.	Dilution factor (DF)	$DF = V_2 - L_1$	(Wash liquor entering-Liquor leaving with wash pulp) / O.D. ton of washed pulp
2.	Wash liquor ratio (R)	$R = V_2/L_1$	Wash liquor entering / liquor leaving with washed pulp
3.	Weight liquor ratio (W)	$W = V_1/L_0$	Filtrate liquor leaving / liquor entering with unwashed pulp
			Solute removal parameters
4.	Wash yield (Y)	$Y = 1-[L_1X_1)/(L_0X_0)]$ $= (V_1Y_1)/(L_0X_0)$	Dissolved solids removed / Dissolved solids entering
5.	Displacement ratio (DR)	$DR = (X_0-X_1)/(X_0-X_2)$	Actual reduction of dissolved solids / Maximum reduction of dissolved solids possible
			Efficiency parameters
6.	Modified Nordan efficiency factor (E_{st})	$E_{st}=\log[(L_0(X_0-Y_1)/(L_1(X_1-Y_2))]$ $/\log[1+(DF/L_{st})]$	Number of ideal counter current mixing stages equivalent to a washer or washing system operating at standard discharged consistency
7.	Equivalent Displacement Ratio (EDR)	(1-EDR)= (1-DR)(DCF)(ICF)	Displacement ratio for standard inlet consistency of 1% and outlet of 12%

TABLE - 2 : IMPORTANT PARAMETERS REQUIRED TO ESTIMATE THE CAPACITY OF THE WASHER

SN	Parameters	Formula	Description
1.	Porosity (ϵ_t)	$\epsilon_t(z)=\{d_f(1-C_y)\}/\{dC_y+d_f(1-C_y)\}$	Ratio of volume available for flow to the total volume
2.	Permeability (K)	$K(t)=[K_1(S_0)^2(1-\epsilon_t)^{1.5}(1+K_2(1-\epsilon_t)^3)]^{-1}$	Function of porosity and specific surface area of fibre
3.	Fractional submergence (μ)	$\mu=\Theta/2\pi$	Part of drum submerged in slurry to its total volume
4.	Fiber production rate (P_f)	$P_F=(1-\epsilon_t)NALd_f$	Mass of cake produced per unit time
5.	Specific loading factor (W)	$W=(1-\epsilon_t)NLd_f$	Fiber production rate per unit area of drum
6.	Efficiency (E)	$E=1-[\{(C_s-C_o)d_i(100-C_{yo})\}/\{(C_i-C_o)d_o(100-C_{yi})\}]\ 100$	Percentage of the solids removed

The various parameters given in Table 1 & 2 are defined as under

(a) Dilution Factor (DF):

It can be defined as the weight of water entering the washing system in excess of the weight of liquid being carried from the system in the cake discharged from washer[2,6], i.e.,

$$DF = V_2 - L_1$$

$$DF = 1 + (V_w d_w / P_f) - (100/C_{yo})$$

(b) Wash Liquor Ratio (WR):

The wash liquor ratio (WR) is defined as the ratio of liquor flow rates at the clean end of the washer, where the washed pulp is discharged. The consistency of washed pulp must be known to relate WR to DF. For displacement washing, WR = 1 implies that the liquor in the pulp pad was displaced by an equal amount of wash liquor[2,6],

$$WR = V_2 / L_1$$

$$WR = [(V_w d_f C_y) / \{P_f(100 - C_y)\}]$$

(c) Weight Ratio (W):

It relates the filtrate flow rate to the liquor entering the washer with the pulp. When there is no change in the consistency through the washer, R & W are approximately equal, provided the change in liquor densities are small[1].

(d) Wash Yield (Y):

This is the solute removal parameter used to describe the solute removed from the pulp during the washing. Y is defined as the ratio of dissolved solids removed to the dissolved solids entering. (Assuming that there is no solute entering the washer with the wash liquor).

$$Y = 1 - (L_1X_1) / (L_0X_0) = (V_1Y_1) / (L_0X_0)$$

(e) Displacement Ratio (DR):

The DR is a measurement of the effectiveness of a washing stage. It is the ratio of reduction of dissolved solids compared to the maximal reduction of dissolved solids possible which could be achieved assuming the `perfect' washing[2,6],

$$DR = (X_0 - X_1) / (X_0 - X_2)$$

$$DR = [(C_i/d_i) - (C_s/d_s)] / [(C_i/d_i) - (C_0/d_0)]$$

(f) Porosity :

Porosity is defined as the ratio of volume available for flow to the total volume. The porosity has been modelled based on average consistency of mat during the cake formation zone. The effect of air on porosity has been considered because of the saturation of cake is approximately 1 in the cake formation zone[6],

$$\epsilon_t(z) = [\{d_f(1 - C_y)\} / \{dC_y + d_f(1 - C_y)\}]$$

(g) Permeability:

Permeability influences the flow of fluid through the porous media. It is a function of porosity and specific surface area and also a strong function of size, shape and orientation of the particles. In pulp washing operation, porosity is very high ($\epsilon>0.8$), therefore

$$K(t) = [\ K_1 S_0^{\,2} (1 - \epsilon_t)^{1.5} \{ 1 + K_2 (1 - \epsilon_t)^3 \}]^{-1}$$

(h) Fractional Submergence:

The angle subtended by the slurry level at the central axis of the drum is taken as an angle of submergence and the part of the drum submerged in slurry to its total volume is known as fractional submergence[6],

$$\mu = \Theta / 2\pi$$

(i) Fiber Production Rate:

Mass of cake produced per unit time is known as fiber production rate. It is highly dependent upon the area of the drum and the cake thickness[6]. It is represented by the equation

$$P_f = (1 - \epsilon_t) NALd_f$$

(j) Specific Loading Factor:

Fiber production rate per unit area of drum is known as specific loading factor. Now a days it is used as an indispensable tool to design a rotary vacuum filter.

$$W = (1 - \epsilon_t) NLd_f$$

1.5 Effect of Variables on Displacement Ratio:

Displacement ratio is a measurement of the effectiveness of a washing stage. It is highly dependent on washer design and operating condition. According to Shackford [8], drainage rate is an important operating variable, which affects the displacement ratio.

The drainage rate of the pulp slurry is an important criteria to be assessed in the initial sizing of the washer in order to achieve optimum operating conditions. The characteristic drainage rate of the pulp slurry will be the key factor which will affect all other operating characteristics of the washer, such as vat level, feed consistency, drum speed and directly and indirectly the discharged consistency.

The ability of a pulp suspension to give up its free water due to force by gravity, pressure or vacuum is generally referred to as the drainage rate. the most common means of expressing this is the freeness. Several methods are used world wide, one of which is the Canadian Standard Freeness (CSF). As all washing methods require the passage of a liquid through a fibrous mass, the rate at which it passes will vary depending upon the following points:

* The fiber itself
* The temperature of the liquid
* The amount and size of suspended fines in the pulp
* The force exerted on the liquid

Drainage rates relating to displacement or thickening processes in pulping operations are expressed in volume per unit time per unit of area. As the rate of volume per unit time goes down, the area required for a particular rate of pulp production increases and vice versa. Thus, free draining pulps require smaller area equipment than slow draining pulps.

The amount of entrained air present in liquid phase of the suspension has a dramatic effect on the drainage rate of the pulp. The amount and size of these air bubbles can have a controlling effect on the drainage rate. The air bubbles take on the properties of a solid, and are literally filtered out by the fiber mass, thus blocking flow and reducing the drainage rate.

The lowered drainage rate due to air results in higher feed consistency required and/ or higher drum speed compared to an "air-free" operation. In addition, air bubbles trapped in the pulp mat will result in wash liquor channeling through the mat due to blockage by air of the interstices of the fiber network.

The amount of air present in the feed to a washer is primarily dependent upon the pulp and liquor handling in the ancillary equipment, along with the normal operating vat level in the washer.

The existing performance of washers using different type of brown stock is not satisfactory. In order to improve the washing performance, it is necessary to evaluate the data on washer the present work aims at laboratory evaluation of brown stock.

1.6 Objectives of present work:

The major objectives of present work are as under:

1. To install a single stage EIMCO K.C.P. rotary drum vacuum washer with filter cloth and commissioning the same.

2. Evaluation of the performance of lab washer using the brown stock taken from the nearby Mill.

3. Evaluation of various parameters based on the laboratory data.

4. To collect washing data from a near by mill and to evaluate the performance using various methods available in literature and to compare the washing efficiency obtained by different methods.

M/S. EIMCO KCP ltd., Madras has supplied a rotary drum vacuum filter with filter cloth. This system has to be installed after making the modification in the setup as some of the components were not supplied/broken during the transportation. The installation and commissioning of the equipment are the major part of the work which consume large amount of time.

After the installation, the performance of the system is to be tested using water, calcium carbonate sludge and pulp, under different experimental conditions. The data obtained is to be used to evaluate the performance of the filter and to compare the data with those predicted using the available physical and mathematical models.

CHAPTER 2

INSTALLATION AND COMMISSIONING OF EIMCO-KCP LABORATORY VACUUM DRUM WASHER

The drum filter was studied and the assembly of the drum filter components were made after analysing the requriments. The equipment was then commissioned. The subject matter is presented in the flowing major sub sections.

2.1 Description of EIMCO KCP drum filter
2.2 Installation of the lab. filter
2.3 Commissioning of the filter.

2.1 Descreiption of EIMCO-KCP drum washer:

The EIMCO-KCP vacuum drum filter is a laboratory filter, provided with filter cloth. The relevant drawing of this equipment is shown in fig.(6). It consist of a rotary drum fitted with Hi-flow filter valves. The other auxiliary equipments consist of a vacuum pump, filtrate pump, vacuum receiver piping connection, feed pump, filter drain assembly, an agitator and a storage tank. The description of various parts is given below.

(a) Vacuum pump

It is a rotatory wet type of vacuum pump, with water sealing effect. It is not equipped with any moisture trap. The vacuum piping run from the inlet connection on the pump directly into the top of the vacuum receiver. The discharge line of the

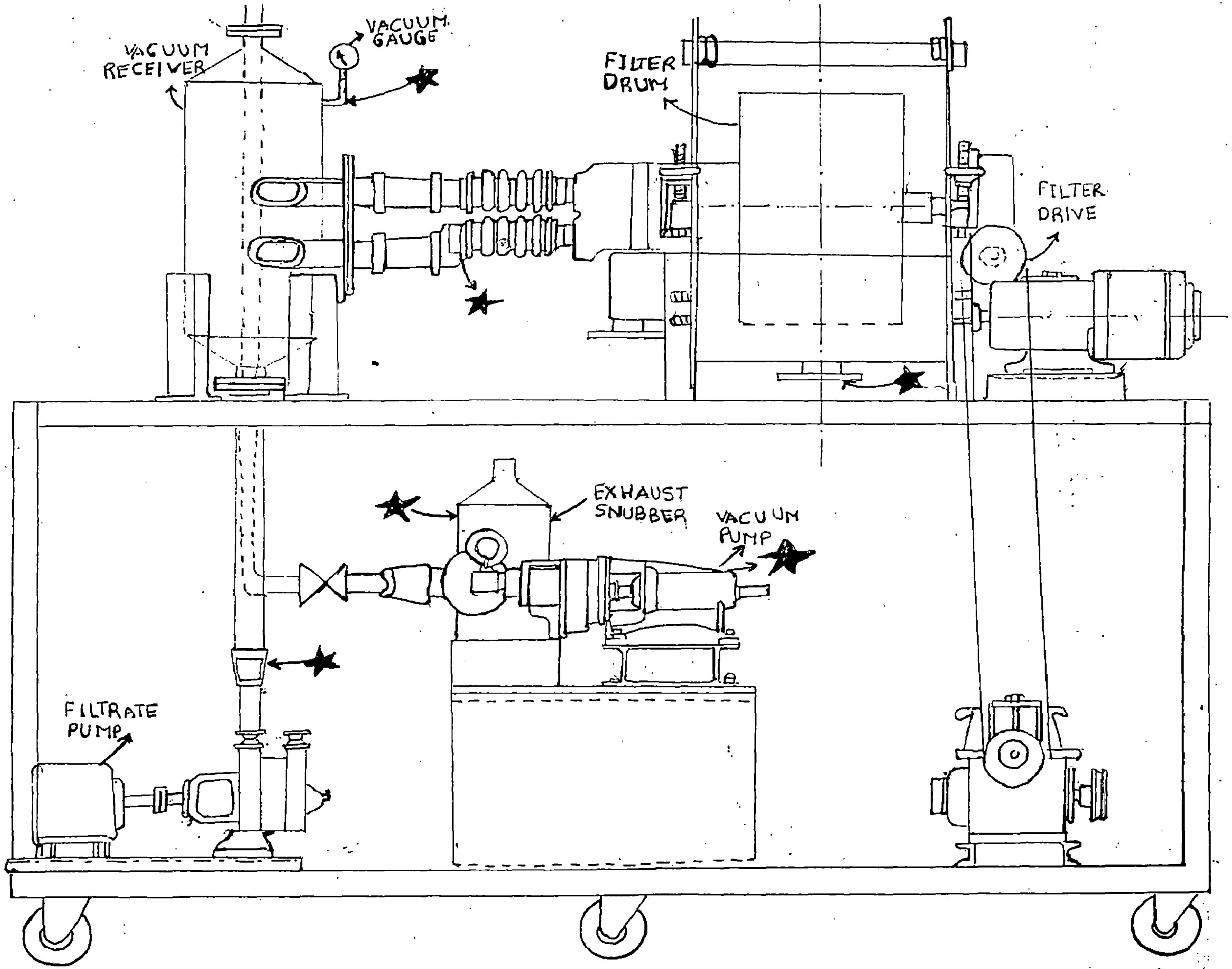


Fig: 6

MODIFIED EIMCO K.C.P 18"D1/4 X 12"F VACUUM DRUM FILTER

★ indicates the modified parts.

pump is connected to the exhaust snuffer, to reduce its noise since pump is located inside the lab.

(b) Vacuum Receiver

The two receivers are located close to the filter at an elevation of two metre from the ground. The elevation permits the gravity drainage from the pvc line connecting the filters to the side connection on the receiver. Vacuum gauge sharing the vacuum reading is also connected to the receiver. The receivers are made up of metal and has ample capacity to store the black liquor, in case if the filtrate pump is not operating. In case, if vacuum regulating valve is used to control the vacuum, it is furnished as an extra equipment. Regulating valve should be installed in the vacuum line at the top of the receiver.

(c) Filtrate Pump

There are two filtrate pumps installed directly below the vacuum receiver, on the solid foundation. The inlet of pump is connected to discharge line to collect the discharged liquor from each receiver. The filtrate pumps are simple close impeller centrifugal pumps.

(d) Filter Drum

It consists of a cylindrical drum of 18 inches (45 cm) diameter and 12 inches (30 cm) face widthwith total surface area of 4492.8 cm^2. It rotates on the trunnion bearings by worm and worm wheel arrangement. The filter drum surface is fitted with perforated covering over which belt runs. Inside, it is fitted Hi-flow filter valves fig. (7).

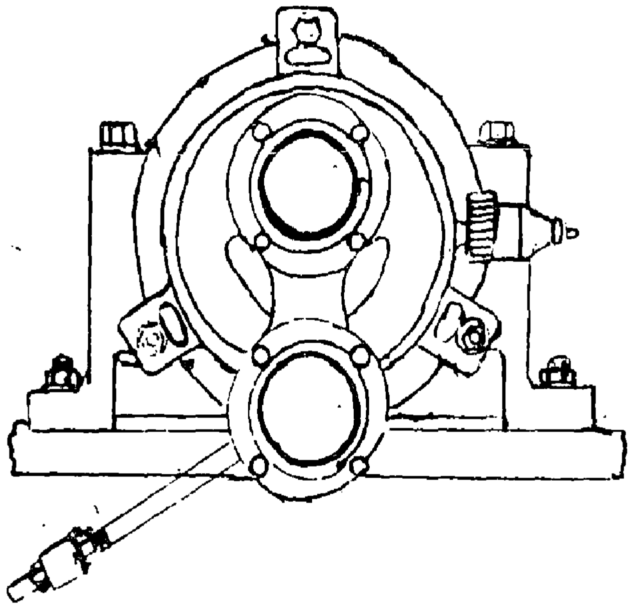
The filter valve assembly is comprised of two basic parts:

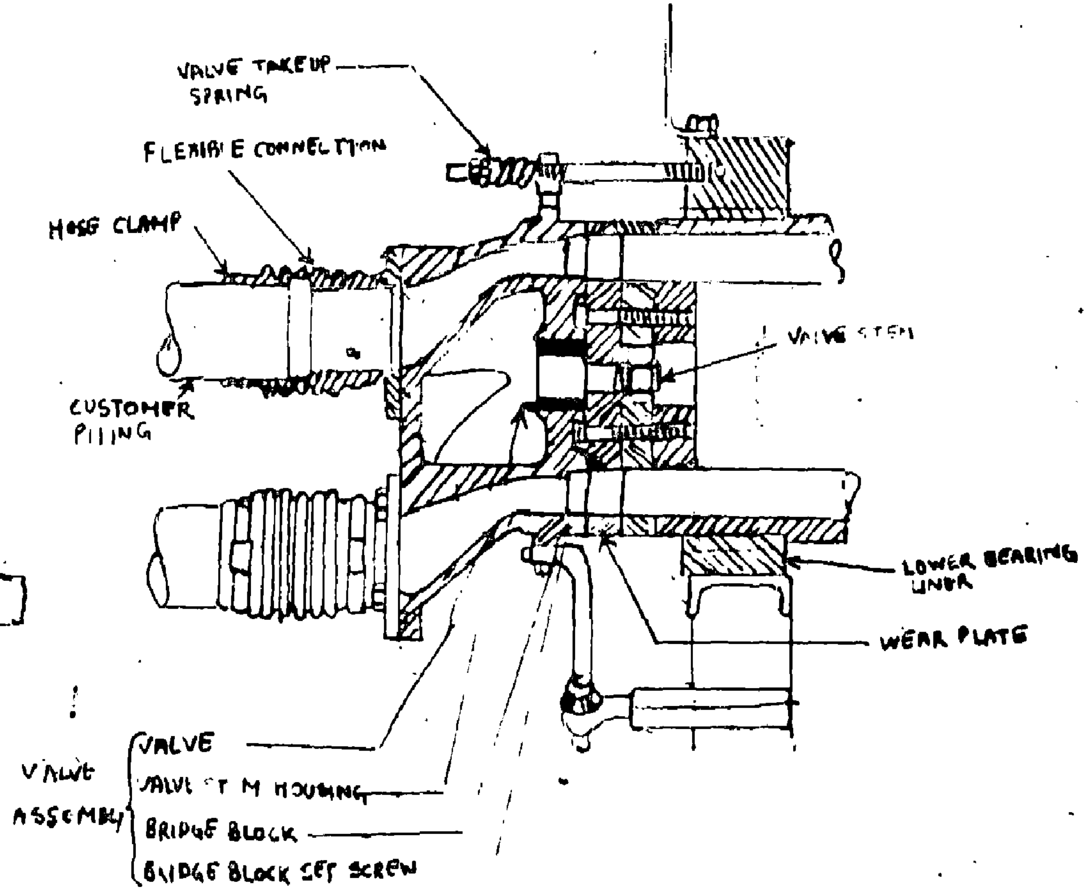
(i) The stationary valve itself and
(ii) A rotating replaceable wear plate

The wear plate which bolts to the end of the drum trunnions, has a projecting valve stem that supports and centers the valves. The valve is held in position against the wear plate by spring-loaded take-up studs to provide a tight seal against the plate face.

The valve automatically controls the entire filtering cycle, simultaneously forming, dewatering and discharging the cake. This is accomplished by the division of the valve into sections which control these functions in their proper sequence as the pipe ports of the wear plate connect with various valve sections during drum rotation.

Because the exact timing and duration of individual functions in the filtering cycle are important to good performance, bridge blocks are used between the valve sections to limit the sizes and the exact position of their openings. This enables accurate control over each stage for sharp liquor separation when required. The bridge was located over and in contact with the various section division and ribs and fitted in to bridge ring drainage channel machined in to valve inner face.





HI FLOW FILTER VALVE ASSEMBLY

The timing of the filtering cycle may be advanced or retarded slightly by altering the portion of valve head. This is done by loosening the spring loaded take up studs.

(e) Filter drive assembly:

The dive assembly consist of a worm wheel and worm shaft. The worm shaft is driven by a chain driven by a motor which in turn rotate the worm wheel and hence the drum. The speed of drum rotation can be increased or decreased by drive adjustment fig. (8).

(f) Rake type filter agitator:

It consist of a crank shaft in turn is connected to the connecting rod, which is attached to the filter drum at periphery. The connecting rod is connected to the crank shaft by a wrist pin. The rake give an oscillatory motion to the slurry in the vat and does not allow it to settle fig. (9).

(g) Feed pump and storage tank:

The feed pump consist of a large centrifugal pump coupled with electric motor by direct coupling method. The inlet of the pump is connected to the storage tank and outlet to the drum vat, through piping connection. The vat is provided with adjustable plates which can vary the level of submergence of the slurry in the vat. Any excess flow of slurry is drained back to storage through the drain line.

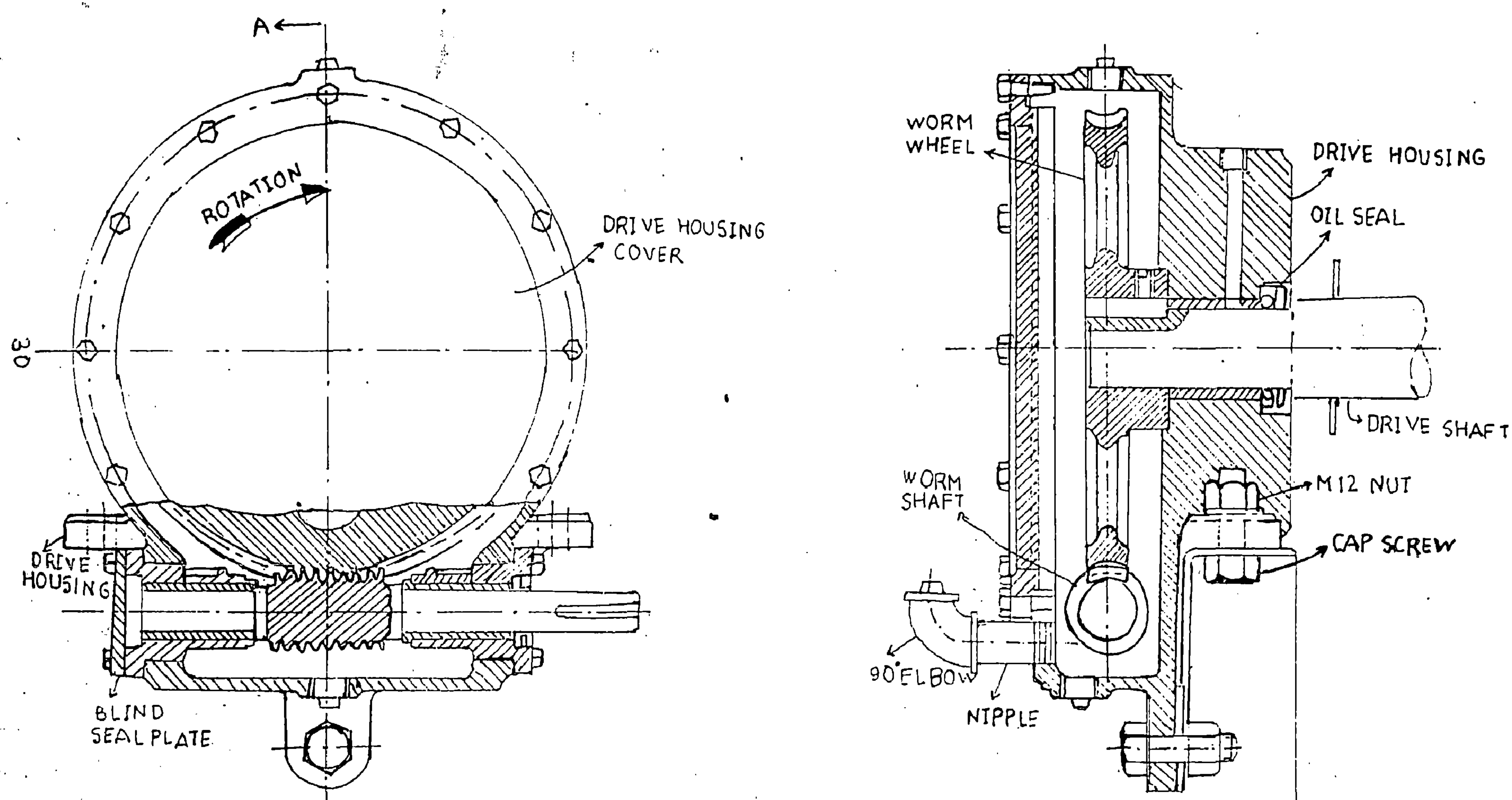
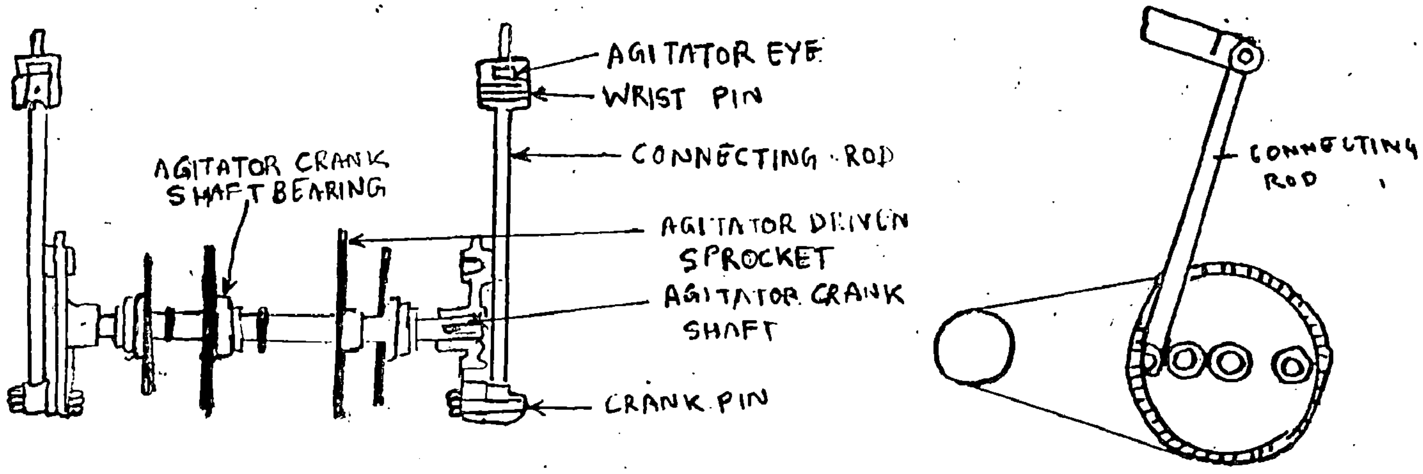
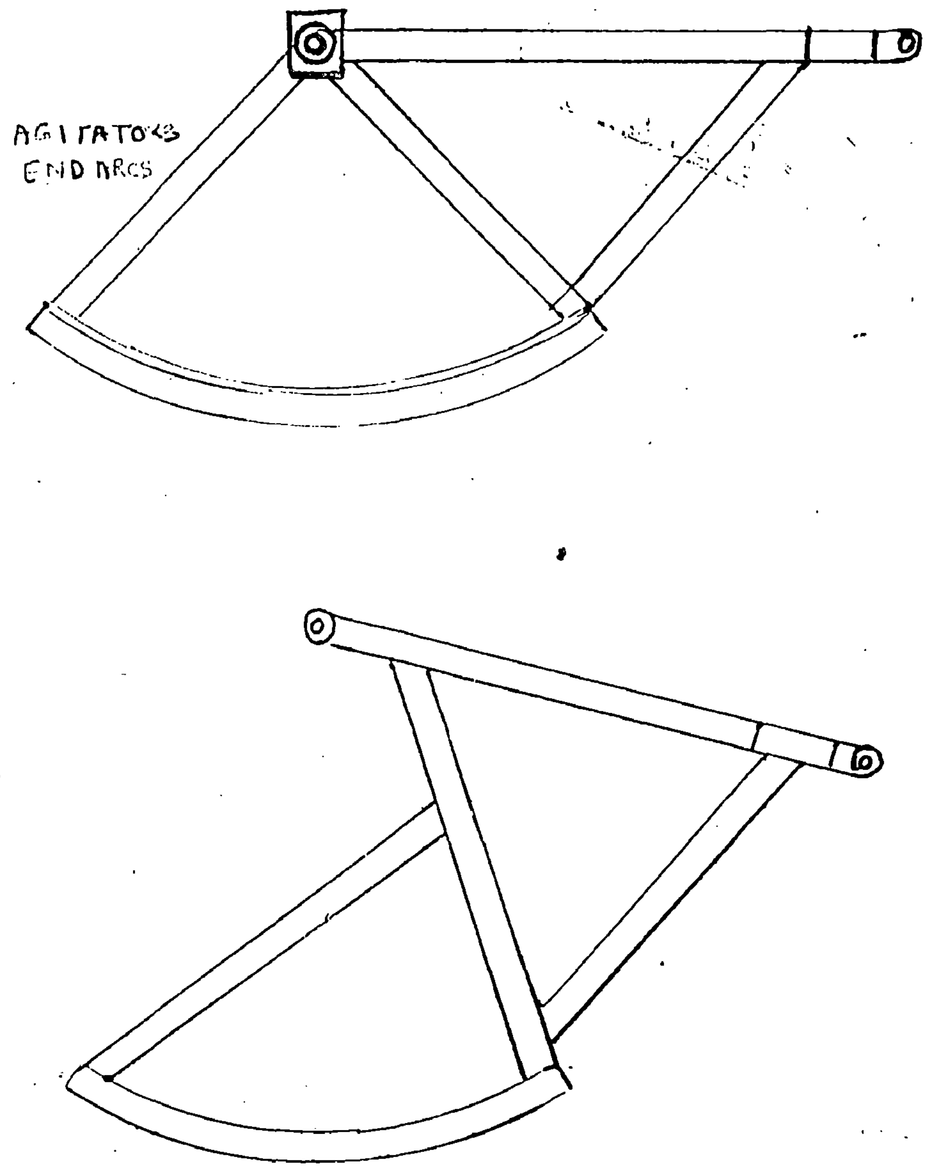


Fig: 8

96 TEETH FILTER DRIVE ASSEMBALY PARTS



AGITATOR CRANKSHAFT ASSEMBLY



AGITATOR RAKÉ ASSEMBLY

Fig:[9]

2.2 Installation of laboratory washer :

The single stage rotary drum filter supplied by the company named THE EIMCO-K.C.P. LTD.,MADRAS is not fully fitted with all equipments. Installation of various parts is done before commissioning and carrying the experiments on it. Modifications of several parts is also carried out in order to achieve the required results. A brief discussion of various installations done is given below,

(a) Installation of wash liquor shower :

The wash liquor shower is provided to wash the pulp mat formed on the filter cloth of rotating drum. The mat is formed by the aid of vacuum applied by vacuum pump.

Two PVC pipes are fitted in the connections provided in filter body on the top side of drum (i.e., washing zone). The pipes are connected to fresh water line by two flexible PVC pipes(since we are using fresh water as a wash liquor).fig. (10).

Two rotameters, one in each pipe line, are provided in the pipe line (not existing earlier) to note the wash liquor flow rate since it is an important parameter in calculating the dilution factor.

To control the flow rate of wash liquor, a regulating valve is provided at the inlet of each rotometer. A tapered connection is provided on outlet end of rotometer for connecting the flexible pipe fittings. This done to avoid any leakage of water. All connections are covered with teflon tape to prevent water leakage.

Previously the wash shower was fitted with two nozzles in each pipe. The nozzle design gives the high pressure shower on the pulp mat and as such it forms a channeling in mat. Also the distance between the two nozzles is more and as such maximum pulp goes unwashed. So some modification is done in shower arrangement.

The holes of about 2.5 mm is drilled throughout the length of shower pipe at equal distance Some holes are drilled in another shower pipe in such a way that its shower covers the area left unwashed by previous shower. This gives the maximum washing zone width. Since the increase in number of holes reduces the water pressure, channeling effect also goes down.

(b) Installation of Vacuum gauge in Vacuum Receiver :

Since there is no vacuum gauge or any other device to read the pressure difference created while doing the experiments, installation of vacuum gauge is very necessary. There are two small pipe fittings in vacuum receiver which were closed. Since he openings are not of standard size, so a small piece of G.I.pipe us taken and threaded on outside diameter in machine shop. One end is fixed to the receiver, while other end is connected to U-shaped pipe on which vacuum gauge is fitted. Various connections are covered with M-seal adhesive to prevent air leakage fig. (1).

(c) Arrangement of seal water line in Vacuum Pump :

Since the vacuum pump fitted in the equipment is of rotary wet type, with water sealing effect, a separate seal water line is fitted in the pump. A threading is done in M/C shop on the G.I. pipe of required diameter and is fitted in the space provided between the inlet and discharge connection of vacuum pump. The other end of G.I. pipe is connected to a hose pipe to get a continuous supply of water when vacuum pump is running fig. (1)

(d) Installation of Exhaust snubber to Vacuum Pump :

Since the apparatus is situated inside the lab, lot of noise is produced with the running of vacuum pump, which is inconvenient for the working atmosphere. So an exhaust snubber is provided in the discharge line of vacuum pump fig. (1). It performs two functions.

1. Act as a silencer to reduce noise.
2. Seal water from pump is drained out through the snubber directly to drain line.

The exhaust snubber consists of a inlet line connected directly to the discharge line of vacuum pump. The seal water along with air, enters the snubber through this line. The air after expanding in snubber escapes through the top opening. The water is drained directly to drainage through the drain line.

(e) Installation of receiving lines from filter drum to vacuum receiver :

While checking the vacuum formation and filtrate flow, it was observed that filtrate is not coming to one of the receiver. The pipe connecting receiver and filter drum is disassembled. It was found fitted with blind packing. So proper packing is done before installing it.

The other pipe connecting receiver to drum was found cracked from one end of its flange so it was welded by plastic welding rod. Since pipes are made up of PVC material, great care was taken during welding, disassembling and assembling fig. (1).

(f) Installation of inlet pipe in filtrate pump :

The equipment is equipped with two filtrate pumps which continuously pump out filtrate collected in the receivers. Since there is no inlet connection in one of the pumps, so proper connections of the pipe is made fig. (1)

The flange of one end connection got cracked and liquor is leaking from that place, so a new flange us installed after getting it fabricated in machine shop. Since the whole inlet-outlet connections are made up of PVC, we can't tightened them. So all joints are get welded by plastic welding, and covered with adhesive to prevent leakage.

(g) Feed pump connection to feed tank :

The feed pump (not shown in fig.) connections to the feed tank is not completed. It is leaking at the inlet end. So the connection is disassembled and again assembled after providing proper teflon tape packing. The outlet pipe going to vat is also joined by adhesive to avoid leakage and the valve provided in the outlet of the feed pump to regulate the pulp going in the vat is changed since previous valve was free and functioning properly. The overflow pipe from pump is extended to avoid foaming.

(h) Feed tank outlet :

The feed tank (not shown in fig.) which is used to store the raw material provided to the feed pump was not provided with an outlet to drain out the pulp slurry/water. An outlet is provided at the bottom of the drum and is fitted with threaded bolt. The bolt is unscrewed to open the drain line.

(i) Connection of pipe line to drain unclean water collected after cleaning the belt :

The water coming from shower after cleaning the filter cloth falls directly to the floor, thus spoiling the whole area and experiment on the washer. So a separate drain line is provided which drain the unclear water coming after washing the filter cloth directly to the drain line fig. (1).

(j) Installation of filter cloth over the drum :

No filter cloth is previously fitted on the filter drum. So a filter cloth is mounted on the drum as per the drawings and then stitched along the width to make it endless. The tightening of cloth is done by the two screens provided for this purpose fig. (10).

(k) Electrical connections of filtrate pump motors :

Previously the filtrate pumps sucked air inside when started and as such they don't pump filtrate/water out. So the electrical connections are checked and changed to reverse the direction of the pump impeller rotation. The pumps now started pumping filtrated out.

(l) Electrical connections for the feed pump :

The feed pump is not provided with electrical connections. So a separate panel is set up on control switch board for feed pump and all electrical connections are properly installed. The feed pump is provided with separate line and ON/OFF switch, so that feed pump can be stopped when our vat is fulled.

(m) Installation of switch box for rake agitator :

A new control switch box is provided for rake agitator drive, since the previous one was not working.

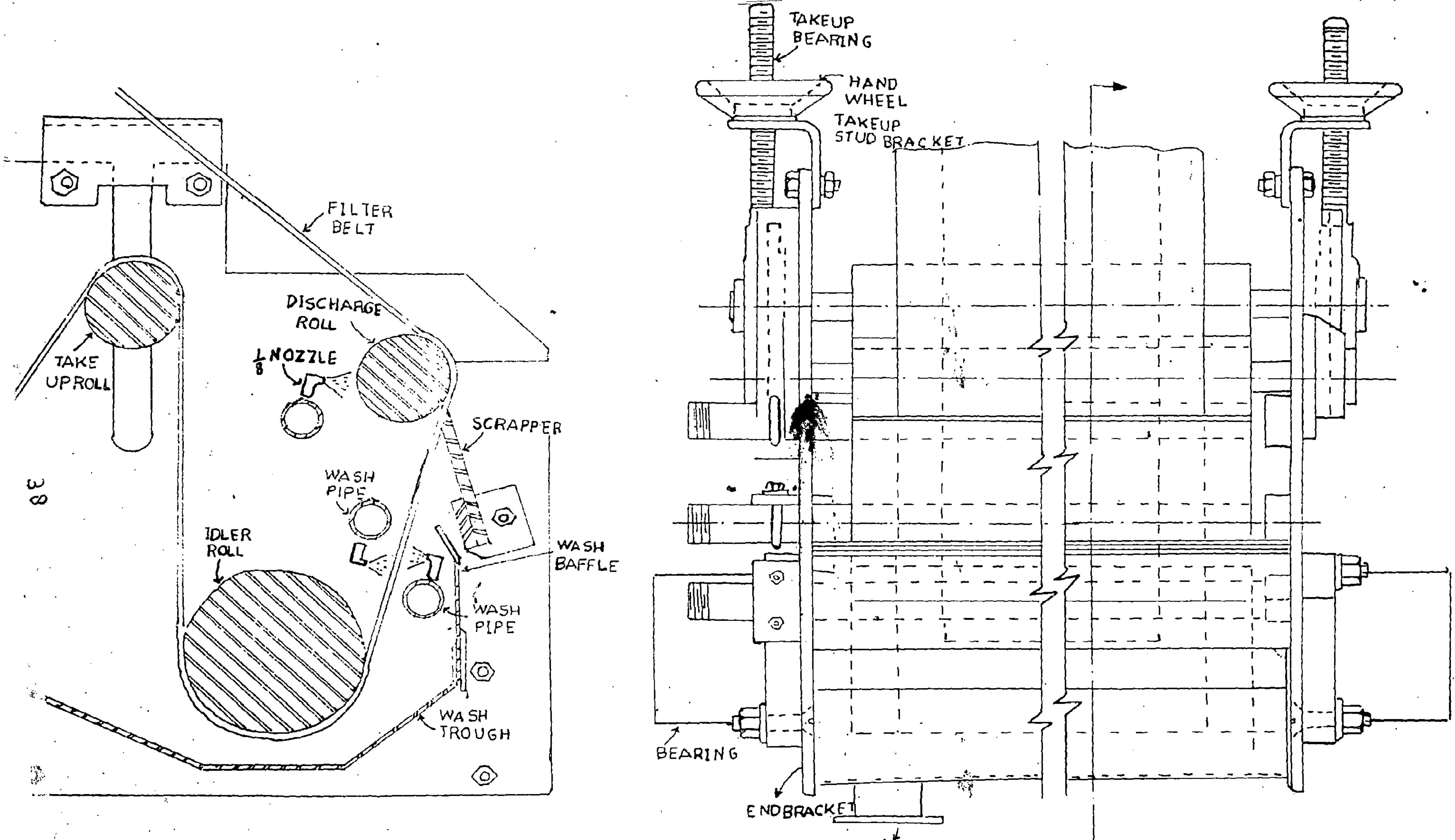


Fig (10)

BELT MECHANISM ASSEMBLY FOR 18" DIA X 12" FACE BELT FILTER

(n) Lubrication of all moving parts :

Since the washer consists of number of pumps, motors and other moving parts their proper lubrication is necessary before commissioning the apparatus.

All the three pumps i.e., feed pump, and two filtrate pumps are properly lubricated by grease by filling the grease caps. All the moving parts of shaft is first cleaned with kerosene to remove any dirt etc., and then lubricated with oil of proper grade. The couplings of pumps and motor is also checked. The vacuum pump is thoroughly lubricated by oil in its moving part. The seal water which flows through the shaft also provides cooling effect to pump.

The chain of drive mechanism of filter drum is properly lubricated with grease. The drive adjustment screw of filter drive is properly lubricated and some load is hanged on it to avoid its slipping. This helps in maintaining the constant speed of drum. Oil level of filter drive is checked.

The rake agitator wrist pin is properly lubricated. All the moving parts as well as sliding parts (i.e., crankshaft, connecting rod etc.,) are properly cleaned and lubricated to avoid over loading of drive motor.

2.3 Commissioning of the washer :

After the installation of various parts and modifications, the equipment is ready for operation. The complete schematic diagram of the system is shown in the fig. (11). The preliminary test is done by water instead of slurry. The following steps are taken :

(i) Fill the feed tank with water up to the sufficient level.

(ii) Start the filter drive motor and make sure the drum is rotating towards the discharged side.

(iii) Open the valve in feed pump inlet line coming to vat and start the feed pump.

(iv) Since we are using water, the agitator may or may not be started.

(v) Open the valves of filter belt wash pipes.

(vi) Turn the seal water to the vacuum pump.

(vii) Start the vacuum pump in order before water reaches the operating level.

(viii) It is noticed that the filter cloth is completely wet as it come out of the vet.

(ix) The water is sucked inside the drum at drying or dewatering zone and through receiver line get accumulated in the receiver.

(x) The vacuum formed can be noted from the vacuum gauge.

(xi) Start the filtrate pump after some time so that enough water get collected in the vacuum receivers. Otherwise the air will be sucked inside. Check the direction of rotation of pumps.

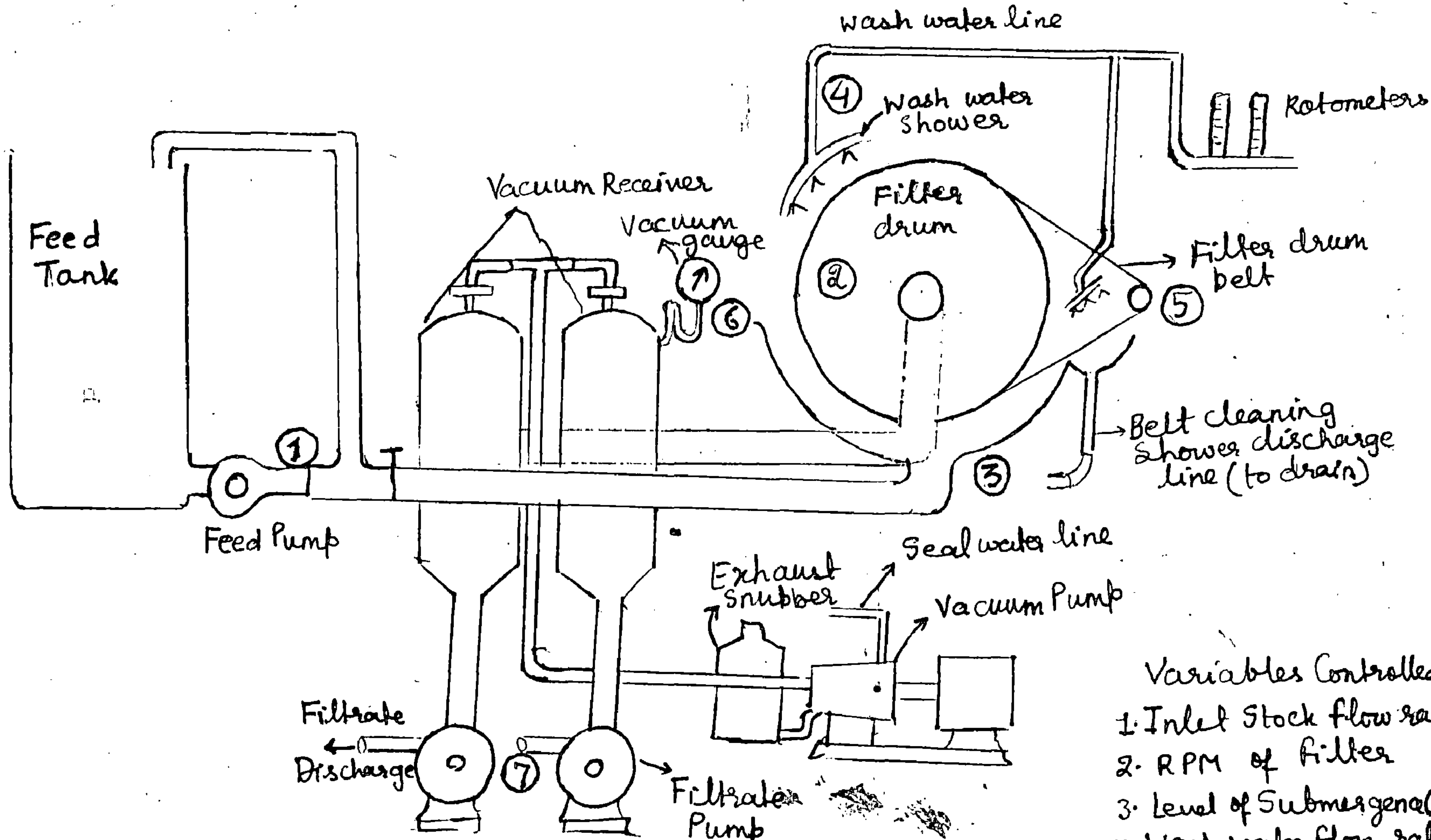


Fig (11) SYSTEMATIC DIAGRAM OF THE LAB FILTER

Variables Controlled/Measured

1. Inlet Stock flow rate to vat
2. RPM of filter
3. Level of Submergence (Plate level)
4. Wash water flow rate
5. Pulp Consistency at Discharge
6. Vacuum in System
7. Filtrate flow rate

(xii) Adjust the feed valve so that water remains below the overflow or operating level to maintain the desired submergence.

(xiii) Adjust the filter speed to obtain desired cake thickness.

(xiv) Open the wash liquor line valves and check the flow rate and points of water falling on filter cloth.

(xv) Check the belt for wrinkling, mooning or biasing and make necessary adjustments by adjusting screws.

Lot of problem is experienced in the vacuum built up. The gauge shows very little vacuum. For that all leakages are located and closed. The seal water flow to vacuum pump is adjusted and all the joints around vacuum gauge and filter drum is covered with adhesive (M-seal) and teflon tape.

Before carrying the experiment with commercial pulp a trial is carried with lime sludge to check the operation of various pumps (especially vacuum pump). The lime sludge is preferred to pulp slurry as it can be easily washed out by water. The lime sludge is filled in feed tank and mixed with some water to bring it to required concentration so that it can be pumped by feed pump.

The feed pump is started so that sludge get collected in vat. Metal strips are placed to get the required submergence. The agitator and drum is started. The seal water in vacuum is turned on and vacuum pump is started. Due to the pressure difference applied by vacuum pump thick mat of lime sludge is formed on the filter cloth at drying zone.

The cake wash liquor line and cloth clean wash line is turned on. The rate of wash flow liquor is adjusted by the adjusting valve and flow rate reading is noted form the rotometer.

Since perfect mat is formed on drum the vacuum gauge is showing the reading (60-70 mm Hg). The cake wash liquor wash the sludge at washing zone and the filtrate is collected in the vacuum receiver.

On starting the filtrate pump, the filtrate collected in the receiver is pumped out. Thus experiment on lime sludge is proved to be successful. After running the unit with water and Calcium Carbonate slurry sucessfully, it was then decided to take the experimental runs to study the effect of various parameters using the commercial pulp. The lime sludge from the filter was thoroughly washed before conducting the experiment with the pulp.

CHAPTER 3

WASHING CHARACTERISTICS OF BROWN STOCK

The washing characteristics of brown stock obtained from a near by mill are evaluated by conducting washing experiments.

3.1 Collection of Pulp from the Industry :

The filter system was used for conducting the washing trials with pulp, collected from the blow tank of the near by paper mill.

The pulp was collected from the blow tank of the mill before its entry to the first stage of brown stock washing system. The collection of pulpas a true representation of the industrial system was quite difficult,as the pulp was very hot (above 80°C). The pulp collected carefully, was cooled to room temperature in the bucket closed with a lid. The characteristics of the cooled pulp are shown in Table 3.

TABLE - 3 : Characteristics of the cooled pulp

S.N.	Parameters	Value
1.	Raw material furnish(%)	
	Eucalyptus	82
	Bamboo	16
	Pine	2
2.	Kappa no.	19
3.	Active alkali(%)	14.5 as Na_2O
4.	pH	11.5
5.	Vat consistency of pulp(%)	1.5

3.2 Trial with commercial pulp :

The unwashed pulp from the near by mill is tested for its consistency. The pulp slurry (about 25-30 kg) is taken in the feed tank and diluted with the water to bring at the required consistency stirred by a wooden rod so that the pulp may not be settled down. The pulp was sent at constant rate to the filter drum and the wash liquor flow rate (25 lph) is adjusted. The filtrate flow rates are measured. The valve is regulated to adjust the flow of slurry in vat up to the submergence level. Two bucket are placed one at the outlet of each filtrate pump to collect the filtrate coming from washing and dewatering zone. One more bucket is provided to collect the discharged pulp. The pulp mat is discharged by the help of doctor blade. The experimental procedure followed is detailed below.

1. Start the filter drum and rake agitator and open filter cloth cleaning valves.
2. Start the feed pump so that pulp slurry can come to vat.
3. When pulp slurry start touching the filter cloth, turn the seal water to vacuum pump and start the vacuum pump.
4. With the aid of vacuum, the mat is form on the filter cloth which is carried out along the circumference of drum.
5. As the pulp mat passes across the dewatering zone, the black liquor is being sucked inside and collected in the vacuum receiver.
6. Wash liquor is applied at washing zone through two wash liquor washing arrangements. The wash filtrate is also sucked inside the drum by vacuum and get accumulated in another vacuum receiver.
7. The two filtrate pump are started along with vacuum pump so that filtrate is collected.
8. Vacuum is noted down from vacuum gauge, the filtrate flow rate of two pumps are the known volume of filtrate in known time. combine flow rate of two pumps is also calculated.
9. The pulp is discharge off in discharge zone by the doctor blade and collected in separate bucket. A sample is taken out to find out the discharge consistency.
10. Following reading are noted down:

    RPM of drum, Pressure difference, wash liquor flow rate, level of feed drum before starting the experiment and after finishing the experiment, time of run of equipment and thickness of cake formed on the mat.
11. The above step are repeating

(a) With varying consistencies (1%,1.5%,1.75%,2%) and keeping other parameter same.

(b) By changing the rotational speed of drum.

(c) By changing wash liquor flow rate.

(d) By changing angle of submergence.

12. Various reading are tabulated and evaluated.

The experiments are conducted on the washing of the mixed hardwood, bamboo and pine Kraft pulp on the rotary drum vaccum filter. The range of experimental variables used in experiment is given in Table 4 given below.

TABLE 4: Range of washing variables used in experiments carried on laboratory filter.

S.N.	Parameters	Range
	Input parameters	
1.	Inlet Consistency(%)	1-2
2.	Speed of drum(1/s)	0.0117-0.014
3.	Angle of submergence	79.322-101.28
4.	Wash water flow rate(lph)	25-50
	Output parameters	
1.	Pressure drop(mm Hg)	20-100
2.	Filtrate flow rate(m^3/s)	$0.17X10^{-4}$ -$0.87X10^{-4}$
3.	Cake thickness (m)	0.005-0.008

The experimental observations for seven run conducted are shown along with other results in Table 5.

The method of calculation of discharged consistency, solid contents in black liquor and density is given in Annexure - 1.

3.3 Interpretation of results

From the experiments carried out as per the description given i earlier - , data was obtained on inlet consistency, drum speed, angle of submergence, pressure drop, wash water flow rate, filtrate flow rate, cake thickness and black liquor concentration (initial and final) are obtained and calculated. This data is shown in Table 5.

Based on the above data following parameters are evaluated. Discharge consistency, porosity of mat, permeability, fractional submergence, fibre production rate, specific loading factor, wash ratio, dilution factor, displacement ratio efficiency and EDR. These are shown in Table 6. A specimen calculation for run number 4 is shown in Annexure - 2

These tables clearly shows that it is possible to evaluate many washing parameters from simple lab. experiments. From the calculation it was observed that the output consistency of pulp has been generally low. The main reason for such findings is high foaming in the system and rather low mat thickness on the belt. These are further aggrevated due to rather lower values of pressure drop experienced across the mat.

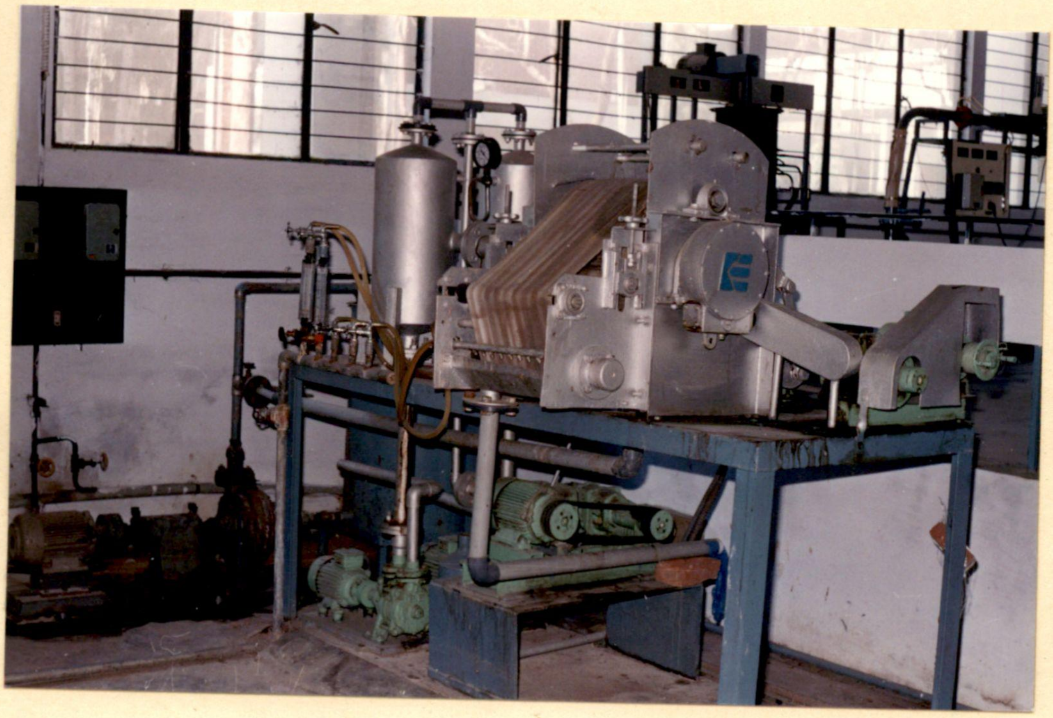
Since the data collected are not sufficient, it is difficult to establish the direct relation ship between some of the processing parameters and the calculated parameters. A lot of time available was utilized in setting up the apparatus, in setting right many if the difficulties experienced during assembly and commissioning. As a consequence many runs on pulp washing could not be taken. Now that apparatus is in working condition, many of the Indian pulps can be systamatically analysed for their washing characteristics using the laboratory rotary drum vacuum filter with filter cloth.

TABLE - 5 : Data collected from the experiments done on lab. washer

Inlet Consistency (C_i) %	RPS	Speed of drum(1/s) N=RPS/60	Angle of Submergence θ°	Pressure drop (mmHg) (Pa)	Wash Water in (lph) Vw	Flow rate in m^3/s V_w 10^{-4}	Filtrate flow rate (m^3/s) V_f 10^{-4}	Density (Kg/m^3) d	Cake Thickness L (m)	B/L Conc. (gpl) C
1	1/85	0.0118	79.322	20 - 40	25	0.1388	0.49	1060.86(i)	0.005	5.020(i)
				(2666 - 5332)				1025.10(f)		4.894(f)
1	1/85	0.0118	79.322	20 - 50	50	0.2777	0.23	1060.86(i)	0.0052	5.020(i)
				(2666 - 6665)				1023.00(f)		4.962(f)
1.5	1/67	0.0149	79.322	90 - 100	25	0.1388	0.188	1056.30(i)	0.007	5.071(i)
				(11997 - 113330)				1028.40(f)		4.991(f)
1.5	1/67	0.0149	79.332	80 - 90	50	0.2777	0.21	1056.30(i)	0.006	4.943(i)
				(10664 - 11994)				1028.40(f)		4.912(f)
1.75	1/75	0.0133	79.332	50 - 60	25	0.1388	0.171	1089.17(i)	0.005	5.001(i)
				(6665 - 7998)				1030.00(f)		4.825(f)
2	1/62	0.0160	101.288	30 - 40	25	0.1388	1.36	1034.00(i)	0.008	4.623(i)
				(3999 - 53332)				1016.00(f)		4.113(f)
2	1/62	0.016	101.288	20 - 30	50	0.2777	0.87	1034.00(i)	0.006	4.624(i)
				(2666 - 5332)				1024.00(f)		4.132(f)

TABLE 6: Calculation of various parameters from the data collected from experiments carried on lab. washer

Inlet cy. (%)	discharge cy. (%)	Porosity E	Permeability (m^2)	fractional submergence of drum	Fiber prod. rate (P_f) (kg/s)	Specific loading (kg/m^2s)	Wash Ratio WR	Dilution Factor DF	DR	Efficiency (%)	EDR
1	3.518	0.9853	6.586×10^{-11}	0.22	6.606×10^{-4}	0.001349	0.8354	-4.5	0.87	88.00	0.514
1	2.308	0.9893	1.060×10^{-10}	0.22	4.590×10^{-4}	9.815×10^{-4}	2.3216	1.82	0.84	87.80	0.077
1.5	7.991	0.9687	2.116×10^{-11}	0.22	2.280×10^{-3}	0.0509	0.0822	-5.42	0.86	93.70	0.778
1.5	3.706	0.9831	5.34×10^{-11}	0.22	1.060×10^{-3}	0.0235	0.1578	0.61	0.83	83.44	0.22
1.75	6.078	0.9887	1.467×10^{-11}	0.22	5.260×10^{-4}	4.139×10^{-3}	0.0753	10.90	0.86	87.50	0.682
2	8.800	0.9664	1.860×10^{-11}	0.28	3.010×10^{-3}	7.108×10^{-3}	0.0654	-1.16	0.90	92.00	0.856
2	5.410	0.9758	1.770×10^{-11}	0.28	1.630×10^{-3}	5.30×10^{-3}	1.04	-8.94	0.89	89.30	0.732



EIMCO KCP LAB. DRUM WASHER

CHAPTER 4

EVALUATION OF INDUSTRIAL BROWN STOCK WASHING PROCESS PARAMETERS BY VARIOUS METHODS

Most of the washing variables reported for evaluation of Brown stock washing by designers known generally are feed consistency, vat consistency, distribution of stock on filter, dilution factor, shower temperature, drum speed, sheet thickness, specific loading etc. It has been impossible to correlate these effects directly with the soluble solids removal efficiency without expressing the amount of washing done on a single stage of a multiple system.

The data relating to washing process of a 3 stage counter current brown stock washing system are collected. Using the data, various parameters are evaluated by the following methods.

- Methods developed by Perkins.
- Equivalent displacement ratio method.
- Modified Nordan's factor method and
- Fundamental method.

4.1 Theoretical displacement ratio developed by Perkins[5]:

By expressing the washing accomplished in terms of the reduction in soluble solids, a measure of the efficiency of the washer is the actual reduction in solids compared to the maximum possible reduction.Consider a single stage system with soluble solids S_v% in the vat liquor, S% leaving in the pulp, and S_s applied with the shower, and sheet leaving the washing stage, with W_p kg of liquor/kg of pulp; the maximum possible reduction in soluble solids by the showers is $W_p(S_v - S_s)$, which would mean that all the vat liquor had been replaced by shower liquor. The actual reduction in soluble solids will be $W_p(S_v-S)$. Thus, S_v-S divided by S_v-S_s is the ratio of the actual reduction in soluble solids to the maximum reduction theoretical possible. Maximum reduction in soluble solids occur when all the vat liquor in the sheet has been replaced by shower liquor and shower efficiency may be expressed as W_s/W_p where W_s equals the shower liquor remaining in the washed sheet. [5]

Let

W_p = Total weight of liquor with the pulp leaving the washer at solids S% .

W_{fn}= Weight of vat liquor with the pulp leaving the washer at solids, S_v %

W_s = Weight of shower liquor with the pulp leaving the washer at S_s %

Liquor balance : $W_p = W_{fn} + W_s$

Solids balance : $(W_p)S = (W_{fn})(S_v) + (W_s)(S_s)$

Substituting : $(W_p)S = (W_p - W_s)(S_v) + W_sS_s$

$$W_s(S_v - S_s) = W_p(S_v - S)$$

$$W_s/W_p = (S_v - S)/(S_v - S_s)$$

Here W_p can be determined directly from the sheet consistency, but W_s, the weight of shower liquor in the sheet cannot be directly measured. As the three terms S, S_s & S_v can be determined by solids analysis of the several liquor, this expression offers the means of measuring shower efficiency.

The same ratio W_s/W_p can be derived theoretically in terms of W_p, the dilution factor D, and the number of applications, n of shower liquor on a single stage. Assuming that the washing action of the shower is a series of perfect dilutions and thickening with the shower liquor being applied in n equal portions, and the consistency of the sheet returns to its original consistency after each application of shower liquor.

Let

W_p = Liquor in sheet in kg/kg of moisture free pulp as it approaches the first shower header.

W_{ts} = Total shower liquor (in kg.)

W_f = Original weight of vat liquor in pulp sheet.

After the first shower liquor is applied, the proportion of W_f remaining in the sheet equals

$$[W_p/(W_p + W_{ts}/n)]$$

and the weight of W_f remaining in the sheet W_{f1} is

$$W_{f1} = [W_p/(W_p + W_{ts}/n)]. W_f$$

After the second shower the proportion of W_{f1} in the sheet is

$$[W_p/(W_p + W_{ts}/n)]$$

and the weight of W_f remaining in the sheet, W_{f2} is

$$W_{f2} = [W_p/(W_p + W_{ts})]. W_{f1}$$

after n shower the proportion of W_{fn-1} remaining in the sheet is

$$[W_p/(W_p + W_{ts}/n)]$$

and $W_{fn} = [W_p/(W_p + W_{ts}/n)] \cdot W_{fn-1}$

By substituting

$$W_{fn} = [W_p/(W_p + W_{ts}/n)]^n \cdot W_f$$
$$= [W_p/(W_p + W_{ts}/n)]^n \cdot W_p$$

Since the total weight of liquor equals the sum of remaining vat liquor plus the remaining shower liquor, therefore

$$W_p = W_{fn} + W_s$$

and

$$W_s = W_p - W_{fn} = W_p - [W_p/(W_p + W_{ts}/n)]^n \cdot W_p$$

since $\quad W_{ts} = W_p + D$

then $\quad W_s/W_p = 1 - [nW_p/((n+1)W_p + D)]^n$

This equation leads to the theoretical correlation between the displacement ratio, W_s/W_p, or it s equal $(S_t - S)/(S_v - S_s)$, and the dilution factor.

By definition, the theoretical displacement ratio is not a function of all the independent and dependent variables of a washing system, but this concept offers a means of predicting the nature and magnitude of the effect on the washing efficiency of the sheet consistency, the number of shower header and the dilution factor. In practice, the term $(S_v - S)/(S_v - S_s)$, is a measure of the effect on washing of all the operating variables, including wash liquor distribution, sheet distribution, shower temperature and variables dependent on pulp characteristics. Some example of latter variable are; the specific loading which control the sheet thickness and drum speed; the drainage rate which determine the vat consistency, cylinder submergence and is the controlling factor on the tonnage rate; and formation which depends on liquor and the amount of air entrainment on the stages.

The faster drum speed and the higher vat consistencies for second and third stages are indicative of a drop in the drainage rate from that in the first stage. As the pulp is not subjected to any mechanical action of a refining nature in passing from stage to stage, this decreases in drainage rate is attributed to the entrainment of air in the sheet on the first cylinder. [illegible]. The minute bubbles of air behave like a solid particles during filtration. They will not pass through the sheet and will fill the voids between the fibers preventing free drainage of the liquor. Foam lowers the washing efficiency of the shower by decreasing the diffusion rate during mixing and they also channel the wash liquor through the sheet so that the shower liquor does not come in contact with all the fibers[5].

The Displacement ratio concept is used in stepwise material balance and as an indication of solids removed in individual washing stages.

In design calculation for countercurrent washers, vat and sheet consistencies are often assumed constant for various stages. With such case the stepwise calculation can be simplified by combining these conditions into a group of factors, one for each stage, again using displacement ratio such that:[5,4]

$R_1 = S_1/S_b$; $R_2 = S_2/S_1$; $R_m = S_m/S_{m-1}$

and

$(R_1 * R_2 * \_ \_ \_ \_ \_ \_ \_ \_ R_m) = S_m/S_{m-1}$

where

S_1 = % solids in liquor from stock leaving stage 1

S_2 = % solids in liquor from stock leaving stage 2

S_m = % solids in liquor with the pulp leaving the final washer

Consider a system with m stages:

S_b = % solids in undiluted blow tank liquor

S = % solids in sheet leaving stage (any given stage)

S_a = % solids in sheet from any intermediate stage a

$S_a = R_a\ S_{a-1}$

S_s = % solids in shower liquor (any given stage)

S_e = % solid going to evaporator

S_v = % solids in vat liquor (any given stage)

R = solid reduction ratio

$$R_1 = S_1/S_b = \frac{\text{\% soluble solids in liquor leaving the first washer wi}}{\text{\% soluble solids in undiluted blow liquor}}$$

$$R_2 = S_2/S_1 = \frac{\text{\% soluble solids in liquor leaving second washer with t}}{\text{\% soluble solids in liquor leaving first washer with th}}$$

R_s = liquor in sheet from washer/liquor in shower = W_p/W_{ts}

R_v = liquor in sheet from washer/liquor in vat = W_p/W_v

R_g = Shower liquor in sheet from washer/total shower liquor

$R_g = R_s(S_s - S)/(S_s - S_s) = W_s/W_{st} = R_s(DR)$

R_b = Undiluted blow tank liquor/ liquor in sheet from washer = W_b/\

R_s = liquor in sheet from washer/liquor to evaporator = W_p/W_c

$$\Sigma R_{(1---m)} = R_1 * R_2 * \text{-------} R_m$$

$$W_{ta}\, S_{s(m-1)} + W_p\, S_m = W_{ts}\, S_o + W_p\, S_{m-1}$$

$$S_{s(m-1)} = (W_p/W_{ts})(S_{m-1} - S_m) = R_s(S_{m-1} - S_m)$$

$$S_v = [W_p S_{(m-1)} + W_v S_{s(m-1)}] / W_v$$

$$= (W_p/W_v)(S_{m-1}) + (W_v - W_p)/W_v(S_{s(m-1)})$$

$$= R_v S_{(m-1)} + (1-R_v)[R_s(S_{m-1} - S_m)]$$

$$R_{gm} = [(S_v - S_m)/(S_v - S_s)].R_s = [(S_v - S_s)/S_v].R_s$$

$$S_m = [1 - (R_{gm}/R_s)].S_s$$

$$= [1 - (R_{gm}/R_s)]\{R_v S_{m-1} + (1-R_v)[R_s(S_{m-1} - S_m)]\}$$

$$= \frac{(1 - (R_{gm}/R_s))\ [R_v + (1-R_v)R_s]}{1 + [1 + (R_{gm}/R_s)](1-R_v)\ R_s} \cdot S_{m-1}$$

$$S_m = R_m . S_{m-1}$$

$$R_m = \frac{[1 - (R_{gm}/R_s)][R_v + (1-R_v)\ R_s]}{1 + R_s(1 - (R_{gm}/\ R_s))\ (1 - R_v)}$$

where $R_{gm}/R_s = D.R_m$, where m = final stage

also

$$R_0 = \frac{[1 + (R_{ga}/R_s)]\ [R_v + (1 - R_v)R_s}{1 + R_s[(1 - (R_{gm}/R_s)](1-R_v)(\Sigma R_{(a+1---m)} - R_{ga}(1 - \Sigma R_{(a+1----m)})}$$

$$R_1 = \frac{[1 - R_{gt}/R_s]\ [R_b R_v + (1 - R_b R_v)\ R_a\ R_b]}{1 + R_e[1 - (R_{gt}/R_s)(1 - R_b\ R_v)(\Sigma R_{(2---m)} - R_{gt}(1 - \Sigma R_{(2---m)})}$$

$$S_m = (R_1 * \ R_2 * \ \_\ \_\ \_\ \_\ \_\ \_\ \_\ \_ R_m)\ S_b$$

$$= (\Sigma R_{o---\ m})\ S_b$$

4.1.1. A sample calculation based on Perkins' method

A washer calculation based on mill data is given below to illustrate the use of the R factors together with displacement ratios to calculate a three stage system.

Basis: Blow tank solids = 29.07 %

Blow consistency = 13.61 % OD basis

Dilution factor = 2, 2.5, 3.0

Vat Consistency = 1.0 % OD basis

Sheet Consistency = 10%

Using the previously developed procedure differennt values were evaluated for the dilution factor of 2,2.5 and 3.0 assuming the displacement ratio for 1^{st}, 2^{nd} and 3^{rd} stages. These values are tabulated below in Table 7.

TABLE - 7 : Values of solid reduction ratio for different DF's

S.No.	Variables	DF = 2	DF = 2.5	DF = 3
1.	DR stage 1	0.81	0.84	0.867
	DR stage 2	0.55	0.565	0.63
	DR stage 3	0.60	0.625	0.64
2.	R_b	0.7057	0.7057	0.7057
3.	R_v	0.0909	0.0909	0.0909
4.	R_s	0.818	0.782	0.75
5.	R_e	1.077	1.016	0.962
6.	R_3	0.257	0.237	0.223
7.	R_2	0.4990	0.473	0.505
8.	R_1	0.329	0.22	0.137
9.	S_m(%)	1.22	0.716	0.448

10.	S_e(%)	11.32	10.68	10.11

From Table 7, it is observed that increase in dilution factor has resulted in cleaner pulp though the concentration of solids in Black liquor going to evaporator has reached from 11.32% to 10.11%. The reduction in pollution load however will be 41.3% and 63.2% when dilution factor is increased from 2 to 2.5 and 2 to 3 respectively.

Thus the concept of determining brown stock washing efficiency by displacement ratio method promote a better understanding of the washing accomplished in a countercurrent system, and the ratio $(S_v - S)/(S_s - S_v)$ offers a practical means of evaluating washing variables.

The major drawback of this method is that it serves well in the case of vacuum drum washers. With new washing methods such as pressure drum washer, diffusion washer and twin roll presses, it is more difficult to compare how well respective type of equipment wash pulp.The answer to this question becomes more complicated if the supply consistency and solid contents in the shower were not the same for all the washers.

The effectiveness of any pulp washer depends on four variables i.e. inlet consistency, discharge consistency, displacement ratio and dilution. While it is already difficult to assess the effectiveness of any given washer, it is even more difficult to compare different type. So a new concept of equivalent Displacement ratio is introduced.

4.2 Equivalent displacement ratio method

The effeciency of a pulp washer depends on four variables mentioned above, it is difficult to assess it's test results. To reduce the number of variables, the actual washer is compared with a hypothetical vacuum drum washer operating under standard conditions of 1% inlet consistency and 12% discharge consistency.

A new Equivalent Displacement Ratio (EDR) is calculated for the hypothetical washer, setting the system's loss equal to that of actual washer operated at the same dilution. The EDR, is a performance parameters which is independent of the inlet and discharge consistencies [3,7].

The EDR is calculated for the hypothetical washer using the formula[3],

$$(1 - EDR) = (1 - DR)(DCF)(ICF) \quad (1)$$

where,

$$DCF = L_D / 7.333 \quad (2)$$

= discharge correction factor

* DCF: It simply state that (1- DR) is proportional to the weight of liquor in the discharge, independent of dilution factor and inlet consistency (7.333 is the ratio of liquor to pulp for 12% discharge consistency)

$$ICF = [99.0(L_V + DF)/[L_V(99.0+ DF) - L_D(99.0-L_V)(1- DR)]$$

= Inlet correction factor (3)

* ICF: It is somewhat more complicated than DCF. This factor is close to 1.0 for inlet consistencies below 2% and can generally be neglected (99.0 is the ratio of liquor to pulp for 1% inlet consistency). The effectiveness of pure dilution extraction washer, such as an open cylinder Decker or a twin roll press (without displacement washing), does not depend on the inlet consistency.

$$L_V = (100 - C_V)/C_V \quad (4)$$

= Inlet ratio of liquor to pulp, kg/kg

$$L_D = (100 - C_D)/C_D \quad (5)$$

= Discharge ratio of liquor to pulp, kg/kg

For dilution extraction washers

$$ICF = 99.0/(99.0 + DF + L_D) \quad (6)$$

where,

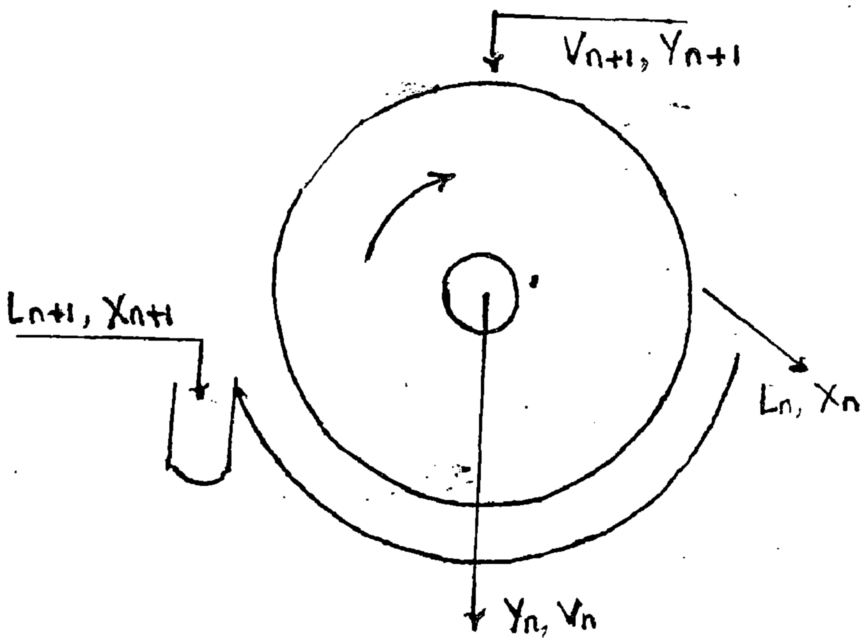
DF = dilution factor

C = oven dry consistency, %

4.3 Modified Norden factor method [3]:

In this method, the actual washer is compared with a dilution extraction washer without displacement washing. The Norden factor is defined as the number of countercurrent extraction washing stages required to be equivalent to a given washer at the same discharge consistency and dilution[1].

Let us consider a washing model



where,

L = flow rate of liquor in underflow, (kg liquor / kg pulp or kg liquor / min)

V = flow rate of liquor in overflow (filtrate), (kg liquor / kg pulp or kg liquor / min)

x = weight fraction of alkali (Na_2SO_4) in underflow (g alk / kg liquor)

y = weight fraction of alkali in overflow, (g alk / kg liquor)

The Norden factor (E) can be calculated by using the following equation,

$$E = \frac{\log(L_{n+1}/ L_n) \, [(X_{n+1} - Y_n)/(X_n - Y_{n+1})]}{\log[(V_{n+1}/L_n)]} \tag{7}$$

Above equation can be simplified when $V_{n+1} = L_n$ (wash liquor ratio of 1), a rather uncommon condition

$$E = (L_n/ L_{n+1}) \, [(Y_n - Y_{n+1})/ (X_{n+1} - X_n)] \tag{8}$$

Provided $Y_{n+1} = 0$, the wash yield Y is then related to the Norden factor E by

$$Y = 1 - [(W-1)/(W.R^E - 1)] \tag{9}$$

When a washing system has n washer in series, the system's washing efficiency factor can be determined from the efficiency factors of the individual washing stages, from the equation (10)

$$E \log R_n = E_1 \log R_1 + E_2 \log R_2 + \_\_\_\_\_\_\_\_ + E_n \log R_n \tag{10}$$

If the wash liquor ratio R is 1, this relationship reduces to

$$E/L_n = E_1/L_1 + E_2/L_2 + \_\_\_\_\_\_\_ + E_n/L_n \tag{11}$$

For a constant underflow, the discharge consistencies from each stage must be the same. Since this is not frequently the case, a modified Norden efficiency factor E_{st} was developed. E_{st}[1] is not dependent on discharge consistency. A standard consistency C_{st} typically 12% is chosen and used in eq. (1) to obtained E_{st} for a washing stage.

$$E_{st} = \frac{\log \{(L_{n+1}/L_n)[(X_{n+1} - Y_n)/(X_n - Y_{n+1})]\}}{\log [1 + (DF/L_{st})]} \tag{12}$$

where $L_{st} = (100 - C_{st})/ C_{st}$; C_{st} = standard efficiency = 12%

The Norden efficiency factor E, as defined in eq. (1)

is a function not of inlet consistency but of discharge consistency. The modified Norden efficiency factor E_{st} as defined by eq. (7) is independent of both the inlet and discharge consistencies. The efficiency factor for the entire system can be calculated by simply adding the E_{st} value of the individual stages. Different types of washers or washers operating at the same DF but over different consistency ranges can be compared on the basis of their respective E_{st} values.

E_{st} is a simple , versatile and useful concept. Experience shows that it is only weakly affected by dilution factor and therefore are useful in modular simulations, where the effect of varying dilution are frequently optimized. Norden efficiency factor and modified Norden efficiency factor have thus become a basic building blocks for most modular computer simulations of pulp washing systems.

When both E_{st} and EDR are defined for the same discharge consistency (e.g. 12%), then the modified Norden efficiency factor and EDR is related as

$$EDR = 1 - (R.W - 1)/(R.W^{Est-1}) \quad (13)$$

A typical vacuum drum filter and its hypothetical equivalent are shown in Fig.[11]. In general, the actual washer and its equivalent will not have the same washing efficiency [3]

$$WE = [(A_F - A_D)/A_F]\ 100\ \% \quad (15)$$

where,

WE = Washing efficiency %

A = ratio of dissolved solids to pulp, kg/kg.

F = Subscript for supply

D = Subscript for discharge

The total losses in a countercurrent washing system can be calculated in any individual stage by subtracting the weight of solids entering with the shower liquor from the solids leaving with the discharge (A_D - A_S); that is, the solids that do not come back with the shower liquor are ultimately lost at the end of the system. Therefore, for one washing stage to be equivalent to another, they both must have an equal difference between the weight solids leaving with the discharge and entering with the shower liquor.

Let us consider that a vacuum washer and its equivalent fig.(11) operating under the condition given below.

Inlet consistency	C_V = 1.5%
Discharged consistency	C_D = 13%
Supply consistency	C_F = 10%
Dissolved solids in vat liquor	S_V = 14%
Dissolved solids in discharge liquor	S_D = 5.92%
Dissolved solids in shower liquor	S_S = 3.9%
Dilution factor	DF = 3.0

To calculata the parameter using modified Norden's method and equivalent displacement method, an algorithm has been developed. This is disscussed in the next section.

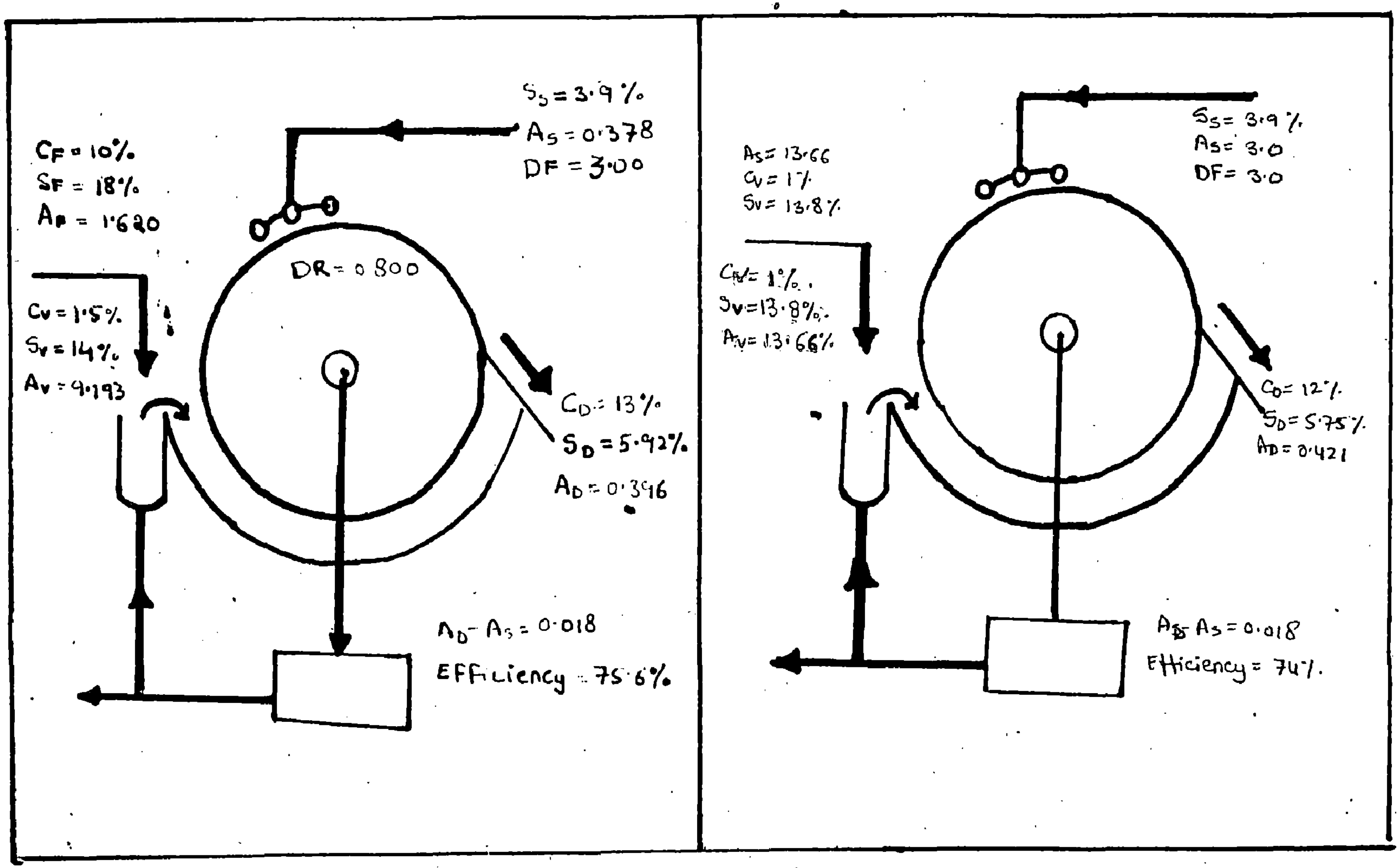


Fig. (12) Comparison of Vacuum and equivalent washers.

4.4 Algorithm for evaluation of brown stock washing parameters using modified Norden and equivalent displacement ratio method.:

Step 1: Given conditions of dissolved solids in black liquor is as follows

$S_V = 14\%$; $S_D = 5.92\%$; $S_S = 3.9\%$

Step 2: Displacement ratio is calculated by using the formula

$DR = [(S_V - S_D)/(S_V - S_S)]$

$= [(14 - 5.92)/(14 - 3.9)]$

$= 0.800$

Step 3: Discharge consistency factor(DCF) is calculated from eq. (2)

$DCF = L_D/7.333$

where $L_D = (100 - C_D)/C_D$

at $C_D = 13\%$

$DCF = 0.91$

Step 4: Calculation for inlet consistency factor (ICF) from eq. (3)

$ICF = [\ 99(L_V + DF)]/\ [L_V(99 + DF) - L_D(99 - L_V)(1 - DR)$

$L_V = (100 - C_V)/C_V = (100 - 1.5)/1.5$

$= 65.66$

$L_D = (100 - C_D)/C_D = (100 - 13)/13 = 6.69$

$ICF = [\ 99(65.66 + 3.0)]/[65.66(99 + 3) - 6.69(99 - 65.66)(1 - 0.8)$

$= 1.02$

Step 5: Calculation of Equivalent displacement ratio(EDR) from eq. (1)

$1 - EDR = (1 - DR)(DCF)(ICF)$

$EDR = 1 - \{(1 - DR)(DCF)(ICF)$

$EDR = 0.815$

Step 6: Calculation of washing efficiency from eq. (15)

$WE = [(A_F - A_D)/A_F].100$

Step 6a: Calculation for A (ratio of dissolved solids to pulp, kg/kg.

A = L (kg of liquor /kg of pulp) • S (kg of solids/kg of liquor)

A = L • S (kg of solids/kg of pulp) = V * S

$V_{n+1} = L_n + DF$

$L_n = (100 - C_D)/C_D = (100 - 13)/13 = 6.69$

$V_{n+1} = 6.69 + 3 = 9.96$

$A_s = V_{n+1}S_s = 9.69 * .039 = ,378$

Step 6b: $A_v = S_v L_v$

$A_v = 14\% \ (100 - C_v)/C_v$

$= 0.14 \ (100 - 1.5)/1.5$

$= 9.193$

Step 6c: $A_D = L_D S_D$

$=[(100 - C_D)/C_D] . S_D$

$=[(100 - 13)/13].0.0592$

$=0.396$

Step 6d: $A_F = L_F S_F$

$=[(100 - C_F)/C_F] . S_F$

$= [(100 - 10)/10] . 0.18$

$= 1.62$

Step 6e: $A_D - A_S = 0.396 - 0.378$

$= 0.018$

Putting the values of A_F and A_D we get

WE = 75.5%

Step 7 : Calculation for wash liquor ratio

$R = V_{n+1}/L_n$

$= (L_n + DF)/L_n$

$= (6.69 + 3)/6.69$

$= 1.44$

Step 8: Estimation of weight liquor ratio

$W = V_n/ L_F$

$= (L_{n-1} + DF)/L_F$

$= (9 +3)/(98.5/1.5)$

$= 0.18$

Step 9: Calculation of Modified Norden efficiency factor E_{st} from eq. (14)

$EDR = 1 -[(R.W -1)/(R.W^{Est} -1)]$

Putting the different values

$0.815 = 1 -[(1.44 * 0.18 -1)/ (1.44 * (0.18)^{Est-1})]$

solving

$E_{st} = 1.596$

Step 10: Calculation of Modified Norden efficiency factor E_{st} from the eq. (13)

$$E_{st} = \frac{\log \{(L_{n+1}/L_n)[(X_{n+1} - Y_n)/(X_n - Y_{n+1})]\}}{\log [1 + (DF/L_{st})]}$$

we have

$L_{st} = (100 - C_{st})/C_{st} = 7.33$

$L_{n+1} = (100 - 10)/10 = 9$

$L_n = 9$

$V_{n+1} = 9.69$

$X_{n+1} = 18\%$

$Y_n = 13.36$

$X_n = 5.92\%$

$Y_{n+1} = 3.9\%$

From material balance equation

$$S_V{*}\ L_V + S_s{*}\ V_{n+1} = S_D{*}\ L_D + (L_V + V_{n+1} - L_D)\ S_b$$

$$0.14{*}\ [(100 - 1.5)/1.5] + .039{*}\ 9.69 = 0.0592[(100 - 13)/13] + (65.66 + 9.69 - 6.69).S_b/100$$

$S_b = 13.36\%$

$$E_{st} = \frac{\log[9/9(18 - 13.36)/(5.92 - 3.9)]}{\log [1 + (3/7.33)]}$$

$= 2.24$

Step 11: We have E_{st} from eq. (14) = 1.596 and E_{st} from eq. (13) using constant discharge consistency of 12% = 2.42

Step 12| Calculation of wash yield from eq. (9)

$$Y = 1 - [(W-1)/(W.R^E - 1)]$$

where E = Norden efficiency factor and can be calculated by using the equation (7)

$$E = \frac{\log (L_{n+1}/L_n)[(X_{n+1} - Y_n)/(X_n - Y_{n+1})]}{\log (V_{n+1}/L_n)}$$

-utting different values

$$E = \frac{\log (9/9)[(18 - 13.36)/(5.92 - 3.9)]}{\log (9.69/9)}$$

$= 12.68$

$Y = 1 - [(0.18 - 1)/0.18(1.44)^{12.68} - 1]$

$= 1.008$

Step 13: Calculation of wash yield expressed in terms of the ex traction step inlet and discharge consistencies

$$Y = [100\ (C_d - C_i)]/[C_d(100 - C_i)]$$

$$= [100\ (13 - 1.5)]/[13\ (100 - 1.5)]$$

$$= 0.898$$

The various rtesults calculated in algorithm are tabulated below in Table 8.

TABLE - 8 : RESULTS FROM ALGORITHM FOR THE EVALUATION OF BROWN STOCK WASHING PARAMETERS

C_V	C_D %	DCF	ICF	EDR	DF	DR	WE%	E_{st10}	E_{12}	Y
1.50	13.0	0.91	1.02	0.815	3.0	0.80	75.5	1.59	12.68	0.898
1.75	13.3	0.89	1.03	0.818	2.5	0.80	76.2	2.60	11.54	0.881
2.00	13.7	0.86	1.04	0.833	3.5	0.81	77.7	2.34	11.09	0.87

4.5 Evaluation of brown stock washing based on fundamental parameters.

The methods of evaluating Brown stock performance have been given are quantitative in nature. No fundamental mechanism has been considered in the above correlation. More fundamental types of correlations are available. The present method is based on the work done by Kukereja et.al.[2,7].

Consider a vacuum washer working at the following conditions:

Inlet vat consistency	$C_V = 1.5\%$
Discharge consistency	$C_D = 13\%$
Supply consistency	$C_S = 10\%$
Dissolved solids in vat liquor	$S_V = 14\%$
Dissolved solids in discharge liquor	$S_D = 5.92\%$
Dissolved solids in shower liquor	$S_S = 3.9\%$
Dilution factor	$DF = 3.0$
Density of fiber	$D_f = 1560\ kg/m^3$

(1) Porosity

$\epsilon_t = \{d_f(1 - C_y)\}/\{dC_y + d_f(1 - C_y)\}$

at $C_{yi} = 1.5\%$

$\epsilon_t = 0.9903$

at $C_{yo} = 13\%$

$\epsilon_t = 0.9125$

Therefore mean porosity,

$\epsilon_t = (0.9903 + 0.9125)/2 = 0.9514$

(2) Permeability

$K(t) = [K_1 S_o^2 (1 - \epsilon_t)^{1.5} \{1 + K_2(1 - \epsilon_t)^3\}]^{-1}$

S_o = Specific surface area of fiber = $0.156 \cdot 10^7\ m^2/m^3$

$K_1 = 3.5$ & $K_2 = 57$

$K(t) = 1.093 \cdot 10^{-11}\ m^2$

(3) Wash ratio

$WR = (V_w d_w C_{yo})/[P_F(100 - C_{yo})]$

V_w = wash liquor flow rate

$= (L_D + DF)(P_F/1000)$ where P_F is in T/sec

$= [(100 - C_{yo})/C_{yo}] + DF$

$WR = [(100 - C_{yo})/C_{yo} + DF](d_w\ C_{yo})/(100 - C_{yo})$

$WR = 1.44$

(4) Fiber Production rate

$P_f = (1 - \epsilon_t)NALd_f$

Size of washer = 10'dia.* 12' face (Mill data)

Area of drum = $2\pi rh = 35.02\ m^2$

Speed of drum N = RPS/60 = 0.0133 (Mill data)

Cake thickness L = 0.05 m

$P_F = 1.765$ kg/s or

$P_F = 1.765 * 10^{-3}$ T/s

(5) Specific Loading

$W = (1 - \epsilon_t)\ NLd_f$

$W = 0.05\ kg/m^2\ s$

(6) Dilution Factor

$DF = 1 + (V_w d_w / P_F) - (100/C_{yo})$

$DF = 2.94 \equiv 3.0$

(7) Displacement ratio

$DR = [(C_i/d_i) - (C_s/d_s)]/[(C_i/d_i) - (C_o/d_o)]$

But this formula valid when we have C values in kg/m^3

so we use the formula

$DR = (C_i - C_s)/(C_i - C_o)$

$DR = 0.800$

(8) Efficiency

$\eta = 1 + [\{(C_s - C_o)(100 - C_{yo})d_i\}/\{(C_i - C_o)(100 - C_{yi})d_o\}]100$

$\eta = 82.0\%$

TABLE - 9 : Comparison of different washing parameters obtained from mathamatical analysis to those obtained from equivalent displacement ratio method.

Parameters	EDR method	Mathematical analysis
Porosity	_	0.9514
Permeability (m^2)	_	$1.093 \cdot 10^{-11}$
Fiber production rate (kg/s)	_	1.765
Wash ratio	1.44	1.44
Dilution factor	3.0	2.94
Displacement ratio	0.800	0.80
Efficiency (%)	75.5	82.0

The methods developed by Perkin is a macromodel using overall material balance for evaluating washer perofrmance. The EDR developed by Luthi is an improvement to the Perkin's method. The modified Norden method is developed on the principle of a contact stage. It does not evaluate efficiency but gives equivalent number of stages. The algorithm developed can be used to evaluate the terms like displacement ratio, washing efficiency and Norden stages. The fundamental methods on the other hand uses equations developed based on the mechanism of transport processes influencing the washing process. This method while being more tedious, requiring information on many factors, it give a better assessment of the washing process.

CHAPTER - 5

CONCLUSION

The EIMCO - KCP lab filter was supplied to the institute, could not be used as such for taking experimental runs. Therefore installation of some of the missing parts and modification of some of the auxiliary equipments was felt necessary. As such in first stage of work various connections like connection required for water flow in vat, vacuum pump intake, vacuum receiver pipings, filter drive assembly etc were made. Filter is now ready to conduct experiment on it.

After finishing installation part, experimental run were conducted to see whether this filter could work or not.

With limited experimental runs, it is found that outlet consistency of the pulp has been generally low. The main reasons for such findings is high foaming of the system and rather very low mat thickness. These are further aggregated by lower values of pressure drop across the mat. As such, the black liquor going with the pulp has been found to be much higher than expected. However with in the limited experimental data, it is possible to evaluate the required washer performance using the equation available in the literature.

An attempt is also made to calculate various Brown stock washing parameters like dilution factor, Displacement ratio, Wash liquor ratio, Weight liquor ratio for a particular data taken from a near by industrial unit. Using this data, various washing efficiency terms are computed and compared using different methods available in literature. It is evident that washing efficiency definition given by Luthi[3], Perkins[5] and Wash yield efficiency given by Crotogino[1] and efficiency equation by Kukreja et al.[2,7] are not equivalent. However, they are useful for comparing various filters, though each model uses different input parameters.

Equivalent displacement ratio (EDR) and Modified Norden efficiency factor (E) are also calculated for mill conditions.

NOMENCLATURE

A = Surface area of Drum, m^2.

C = Concentration of solute in filtrate i: vat ; o: wash liquor ; s: cake pores after washing :(kg/ m^3)

C_y , C_y = Inlet, Outlet vat consistency, %

d, d_f, d_i, d_s = Density of water, fiber, liquor inside the cake pores, liquor in cake pores after

K = Permeability constant of cake, m^2

L = Thickness of the cake, m

N = Speed of the Drum, rpm / 60, 1/ s

P = Vacuum Pressure drop, Pa.

P_f = Fiber production rate, kg/ s,

R = Radius of drum, m

S_0 = Specific surface of fibers, m^2/ m^3

W = Specific loading factor, kg/ m^2 s

ϵ_t = Total Porosity

μ = Fractional submergence of drum

Θ = Angle of submergence

V_w = Wash liquor flow rate; m^3/ s

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ANNEXURE - 1

1. Calculation of discharge of out put consistency :

An empty beaker is weighed. Small amount of discharge pulp sample is put in the beaker and weighed again. the pulp is then thoroughly washed in the filter paper, till all black liquor particles are washed out. It is then kept in the oven for overnight and then again weighed. This value minus the weight of filter paper gives the weight of the O.D. fibers. Then consistency is calculated.

4.4 Calculation of total solid content of black liquor :

For calculating the total solid content of black liquor, we flow the standard method of TAPPI (T650 om - 89).

In this method, we place 25 to 30 gram of sand in weighing bottle and heat the bottle and cap in the oven at 105°C to constant weight. Cool it in a desiccator and weigh to nearest 0.5 mg, by means of a pipet or medicine dropper, transfer enough specimen to weighing bottle to ensure 1 to 3 gm of solids, cap the bottle and weigh to the nearest 0.5 mg. Then place the weighing bottle and cap in the oven (cap off) and heat for minimum of 6h. Remove, cool in desiccator and weigh 9cap on).

% Solids = Weight of dry solids . 100 / weight of specimen

4.5 Density :

Density of liquor is calculated by weighing initially the empty weigh bottle. it is then filled with known volume of black liquor (initial or filtrate) and then again weighing it. Subtracting the two reading, we get the weight of known volume of liquor. by using the formula

$$D = M/V$$

we calculate the density of liquor.

ANNEXURE - 2

The calculation of various washing parameters from the data collected from the experiment carried on laboratory washer is given below

Basis : Single stage washer

Raw material : Mixed Hardwood cooked pulp (82% Euclyptus, 16% Bamboo and 2% pine)

Kappa no.		:	19
Active alkali		:	14.5% as Na_2O
Inlet vat consistency	C_{yi}	:	1.5%
Output consistency	Cy_o	:	3.7059%
Wash water flow rate	V_w	:	25 lts/hr (0.2777 m^3/sec)
Pressure drop	ΔP	:	80-90 mmHg(10664-11994 Pa)
Filtrate flow rate	V_f	:	$0.21 \cdot 10^4$ m^3/sec
Cake thickness	L	:	0.005 m
Black liquor concentration			
Initial (vat)		:	4.943 g/lt
Final (filtrate)		:	4.912 g/lt
Density of black liquor			
Initial (vat)	d_i	:	1056.30 kg/m^3
Final (filtrate),	d_o	:	1028.4 kg/m^3
Density of fiber	d_f	:	1560 kg/m^3
Radius of drum	r	:	23.46 cm
Width of drum	h	:	30.48 cm
Surface area of drum	A	:	$2\pi rh$ (0.4492 m^2)
Speed of drum	N	:	1/67 rev/sec (0.149 1/s)
Angle of submergence	Θ	:	79.332°
Conc. of solute in filtrate			
	C_i	:	5.020kg/m^3
	C_s	:	0.8259kg/m^3
	C_o	:	0.0kg/m^3

(1) Porosity (ref. Table 2)

$\epsilon_t\ (Z) = \{\ d_f(1 - C_y)\}\ /\ \{dC_y + d_f(1 - C_y)\}$

at $C_y = C_{yi} = 1.5\%$

$\epsilon_t\ (z) = 0.9903$

at $C_y = C_{yo} = 3.7059\%$

$\epsilon_t\ (z) = 0.9759$

Therefore mean porosity,

$\epsilon_t = (0.9903 + 0.9759)/2 = 0.9831$

(2) Permeability (ref. Table 2)

$K(t) = [K_1(S_o)^2(1 - \epsilon_t)^{1.5}\ \{1 + K_2\ (1 - \epsilon_t)^3\}]^{-1}$

S_o =Specific surface area of fibers = $0.156 \cdot 10^7\ m^2/m^3$

$K_1 = 3.5$ & $K_2 = 57$

Putting these values in above equation,

$K(t) = 5.34 \cdot 10^{-11}\ m^2$

(3) Fractional Submergence of drum (ref. Table 2)

$\mu = \Theta/2\pi$

Putting different values

$\mu = 0.22$

(4) Fiber production rate(ref. Table 2)

$P_F = (1 - \epsilon_t)\ NALd_f$

$P_F = 1.058 \cdot 10^{-3}$

(5) Specific loading (ref. Table 2)

$W = (1 - \epsilon_t)\ NLd_f$

$W = 0.0235\ kg/m^3s$

(6) Wash Ratio(ref. Table 2)

$WR = (V_w d_f C_{yo})\ /\ \{P_F(100 - C_{yo})\}$

$WR = 0.1575$

(7) Dilution Factor(ref. Table 2)

$DF = 1 + (V_w d_w)/P_F - (100/C_{yo})$

$DF = 0.259$

(8) Displacement Ratio(ref. Table 2)

$DR = [\{(C_i/d_i) - (C_s/C_s)\}/\{(C_i/d_i) - (C_o/d_o)\}]$

$DR = 0.83$

(9) Efficiency(ref. Table 2)

$\eta = 1 + [\{(C_s - C_o)(100 - C_{yo})d_i\}/\{(C_i - C_o)(100 - C_{yi})d_o\}]100$

$\eta = 83.4\%$

(10) Equivalent Displacement Ratio(ref. Table 2)

$(1 - EDR) = (1 - DR)(DCF)(ICF)$

where DCF = discharge correction factor

ICF = inlet correction factor

$DCF = L_d/7.33$, where $L_d = (100 - C_{yo})/C_{yo} = 7.0114$

$ICF = [\ 99(L_i - DF)/\{L_i(99 - DF) - L_d(99 - L_i)(1 - DR)$

where

$L_i = (100 - C_{yi})/C_{yi} = 65.66$

$ICF = 1.024$

$(1 - EDR) = 1.22$

$EDR = 0.22$