A

DISSERTATION REPORT

ON

ANALYSIS OF ENERGY CONSERVATION STRATEGIES AND THEIR IMPLEMENTATION ON PAPER MACHINE NO. 4 OF BILT, YAMUNANAGAR (HARYANA)

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY
in
PULP AND PAPER

Submitted By

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Under the Guidance of

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To My Family, Who have made all this possible and always supported my decisions. I will never be able to pay back what they did and do for me.

(KUNAL GROVER)

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CANDIDATE' S DECLARATION

I hereby declare that the work which is being presented in this seminar report entitled **"Analysis of Energy Conservation Strategies and their Implementation on Paper Machine No. 4 of BILT, Yamunanagar (Haryana)."** in partial fulfillment of the requirements for the award of the degree of Master of Technology (Pulp and Paper), IIT Roorkee, is an authentic record of my own work carried out, under the supervision of **Dr. M. C. Bansal**, Professor., Department of Paper Technology, IIT Roorkee, Saharanpur Campus, Saharanpur.

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

Date: 30/06/2004
Place: SAHARANPUR

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

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ABSTRACT

Paper industry is a known major consumer of water, power and steam world wide. In the global competitive environment, the paper industry can only survive with quality product at the most competitive price. This will require the most efficient utilization of all the utilities and resources. The paper machine section consumes energy in the form of steam and Electric power for drying of paper. An effort has been made to analyze the Paper Machine No.-4 of BILT Yamunanagar (Haryana) as it was before implementing the recommendations for its performance improvement. In this Dissertation, the analysis has been presented about consumption of steam and power in different, the then existing configuration and the quality of product with the renovated energy and power consumption figures with improved quality of production. It is indicated that the theoretical analysis made earlier for making the six proposals for the improvements in PM-4 sections including size press at an approximate cost of rupees 275 Lakhs have really yielded the desired results with a payback period of only 0.73 years.

Chapter 1- Company Profile and Introduction

1.1 Thapar Group of Industries:

The Thapar Group has evolved from a small coal agency to India's third largest corporate entity with significant presence in international business environment.

The groups founder Lala Karam Chand Thapar took over a sick colliery & nursed it back to health and profits. Over the next few decades Thapar group became India's largest producer of coking & non-coking coal. The group exapanded from paper to pulp to chemicals, from paper to paper sacks & laminated cartons, from machinery to electronics & more...

To underline its transnational presence, the Thapar Group has established manufacturing facilities in Africa & industries in the South East Asia, taken up & completed engineering contracts in the Middle East, provided full fledged technical consultancy for one of the largest joint sector pulp mills in Thailand.

BILT: The Brand Name

BILT is the largest paper company, offering the widest product portfolio in the entire Indian paper Industry. They have a paper for every usage right from inexpensive cream wove to premium DO paper. Their complete gallery provides paper manufacturers, electrical equipment, Soap & shampoos, Detergent packaging Industry, and the list is unending...

Coated wood free paper

Art Paper C1S, Art Paper C2s,
Art Board, Black centered Board,
Pulp Board

Wood Free Paper

Cream Wove, Ordinary Map Litho
High Bright Map litho, Copier, Ledger

Industrial paper

ESKP, MF Kraft Paper,
UBK (unbleached kraft)

Specialty & Fine Paper

DO Paper, Bond Paper, Parchment,
Ivory Board, Cheque /MICR,
Posters, Electric grade, Base paper for Laminates

This unmatched range, coupled with a manufacturing capacity that is by far the largest, ensures without doubt, that there is "BILT in Every Paper".

SHREE GOPAL UNIT, YAMUNANAGAR (HARYANA)

The founder of this unit was Foundation Company of England. This mill initially made use of rags as paper manufacturing raw material. As then there was no power supply in Yamunanagar, to its advantage the mill had its own power generation.

After a short period the mill found itself in peril due to various factors including financial problems that forced it to liquidate. The mill remained closed for six months.

The Current Status:

Today the unit has six paper machines including a sophisticated specialty plant and on top the technology to convert raw material of the worst quality to papers of finest qualities.

It has also taken steps for environment protection with the installation of Electrostatic precipitator (ESP), effluent treatment plant (ETP).

Today with a turnover of about Rs. 300 crores and manpower of about 3000 people, BILT Yamunanagar enjoys the reputation of being "efficiently managed", "Financially sound", "self sufficient" and "self managed" company.

1.2 Introduction:

The conservation of energy is an essential step we can under take towards overcoming the mounting problems of the worldwide energy crisis and environmental degradation. In particular, developing countries have increasing awareness on the inefficient power generation and energy usage in their countries. However, usually only limited information on the rational use of energy is available.

The pulp and paper industry consumes much energy and water. The pulp and paper industry is also noted for great percentage of the energy cost in the total production cost. The average energy cost for Indian mills is around 20-25% of total production cost, as against 12-14 % in the USA, Sweden, Finland and other major paper producing countries. The energy cost as percentage of manufacturing cost rose from 15% in 1979-80 to about 25 % in 1992-93, mainly due to the rise in the cost of energy.

1.2.1 Plant Level Comparison:

Energy efficiency of a typical Indian mill is much lower compared to its counterparts in the developed countries owing to the old technology base. Absence of modernization at an aggregate level has reflected in poor energy efficiencies vis-à-vis mills in developed countries. On an average, steam consumption per ton of paper is 6.5-8.5 tons in mills abroad where as it is 11-14 tons in Indian mills. Section wise Steam consumption (tons/ton of paper) is given in Table 1[24]. Similarly, the electric energy consumption/ton of paper in Indian and foreign mills is given in Table 2[24].

Table 1 Section wise Steam consumption (tons/ton of paper)

S. No.	Section/equipment	Indian mills	Mills abroad
1	Digester	2.7-3.9	1.9-2.3
2	Evaporator	2.5-4.0	1.8-2.2
3	Paper machine	3.0-4.0	1.8-2.0
4	Soda recovery plant	0.5-1.1	0.3-0.5
5	Bleach plant	0.35-0.4	0.2-0.25
6	Deaerator	0.8-1.2	0.45-0.7

Table 2 Section wise Electricity consumption (kWh / ton of paper)

S. No.	Section/equipment	Indian mills	Mills abroad
1	Paper machine	465-475	410-415
2	Stock preparation	275-286	164-172
3	Utilities and others	248-252	160-165
4	Soda recovery plant	170-190	127-135
5	Washing and screening section	145-155	116-122
6	Chippers	112-128	92-98
7	Bleach plant	88-92	66-69
8	Digesters	58-62	43-46

The most significant steam consumer in paper industry is thus the paper machine section. The purpose of this system is to provide sufficient drying energy and adjust it in the machine direction to suit the requirements of each paper grade. Paper to be dried places requirements on the surface temperatures of the dryers that the division of sections and pressure controls of the steam system should manage. For proper operation of drainage and steam and condensate system, the system must maintain good and stable evacuation of condensate and non - condensable gases from the dryers. This will give optimum heat transfer of the dryers and energy consumption in drying.

Proper design, operation, and performance of the dryer section's steam and condensate-handling system are essential for efficient operation of modern high-speed paper machines. An inefficient system can increase energy consumption, reduce machine production, and diminish product quality face, and the system's ability to drain the dryers under all machine operating conditions.

The objective of the selection process is to optimize the list of desired end results outlined below:

- Maximize the heat transfer to reach maximum drying rate on dryer limited grades.
- Minimize cross-machine temperature deviation to attain as flat a moisture profile as possible to improve sheet quality.

- Provide a system requiring minimal energy to evacuate condensate, eliminating dryer flooding and avoiding production losses and quality defects.
- Simplify the operation and control of the dryer drainage system.
- Minimize the residual condensate inside the dryers to reduce the drive torque energy requirements and potentially eliminate the related mechanical problems.
- Provide a siphon system to ensure mechanical reliability to reduce maintenance costs.
- Recommend solutions that are affordable at low capital investments.

Table3 Measures for the Effective Heat Transfer

Evaporation factor	Measures	Major points
Heat conductivity	Cleaning on the dryer surface Discharge of drain and non-condensable gas from the cylinder	Effective use of the doctor to remove attached foreign substances Effective use of the drain discharge siphon Drain and air has poorer heat conductivity than cast iron
Uneven drying	Pressure control Temperature control Installation of BM meter	Pressure control Section and header pressure detection Temperature control Detection of surface temperature by sensor at a few points along the dryer surface Measurement and control of paper moisture, weight, thickness
Ventilation	Adjustment of air flow line inside the dryer Reduction of thermal resistance, promotion of dispersion Removing the dryer pocket	Correction of hood form Higher air temperature for dispersion Lower humidity and higher speed Ensuring uniformity in cross direction

Chapter 2- Literature Review

2.1 Papermaking:

The papermaking process is shown in Fig. 1 and can be summarized in three stages:

Dewatering,

Pressing,

Drying.

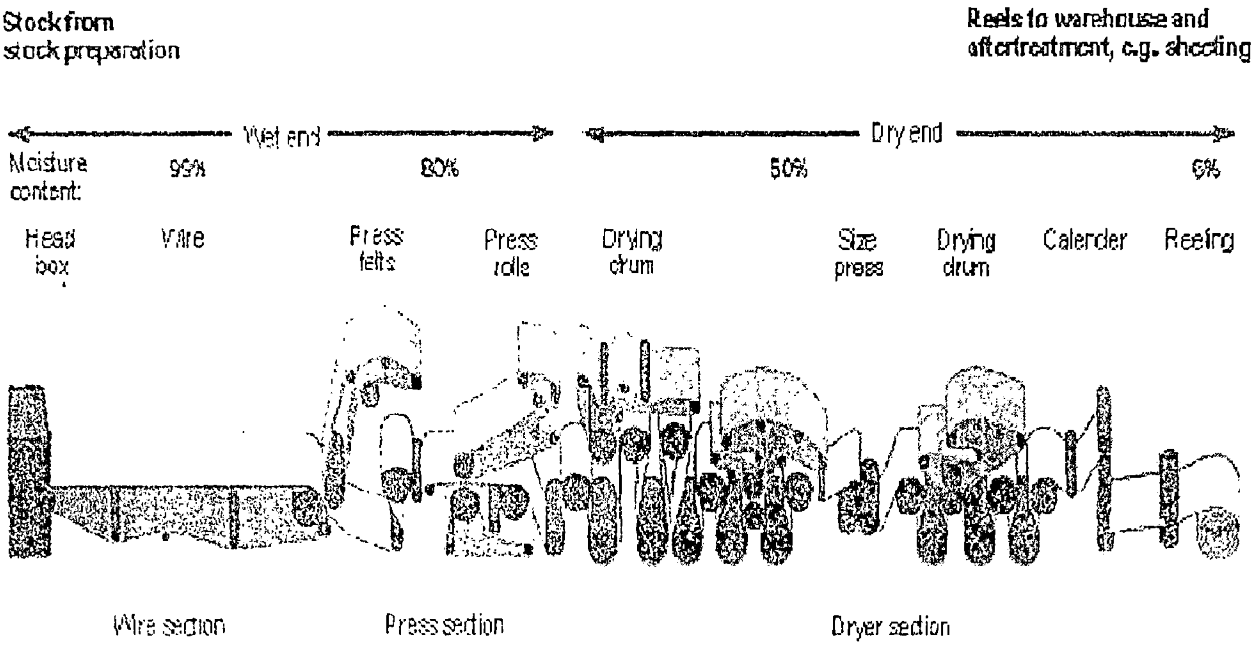


Fig. 1 Paper Machine [19]

2.1.1 Dewatering:

This is in practice the first stage of the pulp drying, and it is named wire section or wet section. In the wire section the stock is dewatered on one or more wires. The highly diluted (0.2–1% kg of solids/kg of pulp) stock flow onto the wire from a head box and is dewatered. The stock leaves the wire as a web of paper with a dry solids content of about 20%. Depending on the design of the wet section, the paper machines are called:

- Fourdrinier machines, where dewatering and sheet formation take place on an endless wire felt which is stretched between a number of rolls,

- Twin wire machines, where the sheet is formed between two wires and dewatering takes place in both directions,
- Hybrid machines featuring both a Fourdrinier and a Twin wire.

2.1.2 Pressing:

Dewatering of the paper web continues in the press section, where the web is pressed between press rolls. Usually the press section consists of three or four such press roll stages, in which the dry solids content of the paper increases step by step. After the final press roll nips, the dry solids content is about 30–50%. The presses are usually fitted with press felts which distribute the pressing pressure on the paper web and suck and remove water. There are three basic different press types:

- Suction press, consists of a perforated suction roll revolving against a solid roll with a granite or rubber shell: the paper web is constrained to pass through them. The suction roll is provided with a vacuum pump that provides the suction action.
- Vented nip press consists of a vented (grooved) solid roll and a counter roll with a smooth surface. In the nip, water is pressed out of the felt down into the grooves and is thrown out by centrifugal force,
- Felt wire press is a plastic wire passing between the felt and the lower roll. The plastic wire facilitates removal of the expelled water from the press roll nip.

2.1.3 Drying:

In the dryer section the paper web is dried to a dry solids content up to 95%. This is accomplished by dryer wires which press the paper web against steam heated drying cylinders. The dryer section is encased in a dryer hood. It is vital for good ventilation to be maintained in the dryer hood so that moist air can be removed. The moist air is heat exchanged and its heat content utilized. This heat can be used, for example, to make hot water or to heat the premises. Paper machines are often classified on the basis of how the dryer section is designed:

- Multi - cylinder machines have a large number of steam heated drying cylinders with diameters of 1.5–1.8 meters (newsprint, fine paper, kraft paper, and other grades).
- Yankee machines have a large drying cylinder (Yankee cylinder) with a diameter of 4–6 meters (one side glazed paper and other grades).

- Combination machines with one Yankee cylinder and a number of ordinary drying cylinders.
- The Yankee cylinder not only dries the paper web but also gives a smooth surface to the paper. This is accomplished by pressing the paper web against the brightly polished Yankee cylinder. The web sticks to the cylinder until it has become dry enough to be released.

2.2 Tasks and Requirement for Dryer Section:

A dryer section and drying process have the following basic requirements:

Drying Capacity:

Drying should be efficient using minimum machinery. During equipment is large and expensive design of a dryer section should give maximum evaporation capacity per dryer unit for all paper grades produced.

Evaporation Profile:

Paper quality should remain high even with high evaporation efficiency. The crass machine evaporation profile is especially vital because moisture profile variations of paper in this direction cause variation in paper properties and influence runnability.

Runnability of Dryer Section:

Dryer section runnability is very important for production efficiency of a paper machine. Breaks occurring on the dryer sections are often major cause of last production time. The significance of runnability becomes greater as paper machine operating speeds increase.

Good Energy Economy:

Design of the dryer section and associated process components such as steam, condensate, and ventilation systems should minimize energy consumption in the drying prices and recover surplus heat for other section of the process.

2.3 Multicylinder Drying or Contact Drying:

The dominant position of cylinder drying on paper and board machine is due to the following factors.

Cylinder drying is a cost-effective method for energy efficiency. The unit has a hood with an efficient heat recovery system using a high dew point. The heat source is low-pressure steam. Such steam is often the most inexpensive form of energy at a paper mill.

Some prevention of the effect of improving web smoothness and cross machine shrinkage particularly in a single-felted design is possible.

2.3.1 Mechanism of Water Removal:

The dryer section of a paper machine must provide each water molecule with enough energy to break the chemical and/or mechanical bonds, to convert from liquid state to the vapor state, to overcome frictional resistance to vapor flow, and sometimes to induce convection currents in the surrounding atmosphere, to provide adequate ventilation for removal of the released vapors. (In most cases the ventilation is provided by other means usually mechanical fans.) This energy is normally supplied in the form of heat, which raises the kinetic energy (temperature) of the water molecules, thus allowing them to break away from the sheet.

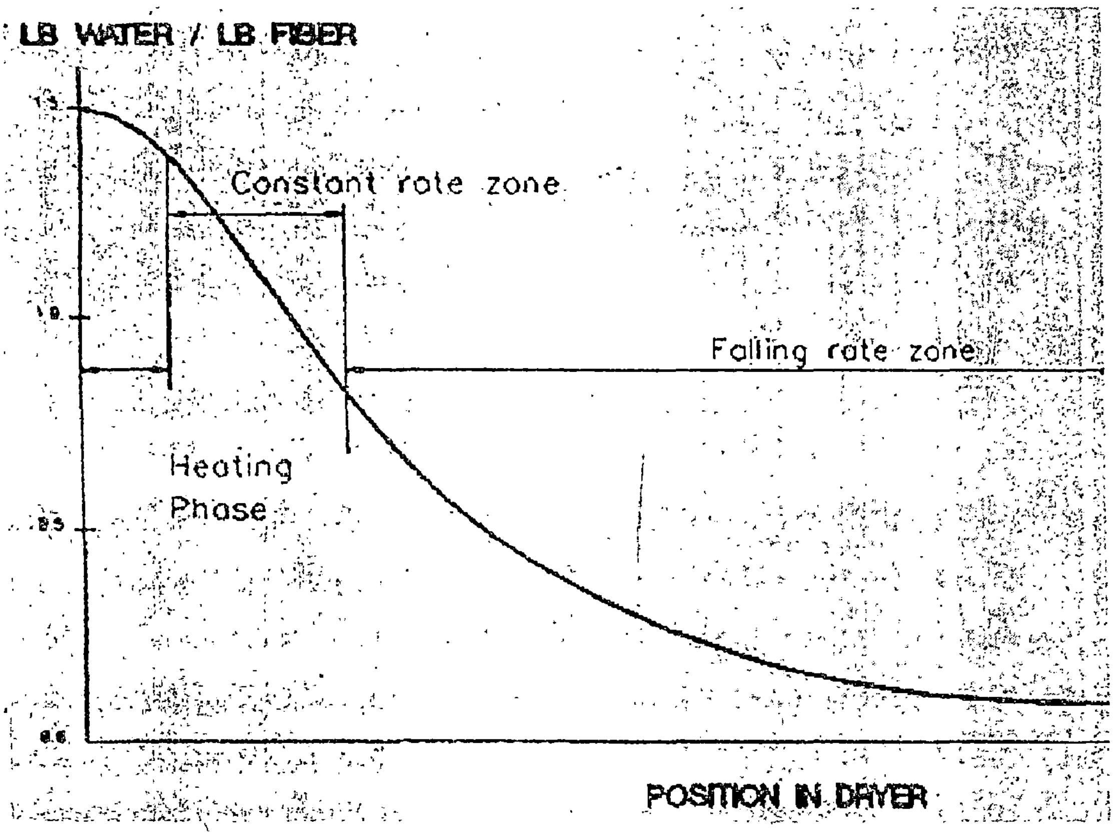


Fig. 2 Shows Three distinct Drying-rate stages

It is widely accepted practice to divide the drying of most materials into three distinct drying-rate stages shown in fig.2:

- Warming-up stage,
- Constant-rate stage,
- Falling-rate stage,

This idealized concept is also useful in the study of paper drying in general. However, superimposed on this general pattern are the intermittent supply of heat and/or the varying rates of vapor removal. During the warming-up stage, heat is supplied to the sheet at a rate greater than that needed for evaporation. The surplus heat raises the sheet temperature, and hence the rate of evaporation, until the heat demand for evaporation, losses, etc., comes into equilibrium with the heat supply. At this point constant-rate drying begins. Throughout this stage evaporation continues at the rate determined by the balance of heat supply and vapor removal. During these first two stages, water evaporates from a "plane" (which follows the contours of the liquid water surface). As drying proceeds, this plane recedes deeper into the pores of the sheet, and the surface-tension (capillary) forces collapse both fibers and the sheet structure. When the free water has been evaporated and bonds of significant strength must be broken to remove more water (i.e.. evaporate water with a depressed vapor pressure), the falling-rate stage begins.

It is during this final stage that actual drying out of the sheet occurs. As the plane of evaporation recedes farther and farther into the sheet the resistance to heat transfer increases, the frictional resistance to liquid and it becomes necessary to break stronger and stronger mechanical bonds and some of the weaker chemical bonds. Thus the rate of evaporation falls off.

Actually, there may be as many as three phases in the falling-rate stage, each characterized by its own rate of change of drying. The first phase is associated with the more easily removed moisture in the voids of the fiber network. Once the large pores are emptied, evaporation occurs throughout the sheet wherever water has been left behind, due to its exceptionally strong bonds. This is the second phase, somewhere in which the drying of paper and board normally ends. At the end of the second phase the sheet essentially oven dry. For most practical purposes this taken as zero moisture content. Further drying, the third phase requires more drastic treatment to remove the final molecules of water. Since this is only of academic interest, it will not be elaborated upon here.

2.4 Steam and Condensate System:

Fig. 3 shows a simplified steam and condensate system for a paper machine. The most significant steam consumer in paper industry is the steam and condensate system. The purpose of this system is to provide sufficient drying energy and adjust it in the machine direction to suit the requirements of each paper grade. Paper to be dried places requirements on the surface temperatures of the dryers that the division of sections and pressure controls of the steam system should manage. For proper operation of drainage and steam and condensate system. The system must maintain good and stable evacuation of condensate and non - condensable gases from the dryers. This will give optimum heat transfer of the dryers and energy consumption in drying.

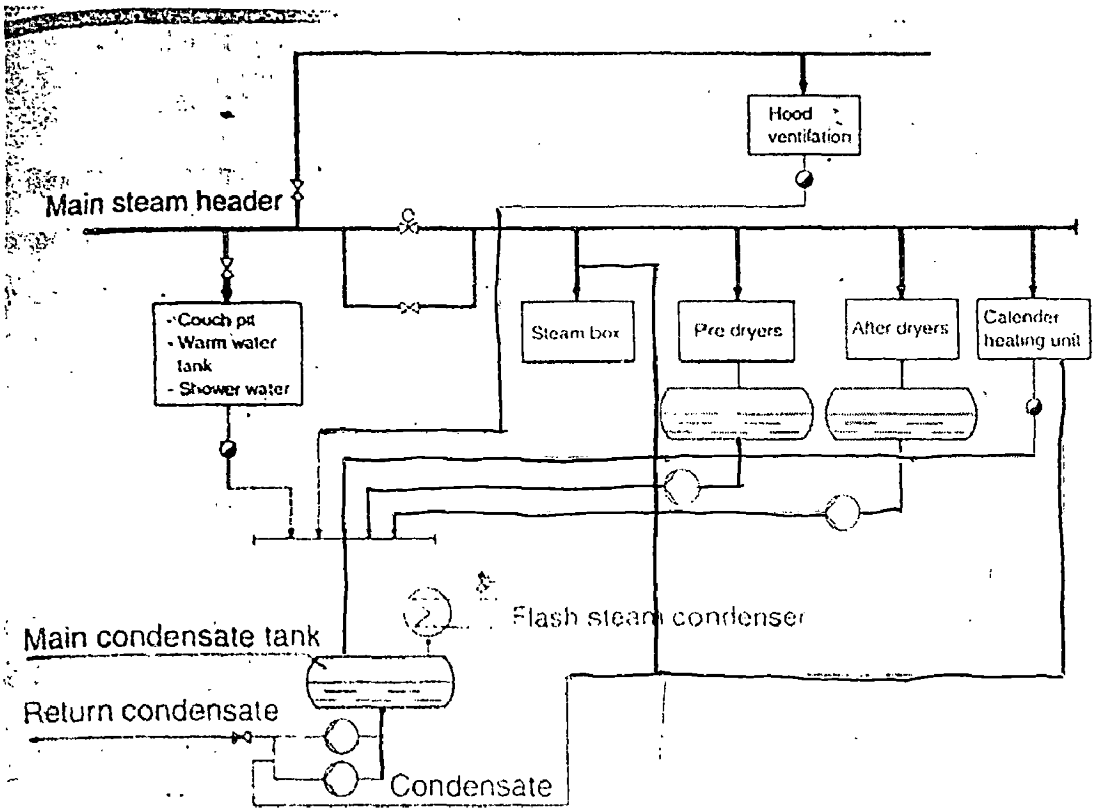


Fig. 3 Paper machine steam and condensate system[2]

The steam and condensate systems almost always employ a case-by-case design. It depends on the dryer section, production, available steam pressure, quality and run-ability factors, etc.

The steam and condensate systems for different paper grades are parallel systems, cascade systems, thermocompressor system. They differ primarily in the size and number of steam sections and the number of pressure controls. Corresponding differences can also exist in the systems for a particular paper grade. The following are the influencing factors.

- Available steam pressure
- Machine speed
- Basis weight
- Sheet dryness content after press section
- Characteristics related to paper quality

2.5 Steam Distribution and Condensate Removal:

Steam is supplied to the paper machine either through non-condensing turbine (back pressure turbine) or directly from boiler house through a pressure reducing value. The use of turbine is a second economic practice and turbine drive provides a wide range of speed control for direct mechanical drives but it complicates the dryer steam supply system. Steam should be separated from the oil as it forms insulating layer inside the cylinders.

Steam lines should have drop-legs to drain out the condensate formed during charging of the line. From the main steam header, steam is supplied through branch pipes separately for drying cylinders, felt dryers and air heating systems.

Each cylinder must have separate valve to regulate steam pressure inside the cylinder and therefore temperature on the surface of the cylinder, according to drying curve for each quality of paper. Setting of valves is done very rarely except during change in the quality of paper. For regulating steam pressure in relatiOon to the dryness of the web, main steam valve is operated which to supplies steam to all the cylinders.

Temperature of paper web during drying should not reach to a level, which would damage the structure and properties of paper being dried. Presently, several quality of paper is dried at a steam temperature in the range of 175-180^0 C.

Steam is supplied to the cylinders with a small degree of superheat (20-40^{0}C) avoid condensation in pipeline and reach the cylinders saturated and dry. The use of the superheated steam adds very little of the heat value and drying is more erratic. With 80^{0}C superheat, the rate of heat transfer is increased only by 3% more than the saturated steam of the same pressure. The beneficial effect of superheated steam above 80^{0}C is controversial. As a thumb rule, the temperature of steam should be about 10% higher than the condensing temperature of steam and surface temperature of cylinders 15^0 C lower.

The steam is supplied for conventional drying cylinders at a pressure of 1.1-3.5 kg/cm^2, or may be as high as 10.5 kg/cm^2 for M.G. cylinder. The trend now a days is to use higher pressures though it may have detrimental effect on paper.

The above requirements can effectively be met by proper condensate removal; removal at the right position and at the rate of the formation along with all the non-condensable gases.

(a) By employing the shortest traverse flow of the condensate.

(b) By preferably providing a higher temperature in the mid position of all the cylinders than at the edges. This compensates for all increased drying effect of the paper edges subjected to more air movements than in the middle.

(c) Both these attributes require the condensate removal pick-up tip positioning half way across the dryer or splitting into more than one pick up about half way position.

(d) By keeping the amount of retained condensate as low as possible especially in the rimming condition, hence again the minimum clearance required.

(e) By inducing flow of non-condensables towards the siphon tip, the revolving siphon not only induces the flow but also searches the position of non-condensables.

The steam and condensate systems may be divided into the following basic groups.

1. Parallel system.
2. Series system or blow through system. Blow through system can be further divided as:

(a) Cascade system.

(b) Ejector system or thermo-compressor system.

2.5.1 Parallel System:

In parallel system steam is fed to individual or group of cylinders at the same pressure. Defect of parallel system is that for each cylinder only that much steam is supplied which condenses in the cylinder. Velocity of steam near the wall of the cylinder is low and pockets of air are formed which reduces heat transfer coefficient. The advantage is that temperature of each cylinder can be set properly and proper regulation of temperature on the surface of each cylinder is possible. This system is now used rarely and is met only on old and slow speed paper machines. Figure 4 shows the typical parallel steam supply system in which steam is supplied directly from the main steam header to each group and condensates are then sent to the main condensate header. Modern design of drying cylinders employs different combinations of series system.

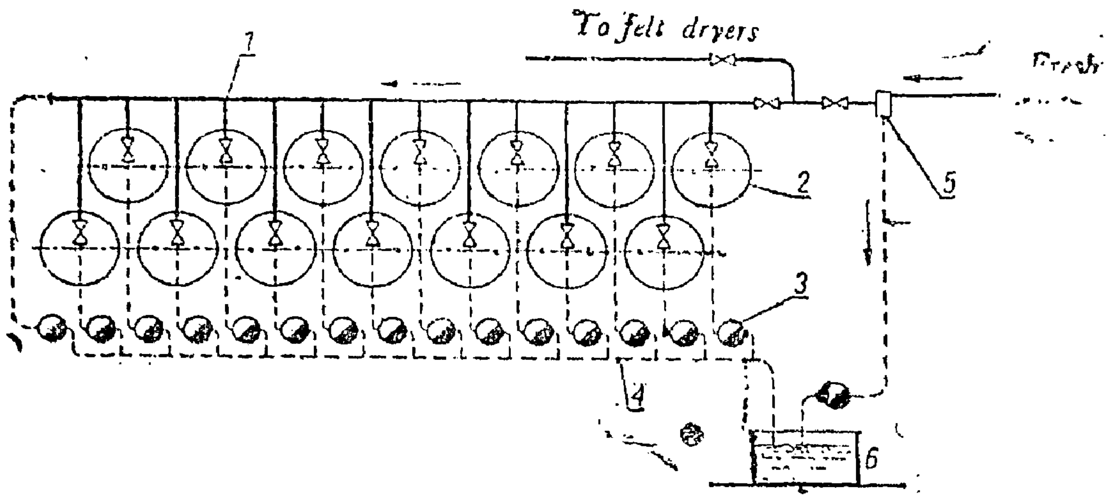


Fig. 4 Parallel steam supply system[5]

1. Main steam header, 2. Drying cylinder, 3. Condensate trap, 4. Condensate pipe, 5. Cooling of steam, 6. Condensate tank.

2.5.2 Cascade System:

The cascade system normally finds use in the following conditions:

With stationary siphons

Only low-pressure steam is available and used in drying

Operating and Design Principles:

Figure 5 shows a typical three-step cascade system. In this system, the dryers in the dryer section have three-steam sections, main, intermediate, and wet end sections. The system also includes a condenser and a vacuum pump. The main steam section receives all the required steam from the main steam header. The means that the steam pressure level in this section is highest. The maximum value is the main steam header pressure minus 20kPa. The paper moisture control system gives the set point for the pressure in this section. The number of dryers in the main section is about 50%-60% of the total number. Main section can have further division into groups with a separate pressure control possibility to control the drainage.

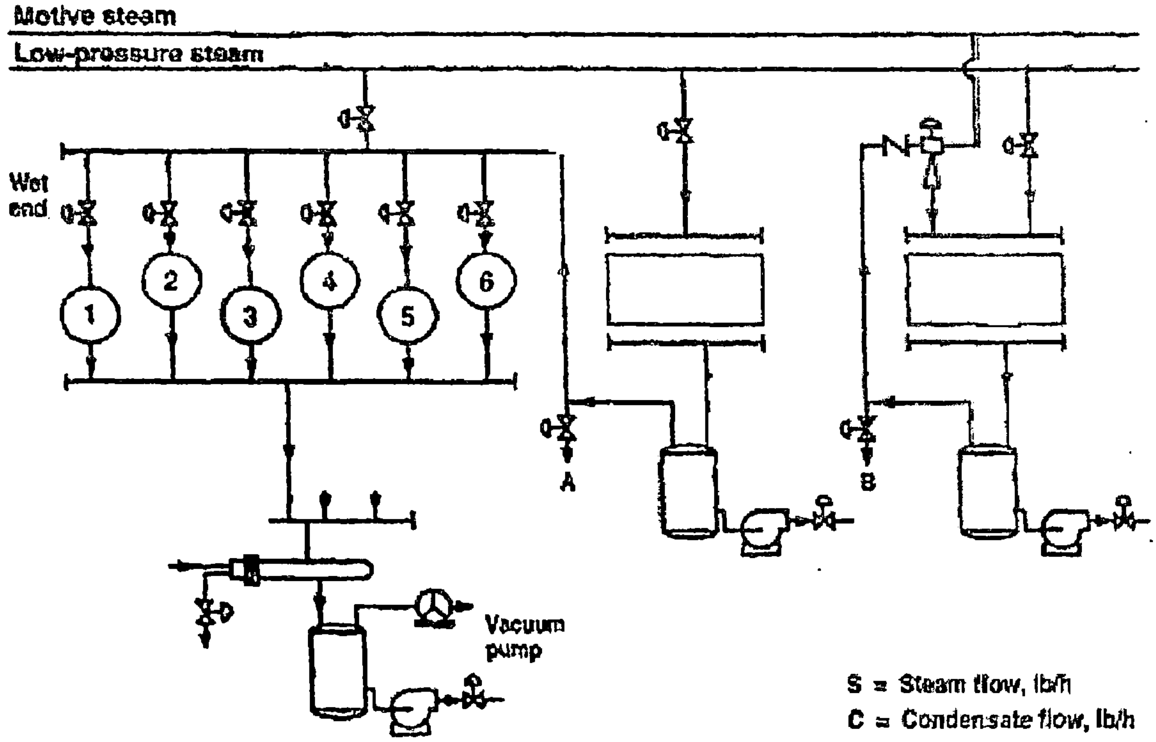


Fig. 5 three step cascade system [20]

Condensate water from this section goes to the condensate tank of the section. As explained in the discussion on differential pressure control, blow through steam also flows with condensate to the condensate tank. It applies also for flow control system. The condensate tank separates condensate and blow through steam. Blow through steam goes to dryers of the intermediate section. To make steam flow from the condensate tank to the intermediate section, a slightly higher differential pressure is necessary between main and intermediate section, than between the steam and condensate headers of the main section. The dimensions of the sections are such that the blow through steam from the condensate tank and the flash steam produced in the tank fit into the intermediate section during normal running conditions. Additional steam from the main steam header is also necessary in the intermediate section to maintain the pressure at the desired level. In other words, additional steam adjusts the intermediate section pressure level.

For drying, a normal range for PF (temperature difference of dryers from one section to another) is 50-100 kPa. The cascading function from the intermediate section to the wet end section is similar. In other words, the wet end section pressure is the intermediate section pressure minus differential pressure, P.F. In some cases, the control in the machine direction can also be such that calculation of the wet end and intermediate section pressure uses the main section pressure. Monitoring the cascading function is easier by calculating pressures section after section. This is especially important when steam sections are internally divided into several pressure controls or separately controlled dryers exist in the section. The differential pressure, PF between the sections is then the lowest pressure of the section producing blow through steam and the highest pressure of the section receiving that steam.

The condensate from the wet end section goes to tank 1. In this case, differential pressure is controlled in the same way as in the other sections by the control valve before the tank. The pressure in tank 1 must be sufficiently low (often vacuum) for the control valve to perform its task. The condenser is the "basic tool" for obtaining the required vacuum and ensuring differential pressure for the wet end section.

Cascade system has the following advantages:

- Only one steam pressure level is needed
- Reliable and simple basic operation
- Several grouping and control methods are possible
- Steam sections can have several separately controlled sections and dryers while still leading the condensate to the same condensate tank

Disadvantages for the cascade system are as follows:

- Rather unsuitable to rotary siphons with low-pressure steam
- Control range of drying capacity is narrower than with thermo- compressors
- Certain running methods and pressure stepping is necessary (This can also be an advantage)

2.5.3 Thermocompressor System:

Construction and Operation of a Thermocompressor:

A thermocompressor is a device that uses high-pressure steam to entrain steam at lower pressure and discharge the mixture at some intermediate pressure. Thermocompressors commonly used on a paper machine have an automatically controlled spindle usually called a variable orifice. This is the most prevalent type and is more efficient because it uses the full velocity energy of the motive steam supply even at low flow. The basic thermocompressor consists of a body, diffuser, nozzle, spindle and cylinder or diaphragm actuator with a positioner to actuate the spindle. Fig. 6 illustrates this.

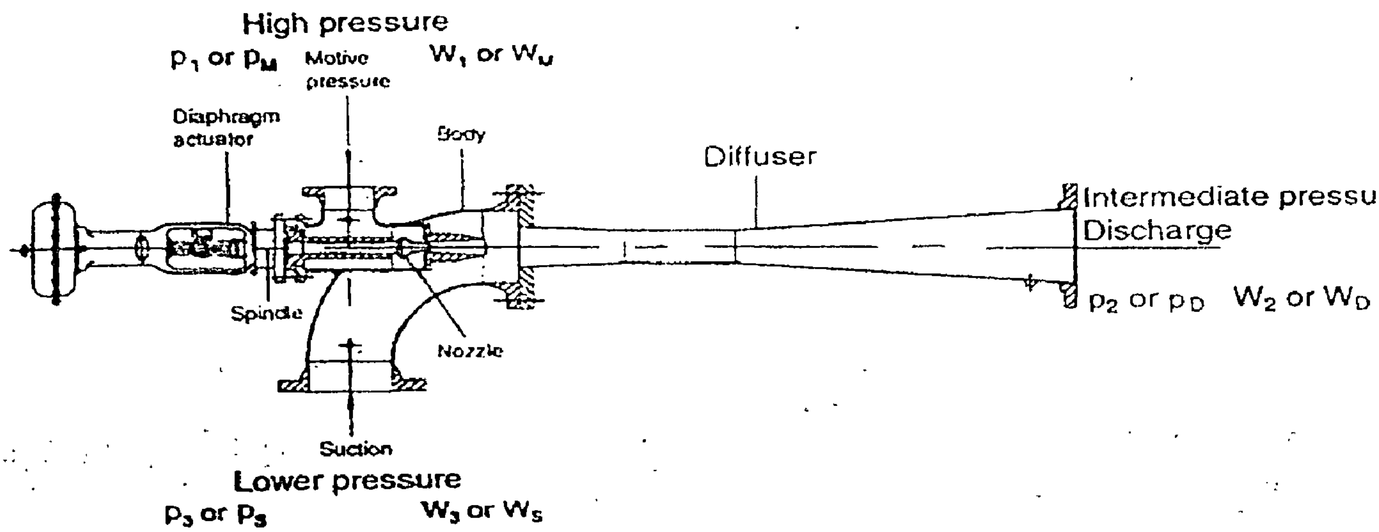


Fig. 6 Basic automatic Thermocompressor[2]

Fig. 7 shows a typical thermocompressor control group. The thermo-compressor uses high-pressure motive steam to recompress lower pressure blow through steam back up to the required dryer pressure. Thermocompressors are widely used on modern paper machines. They provide greater flexibility of operation and good control over differential pressure and blow-through steam flows. However, they can cause many operational problems if they are not applied properly. Each thermocompressor is custom designed for the application. The motive-steam nozzle and the throat section, where the motive steam and blow through steam are mixed, are bored to exact dimensions to suit the anticipated operating conditions. The designer of the steam and condensate system must have accurate values for the blow-through flow rate, differential pressure, piping loss, and minimum and maximum dryer pressures. The throat bore of the thermocompressor is set by the lowest operating pressure and the blow through flow under this condition. Once the throat size is set, the flow of motive steam required to produce proper throat conditions at the maximum dryer pressure can be determined. This condition sets the maximum flow of motive steam and the bore diameter for the motive steam nozzle.

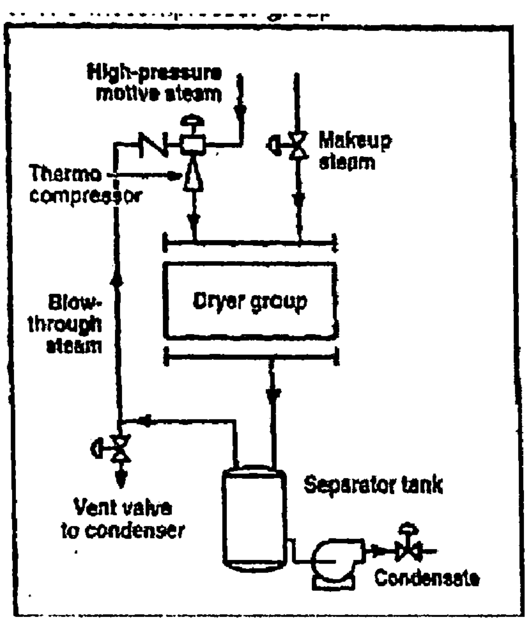


Fig. 7 Typical thermocompressor system[20]

Most thermocompressor problems can be related to inaccurate estimation of blow through flow rate or operating pressures. An accurate estimate of blow-through steam flow provides accurate operating conditions from which the thermocompressor throat and nozzle bore size can be checked. The thermocompressor's size is frequently mismatched with the machine's current operating conditions. Machine operating conditions may have changed from the original design, or the original design pressures may have been incorrect. A mismatched thermocompressor will either be unable to develop sufficient blow through steam flows to the dryers or it will vent excessive steam to the condenser. The changes that are required are often simple. Thermocompressors can be reworked so that the bore size matches the current operating conditions. The key in performing this rework is the proper determination of flows and pressures. Thermocompressor sizing should always be checked when a machine is rebuilt to operate at higher speeds, with different grades, or at different dryer pressures. Thermocompressor problems can often be related to problems external to the thermocompressor. Small line sizes, unusual piping configurations, or improperly designed check valves can produce excessive pressure losses that force the thermocompressor to recompress the blow-through steam over a higher differential. Pressure gauges should be placed at the inlets and outlet to the thermocompressor so that excessive pressure losses can be identified.

2.6 Condensate Removal:

2.6.1 Condensate Behavior:

Behavior of the condensate has been classified into puddle, cascade and rimming condition. (Figure 8) The behavior is a result of dryer speed, condensing load inside the dryer, dryer diameter and inner surface finish and siphon clearance.

The rotational velocity of the dryer applies a centrifugal force on the condensate. At speeds below 400 fpm, (120m/min) low centrifugal force has little effect on the condensate puddled at the bottom of the dryer. As the rotational speed is increased to approximately 700 fpm, (215 m/min) a combination of rimming and full cascading condition occurs. A thin film of condensate covers the entire periphery of the dryer while the bulk begins to approach the top of the dryer and then collapses. This condition, referred to as a "cascade," occurs when gravity overcomes the centrifugal force and the condensate layer collapses to the bottom of the dryer. At approximately 1,100 fpm, (335 m/min) the centrifugal force is significant enough to defeat gravity causing the condensate to go into a full rimming condition.

Throughout the different condensate transitions, from a puddle up to an initial rimming condition, the heat transfer through the dryer is satisfactory. In a puddle and cascading condition, the steam is condensing directly on the inner surface of the dryer resulting in the best heat transfer possible.

In the initial rimming condition while the periphery of the dryer is completely covered, the acceleration and deceleration of the condensate due to gravity causes a turbulent oscillating condition. This condition permits excellent transfer of heat from steam to the inside of the dryer wall. The reduction of this oscillating motion, due to increased speed, reduces the agitation of the condensate, reducing the heat transfer.

Figure 9 depicts the effect of speed on the condensate heat transfer for various siphon system conditions. Below 1,000 fpm, (305 m/min) in all cases, the heat transfer rate is very high. As the speed is increased, each curve decays according to the efficiency of the siphon system. To maximize the heat transfer, it is necessary to re-establish a turbulent condition.

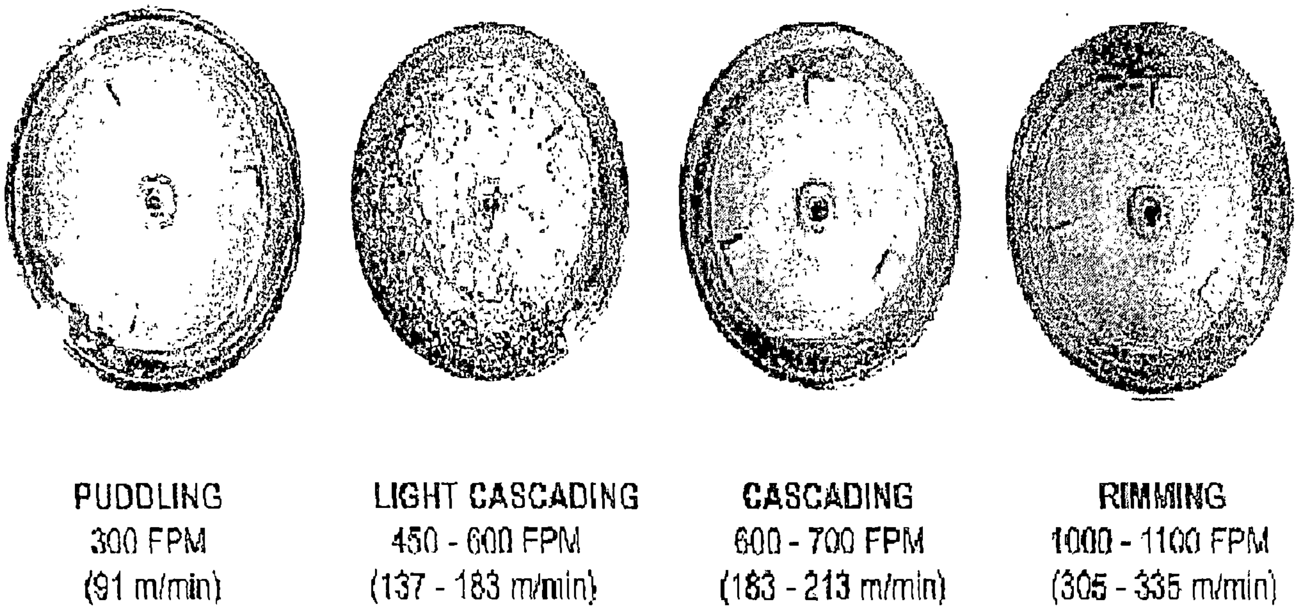


Fig. 8 Condition of condensate inside dryer cylinder[15]

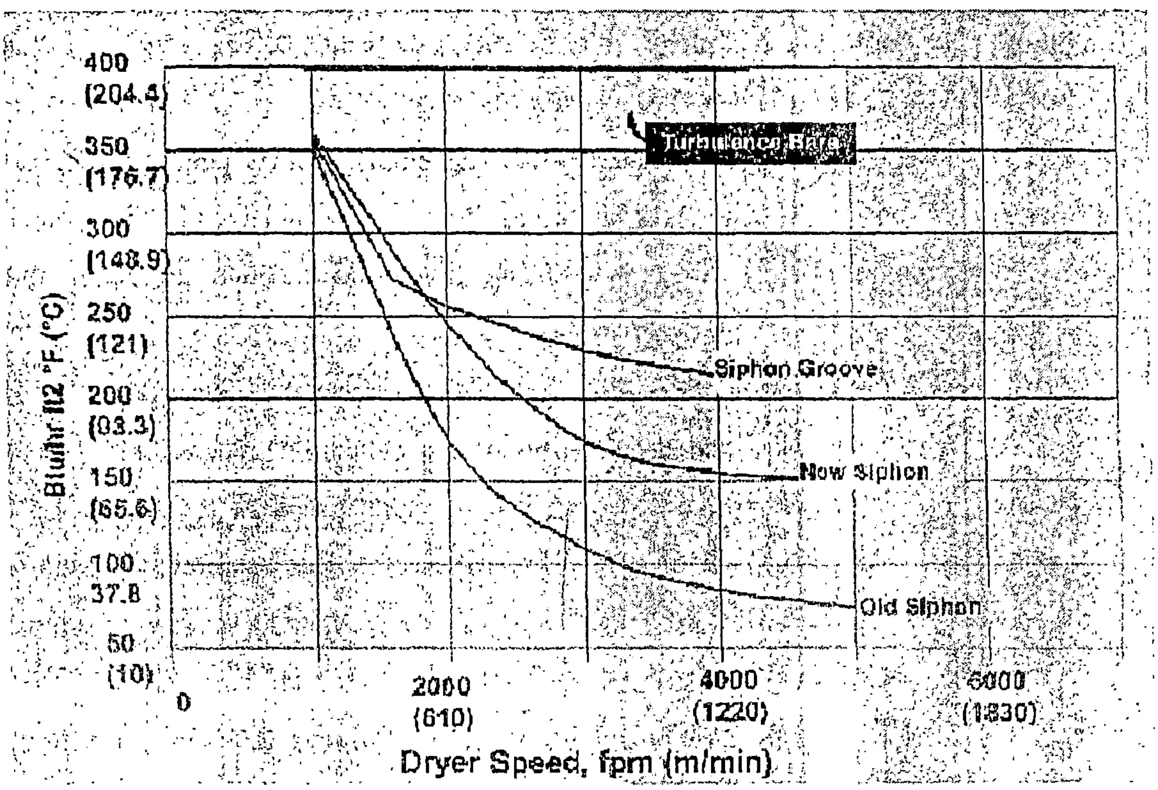


Fig. 9 Effect of machine speed on heat transfer co efficient for various siphon system Condition [15]

2.7 Condensate Removal Equipment:

2.7.1 Purpose of a Dryer Drainage System:

- Control pressure and differential pressure over entire range of operation
- Efficient condensate removal – No flooding
- Maximize heat transfer
- Maintain uniform profile
- Minimize steam requirements
- Optimize sheet quality

For removing the condensate formed inside the drying cylinder different type of scoops and siphons are employed depending on type of paper machine, design parameters and quality of paper produced. Lately, scoops and siphons of different design (fixed, rotary-single, double with scoops and without scoops) have been built.

Condensate removal with a stationary or a rotary siphon requires pressure difference. Differential pressure is measured between the steam and condensate headers before and after the joint. Pressure difference causes so called blow through steam flow through the dryer. Blow through steam reduces the density of condensate in the siphon (turns it into drops) and also removes non - condensable gases from the dryer. The quantity of blow through steam of the total steam supplied to the dryer is about 10%-20% for stationary siphons and 25%-30% for rotary siphons. Stationary siphons use the condensate kinetic energy in condensate removal (rimmed condensate) for rotary siphons the centrifugal force of condensate must be overcome. This means higher-pressure difference and higher amount of blow through steam.

Two-phase flow occurs in the siphon pipe due to the combined effects of condensate, blow through steam is flash steam produced by reduced pressure. A theoretical analysis of the two-phase flow is complex. However flow calculation of steam and water mixtures can be used as a good approximation.

2.7.2 Siphon Types and Selection:

Table 4 depicts the recommended siphon as a function of dryer speed and lists the requirements for installation.

Table 4 shows the siphon performance at different speeds [15]

Siphon Type	Machine Speed in fpm (m/min) (0 - 91) 0-300	(91 - 214) 300-700	(214 - 305) 700-1000	(305 - 610) 1000-2000	(610 - 914) 2000-3000	(914+) 3000+	Installation Requirements
Stationary Elbow with spring bracket	Good	Fair	No	No	No	No	Manhole or Hand Hole
Rotating Scoop	Good	Good	Good	No	No	No	Manhole
Conventional Rotating	No	No	Fair	Good	Fair	No	Manhole
Cantilevered Stationary Siphon	Good	Good	Good	Good	Good	Good	Manhole with enclosed gears

2.7.2.1Stationary Elbow with Spring Reinforcement:

The stationary siphon as depicted in Figure 10 is applicable for machines operating at speeds below 500 fpm (150 m/min). This siphon is comprised of stationary horizontal and vertical pipes that are joined by a knuckle. The knuckle is reinforced with a brace and spring, increasing the rigidity of the system. This siphon requires a nominal clearance of 3/4" to 1" (19 mm to 25.4 mm). At slow speeds, where it is recommended, the condensate is in a puddle condition and the vertical siphon pipe is immersed in the puddle of condensate. Required differential pressures range between 0.15-0.25 kg/cm^2 with blow through flows between 8% - 12% of steam condensed.

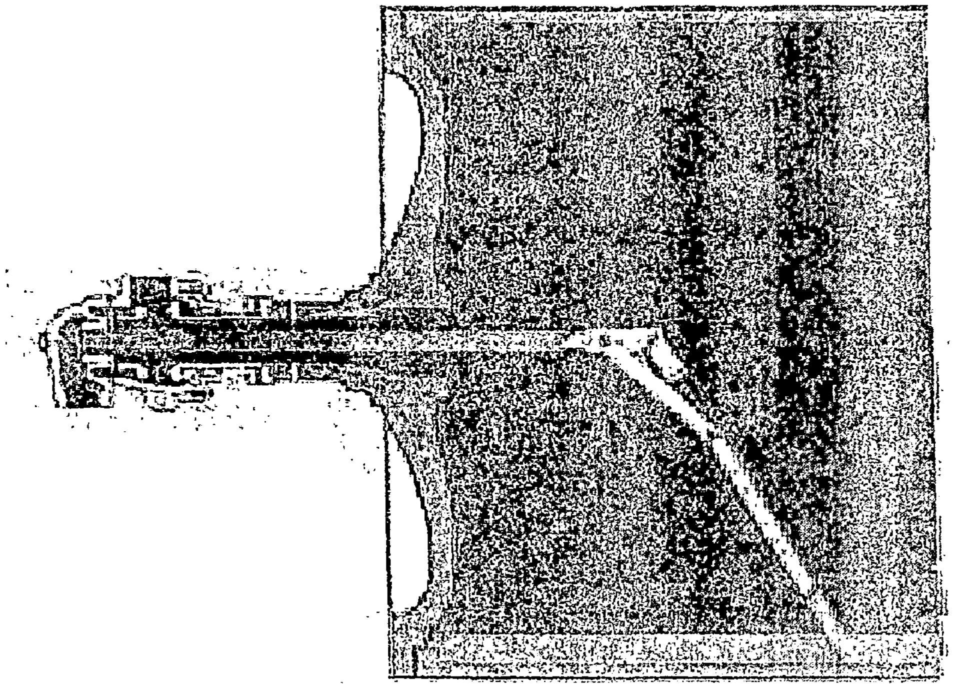


Fig. 10 Bent stationary siphon, no manhole.[15]

2.7.2.2Rotating Scoop:

Figure 11 depicts a typical rotary scoop (rotating siphon). The design of the scoop and vertical riser pipe is specifically designed for machines operating between 300-700 fpm (90 – 215 m/min). At these speeds the condensate behaves between a puddle and a cascade condition. The installation of this siphon requires a manhole.

The wide frontal opening and close clearance of 0.070" (1.8 mm) of the scoop is designed to maximize the condensate collected during each pass. As the rotation continues, the condensate is mechanically lifted to the center of the pipe and is discharged. The extended elbow in the vertical riser functions analogous to a trap to reduce the blow through steam flow while the siphon shoe is outside the condensate pool. This rotating siphon system requires a differential pressure, depending on the speed, between 0.2-0.4 kg/cm^2 with a blow through flow between 15-18% of the condensing load.

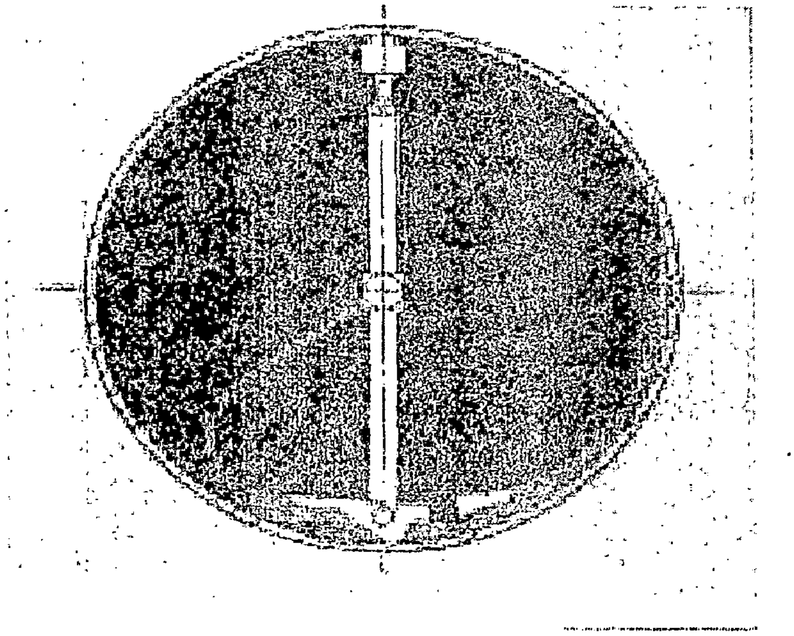


Fig. 11 Rotary scoop, rotating siphon.[15]

2.7.2.3 Conventional Rotating Siphon:

Figure 12 depicts a conventional rotating siphon. Fitting of the siphon requires a manhole. The siphon is comprised of a pick-up shoe that is secured inside the dryer using a spring-loaded vertical support. Attached to the pick-up shoe is a curved pipe that connects to a spider and is bolted to the dryer head. On the inside of the spider is a horizontal pipe that discharges condensate on the outlet of the steam joint. The pick-up shoe is designed with a clearance of 0.07" to 0.11" (1.8 mm to 2.8 mm) and for drainage flow around the complete perimeter. In a rimming condition with a relatively uniform condensate thickness surrounding the shoe, the close clearance pick-up shoe reduces the condensate thickness thus improving heat transfer. Since the system rotates with the dryer, it is subjected to the centrifugal force. Moderate differential pressure is essential to ensure condensate drainage.

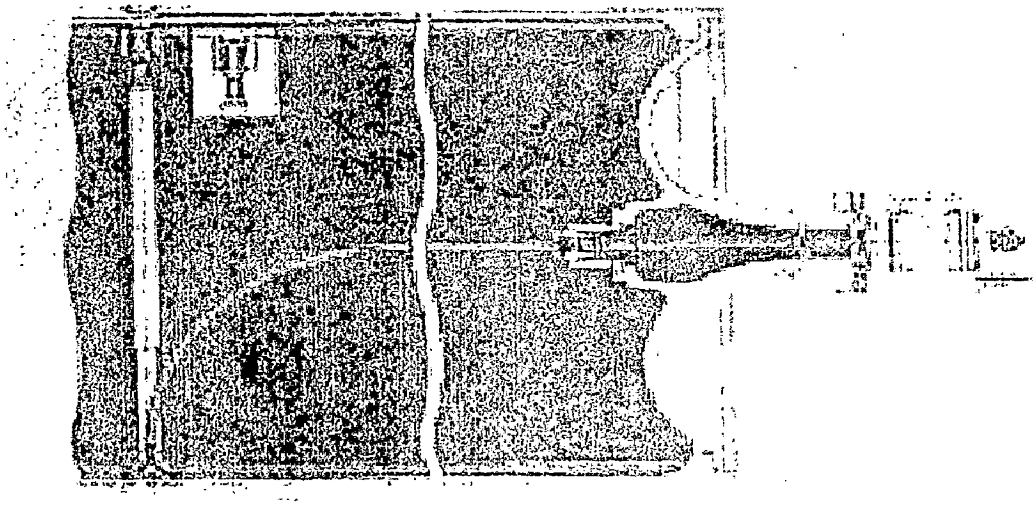


Fig. 12 Rotating stationary siphon. [15]

2.7.2.4 Cantilevered Stationary Siphon:

The stationary siphon depicted in Figure 13 is applicable for any machine speed. This system is comprised of an external support that is bolted directly to the bearing cover of the dryer. The rigid external support of the steam joint body, along with the dual support of the cantilever section and vertical brace inside the dryer that supports the siphon pipe, provides the required rigidity for the complete system to withstand the dynamic forces of the condensate at any speed. Any less support to this complete system may induce sufficient vibration to the point of failure.

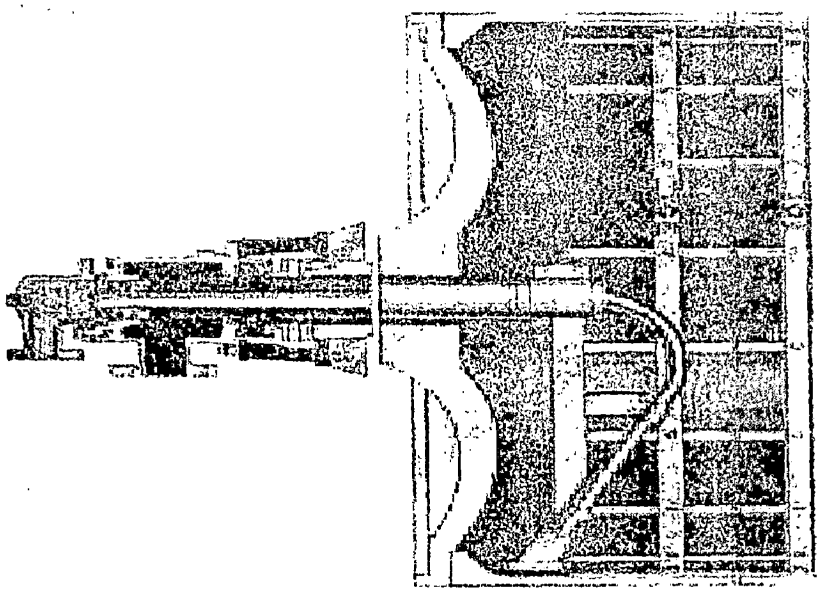


Fig. 13 High speed stationary siphon. [15]

2.8 Basis Weight and Moisture Control:

Most of the paper mills would like to control the basis weight and moisture parameters of the paper at least in the machine direction of the paper. Machine direction control involves the stock flow control while cross direction control involves control of individual jets at the headbox.

The paper machine as a whole can be considered as two inputs and two output systems as shown in the fig 14. Stock flow to the headbox is controlled to control the basis weight while steam pressure to the dryers is controlled to control the paper moisture and therefore it becomes multi input and multi output (MIMO) system.

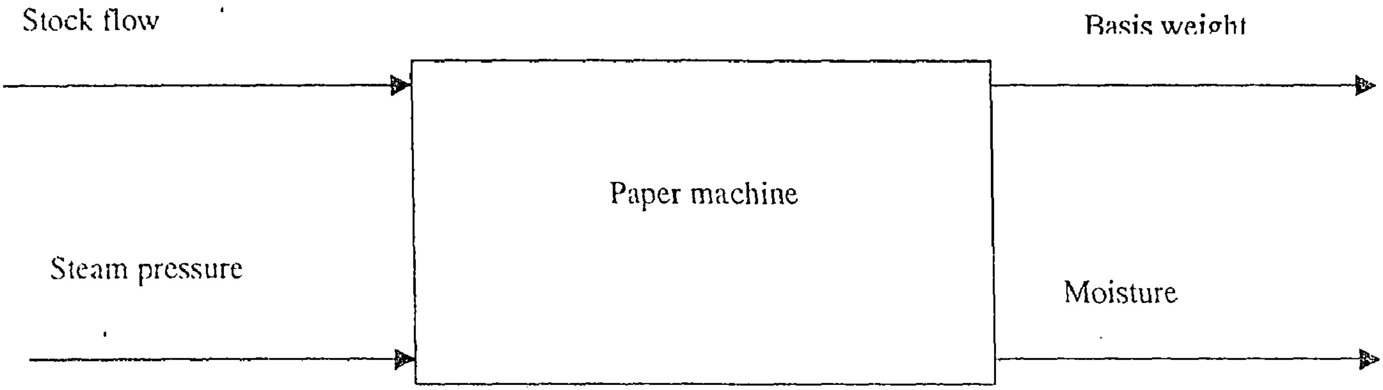


Fig. 14 Paper machine as a MIMO system[21]

Basis weight and moisture interaction is illustrated in fig 15. The decoupling of these two loops is done using the standard control techniques, which would enable to decouple the loops into two independent loops so that the normal control algorithms can be implemented.

In the case of moisture, a cascade control loop has been implemented. The outer loop will provide a set point to the inner loop, which controls the steam control valve to get desired moisture. The cascade control of the moisture control is shown in fig 16. And basis weight control loop is shown in fig. 17

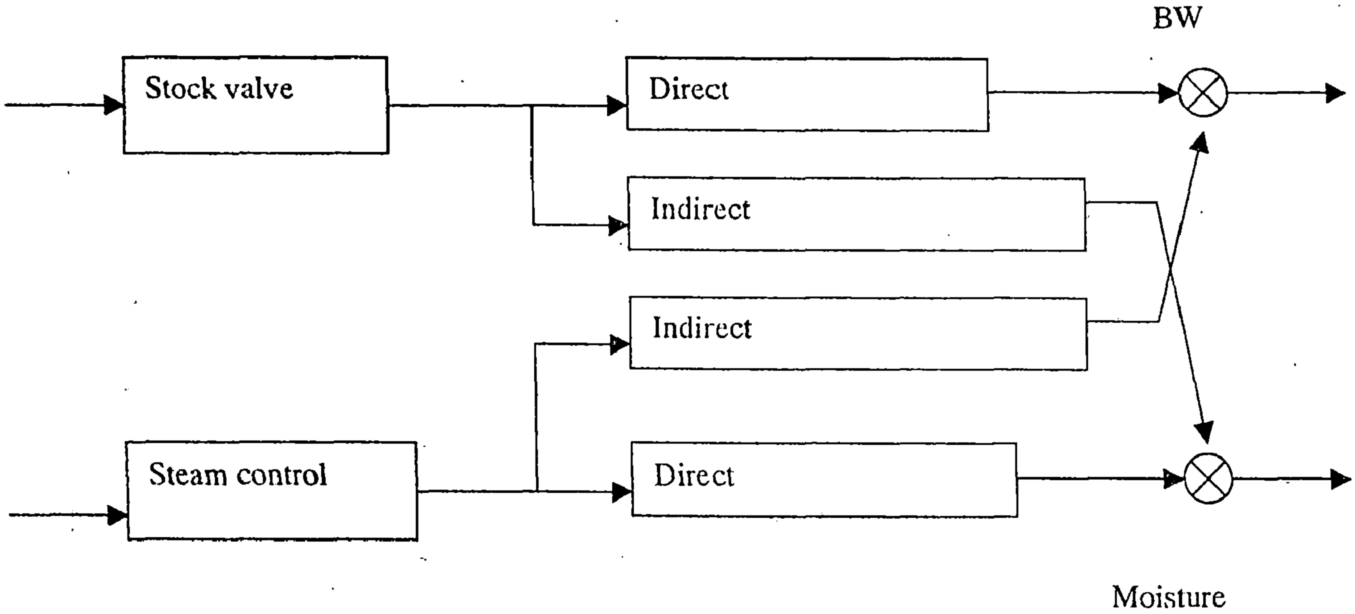


Fig 15. Basis weight and moisture interaction[21]

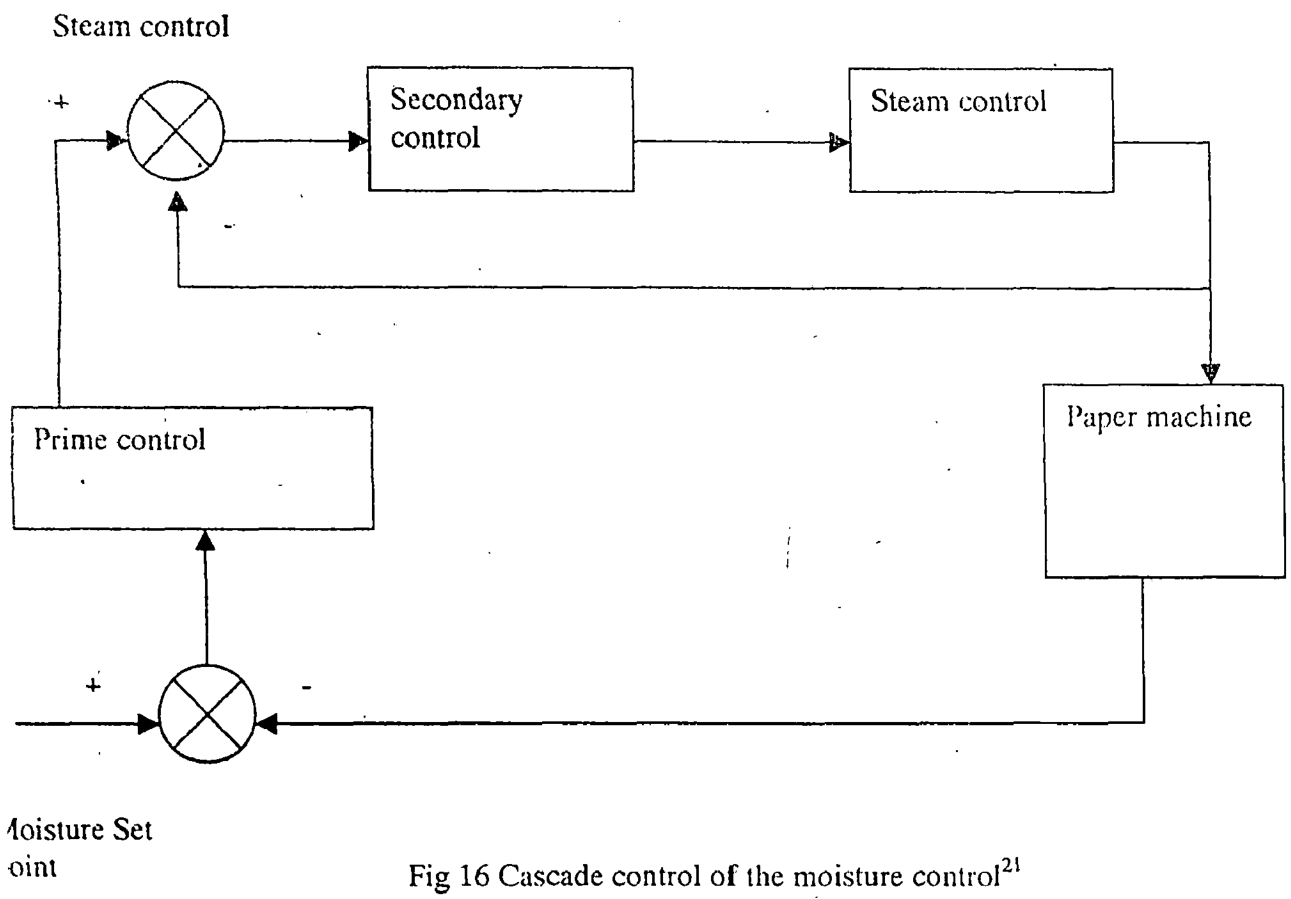


Fig 16 Cascade control of the moisture control[21]

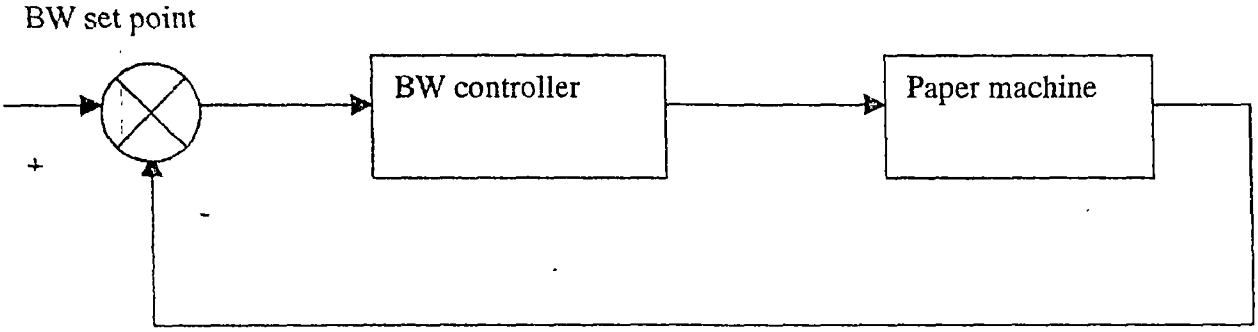


Fig 17. Basis weight control loop[21]

Chapter 3- Recommendation and Implementation

3.1 Facility Description of the BILT, Yamunanagar Plant:

The plant has 6 paper machines of different capacities to dry paper and the details are given as below in table 5:

Table 5 Capacity and Quality of paper machine at BILT Yamunanagar

Details	PM-1	PM-2	PM-4	PM-5	PM-6	PM-7
Product	SS Art Bond Plus, Sunbeam Ledger	Sunlight Offset, sunlit White, Lucky Parchment, Sunlit Bond, SS Map Litho	Duplicating paper, Sunshine Map Litho, Coating base	Super printing grades, Base paper for coating paper	Carbon tissue (CTA)	Royal executive bond, Laminate base paper
Installed capacity t/d	24.51	24.93	88.45	26.13-108.86	3.72	33.05
Operating capacity t/h	22.08	22.32	75.12	23.52-97.92	2.88	27.12
Average steam consumption (in dryers), t/t of paper	3.2-3.4	3.2-3.4	3.7-3.9	3.6-3.8	3.1-3.4	3.5-3.8
Average inlet moisture before drying, %	62	63	61	60	62	60
Average moisture at reel, %	2-7.5	2-7	2-7	2-6.5	3-6	2-7.5
Steam used	LP steam	LP steam	LP steam	LP steam	LP steam	LP steam

If we compare all the paper machines, the PM-4 is the fastest machine and the production rate is higher than other machines and steam consumption / ton of paper is around 3.7- 3.9 which is on the higher side.

3.2 Goals to Achieve:

- Run size press with same specific steam consumption.
- Reduce the steam loss from the machine.
- Improve the drainage rate drying cans.

- Install pocket ventilation system.
- Installation of BM meter to reduce machine direction variation in properties.
- Increase the condensate recovery.

3.3 Observation and Analysis:

General observations of paper machines

3.3.1 Steam Leakages:

These are obvious heat losses, which should be corrected as quickly as possible. Small and large leaks can be detected by the noise of escaping steam and the flume length formed. An obvious steam leakage occurs at pipe joints, flanges, valves and unions, but steam losses from malfunctioned steam traps are less evident. Steam leaks must be rectified at the earliest. External steam leakages are easily identifiable since live steam blows out continuously. A significant percentage of uncounted steam losses in the plant are due to such leakages. Online sealing techniques would help to plug such leakages. The identified steam leakage areas and the quantity of steam leakages are given in table 6.

Table 6 - Steam leakage areas and quantity of steam leakages

Area/ Location	Type of leakage	Flume length, m	Quantity. T/hr
Steam leakages through punctured post dryer steam header of PM-5	Line joint leak	1.5	1
Puncture in the steam traps of PM-5	Leakage from steam trap	10 nos * 100 mm	0.5
PV fan- 1&2 area of PM-5	Major leak in the LP steam pipe	1	0.5
Steam leakages through punctured steam header of PM-4	Line joint leak	2 * 400 mm	0.3
Puncture in the steam traps of PM-4	Leakage from steam trap	12 * 200 mm	0.25
Steam leakages through punctured steam header of PM-1,2	Line joint leak	4 * 400 mm	0.5
Puncture in the steam traps of PM-1,2	Leakage from steam trap	12 * 100 mm	0.3
TOTAL			3.35

3.3.2 Flash Steam Recovery:

Flash steam is produced when condensate at a high pressure is released to a lower pressure and can be used for low pressure heating. The flash steam quantity can be calculated by the following mathematical formula with the help of steam table.

$$\text{Flash steam available, \%} = \frac{S_1 - S_2}{\ddot{e}_2}$$

Where: S_1 – Sensible heat of higher pressure condensate

S_2 – Sensible heat of steam at lower pressure (at which it has been Flashed)

$\ddot{e}_2$ – Latent heat of flash steam (at lower pressure)

Higher the steam pressure and lower the pressure of flash steam, the greater the quantity of flash system should run at the lowest possible pressure so that the maximum amount of flash is available and the back pressure on the high pressure systems is kept as low as possible. The identified flash steam losses from the paper machines are discussed as below in PM-4.

Flash steam loss is noticeable at the main condensate tank. This leads to increased fresh LP steam consumption. The reasons for high flash steam are increased blow through steam from the dryers.

3.3.3 Condensate Recovery:

When steam condenses and gives up its latent heat (or enthalpy of evaporation), the result is the formation of hot condensate. Depending on steam pressure this condensate can contain blow through steam. Further, condensate is also a pure form of water and can be used as boiler feed water without further treatment, saving fuel, raw water and chemicals used in boiler feed water treatment. Every 6 ^{0}C rise in feed water temperature, there will be approximately 1 % saving in the fuel consumption in the boiler. The condensate quantity recovered from each of the paper machines is discussed in table 7. Condensate recovery of paper machine 4 is very low and steam consumption rate was very high so more amount of condensate are draining out. :

Table 7 - Condensate recovery of different machines

Paper machine no.	Condensate recovery %
PM-1	75
PM-2	75
PM-4	70
PM-5	70
PM-6	80
PM-7	85

3.3.4 Insulation:

The radiation and convection losses are found to be high if the insulation is not provided for the hot surface. Higher the surface temperature more the heat loss into the atmosphere. The surface heat loss also depends on the velocity of air passing over and the emissivity of the surfaces. The uninsulated surfaces of the paper machine steam distribution lines were observed and details are discussed as below:

- Steam coil headers pipes PV fan chambers, valves and flanges are exposed to atmosphere without any insulation for paper machine # 5. These need to be insulated as quickly as possible because the surface temperature is above 100 ^{0} C.
- Steam header and condensate header distribution network of all paper machines are exposed to atmosphere from no. of locations.

3.3.5 Paper Machine Side Observations for PM-4:

- Return condensate line pressure for few of the dryer headers is less than return header pressure.
- No hood shutters or doors at the bottom side.
- Heat is not recovered from exhaust air.
- High blow through rate of steam to drain condensate from dryer.
- There are bucket siphons for condensate removal.
- Felts in dryer part should be removed by monofilament dryer fabric and felt dryer also.
- Pocket ventilation system should be installed.

Table 8 Process Conditions at PM-4 during Energy Balance

Particulars	Units	60 GSM	70 GSM
Machine speed	m/min.	325	280
Deckle	M	3.2	3.2
LP Steam consumption	Tons/hr	12.2	12.5
LP steam pressure	kg/cm^2 g	2.5	2.5
No. of dryer group		2	2
No. of cylinder in pre dryer section		26	26
Steam pressure in pre dryer	kg/cm^2 g	0.5	1.0
No. of cylinders in post dryer section		6	6
Steam pressure in post dryer	kg/cm^2 g	0.3	0.6
Specific evaporation rate	kg/ hr m^2	9.3	9.65
Specific steam consumption	tons/ton of O. D. Paper	3.8	3.9
Specific steam consumption	tons/ ton of water evaporated	2.42	2.49

Dryer cylinder and pocket ventilation condition analysis for PM-4 is given in figs.19-23. These graphs depict the variation of cylinder surface temperature, moisture level in pocket ventilation above the cylinders, differential temperature of supply steam and top surface of the cylinder and differential pressure between steam header and condensate header. The detailed evaluation is given in Appendix-2-6.

3.4 Analysis of Performance of Paper Machine-4 Dryers:

Since large number of variables determines the performance of the dryer section of the paper machine, constant monitoring and measurement of operating parameters were carried out. The performance evaluation exercise was done with much attention by monitoring the individual components such as

- Dryer cylinders
- Pocket ventilation system
- Hood air system
- Siphon condition
- Condensate removal & flash steam usage level etc.

Among these condensate removal for the major component that effect the overall performance of the dryer section. The performance of the dryer section is done by the following analysis:

3.4.1 Steam and condensate analysis,

Siphon and cylinder analysis,

Blow through and condensate system analysis

3.4.2 Energy balance analysis on siphon

3.4.1 Steam and Condensate Analysis:

An assessment of the plant machine dictated that the steam and condensate system being used at PM-4 is the simple bucket system, wherein live steam is being injected to each dryer group and the condensates are collected separately. At the same time, the flash steam is being simply discharged to the atmosphere which does also is part of the significant loss. Present steam and condensate removal system is given in fig. 18.

The machine operating condition such as speed, steam pressures, moisture content of the sheet, size of cylinders and grade of paper are among the key parameters, which decide the steam flow requirement to the cylinders. Higher the condensing rates for a given sheet, the higher the performance of the dryer section. The steam pressure, moisture content of the sheet, pocket ventilation system and exhaust system mainly influences the drying rate. The inlet and outlet steam condition, paper sheet condition before dryer and after dryer, machine running condition are given in Appendix-2-4 and summary of this is given in table 8

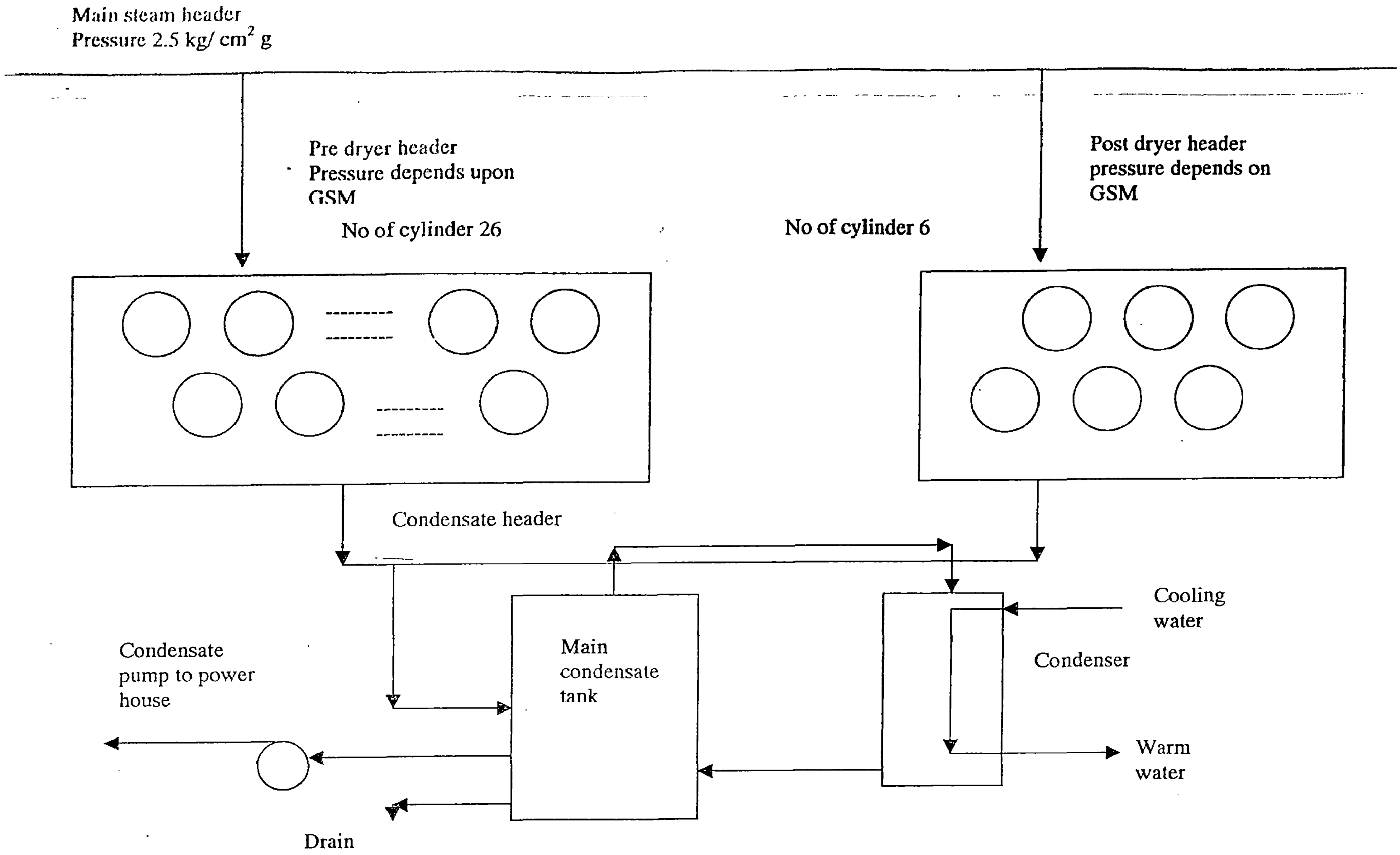


FIG. 18 Steam supply and Condensate removal System of PM-4.

Fig. 18 Steam supply and condensate removal system of PM-4

3.4.1.1 Observed Moisture Levels in Pocket Ventilation System:

The humidity level up to dryer 7 and from 11 to 13 is under limit but in other dryers pocket humidity level is very high which cause reduction in drying rate. In most of dryer relative humidity is very high which reduce the water carrying capacity of air. Pocket humidity profile is given in fig. 19.

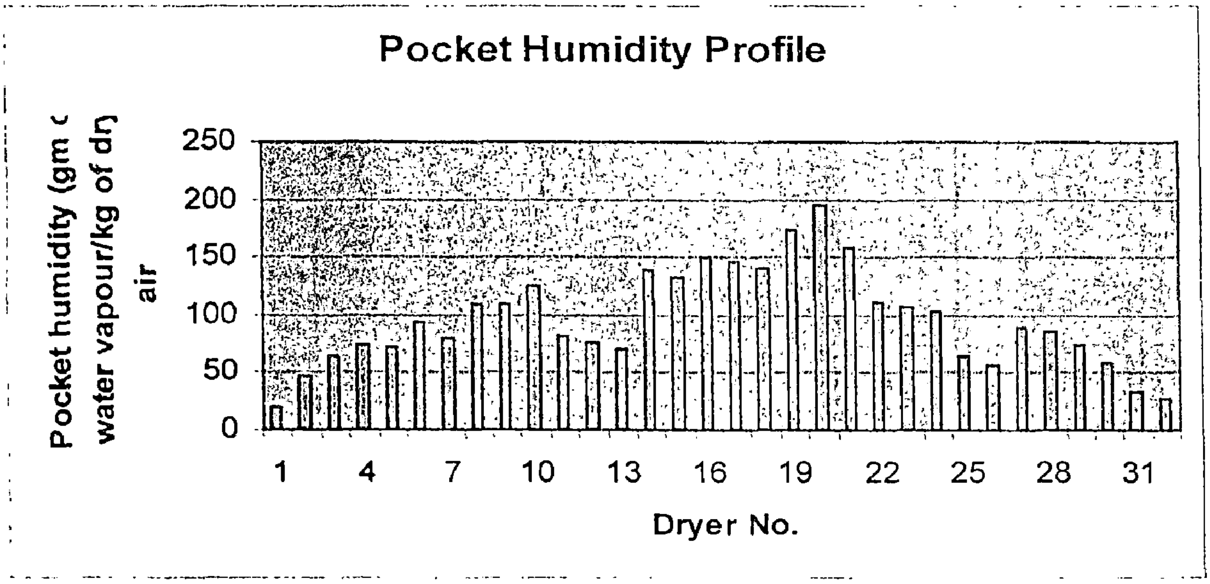


Fig. 19 Pocket Humidity Profile

3.4.1.2Observed Pocket Ventilation Temperature:

The pocket ventilation temperature is increasing gradually from feed end to outer end. From dryer 11 to 15 it falls. And temperature again falls when post dryer came due to lower steam pressure in post dryer. Pocket ventilation temperature profile is given in fig. 20.

3.4.1.3 Observed Dryer Surface Temperature Profile:

Dryer temperature profile is not uniform in pre dryer as compared to post dryer. In dryer 7 & 13 dryer temperature is very low due to poor drainage. Dryer surface temperature is given in fig. 21.

3.4.1.4Observed Differential Temperature of Inlet Steam and Dryer Surface Temperature:

The differential in temperature between inlet steam and dryer surface temperature depicts the behavior of condensate removal rate. Higher difference in temperature indicates problem with the condensate removal. The difference in temperature should be gradually reduced from one end to the other. Differential temperature of inlet steam and dryer surface temperature is given in fig. 22.

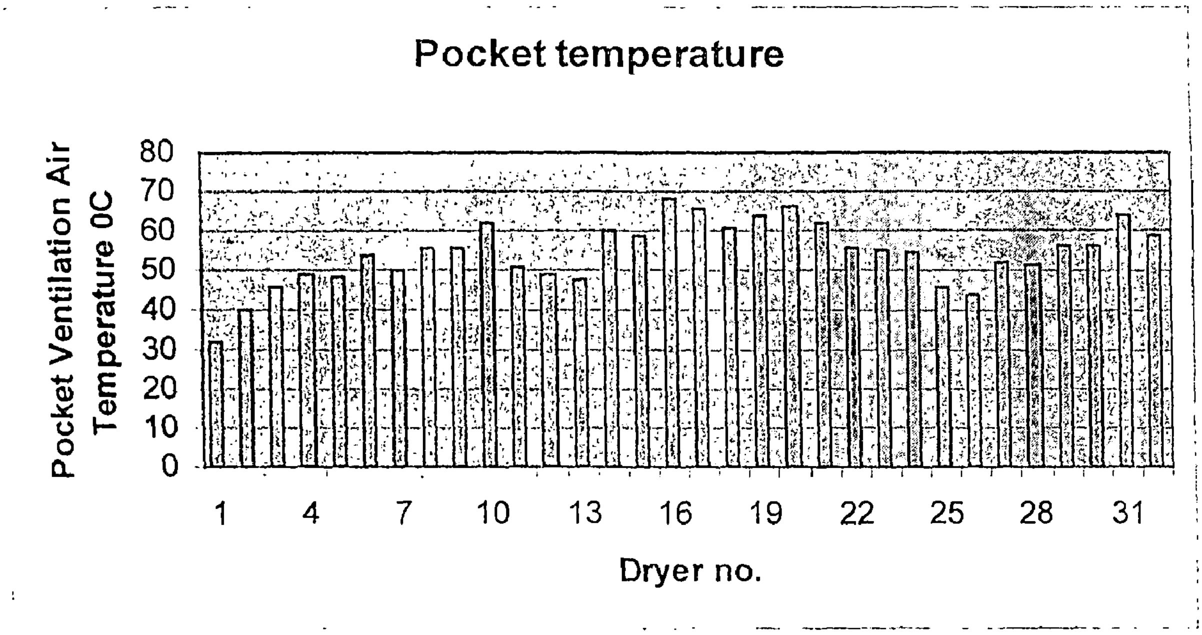


Fig. 20 Pocket Temperature profile

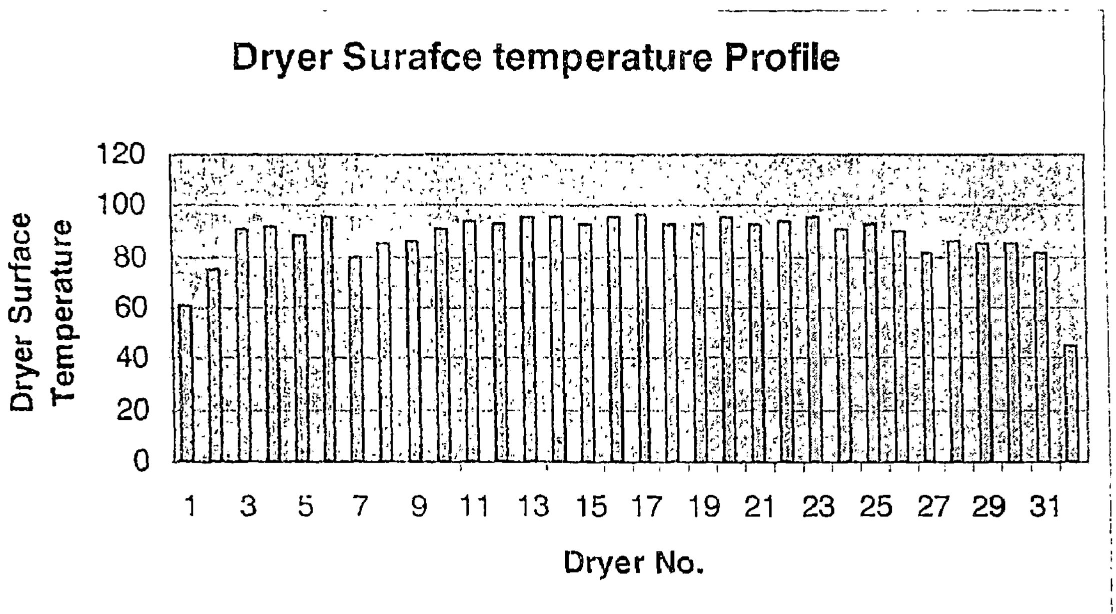


Fig. 21 Dryer Surface Temperature profile

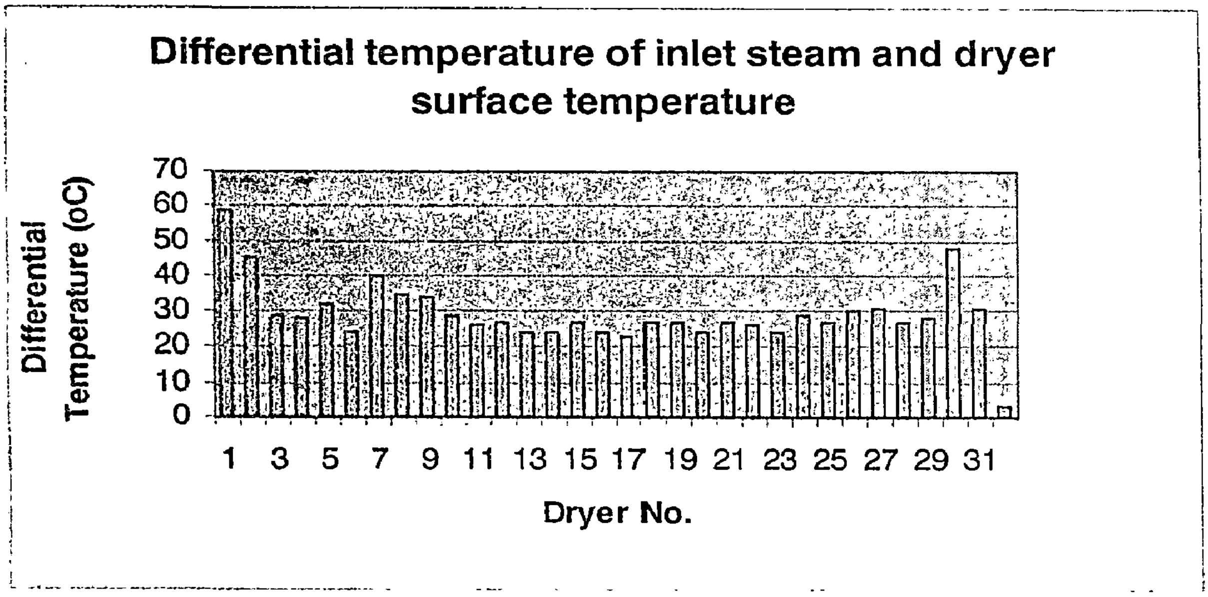


Fig. 22 Differential temperature of inlet steam and dryer surface temperature

3.4.1.5Observed Differential Pressure in Dryer Cans:

Differential pressure in dryer cans is between 0.3-0.4 kg/cm^2, which on the higher side, most of it is due to siphon, line drop and centrifugal pressure drop. This drop is increasing step by step as we reaches in the middle of cylinders. Differential pressure between steam header and condensate header is given in fig. 23.

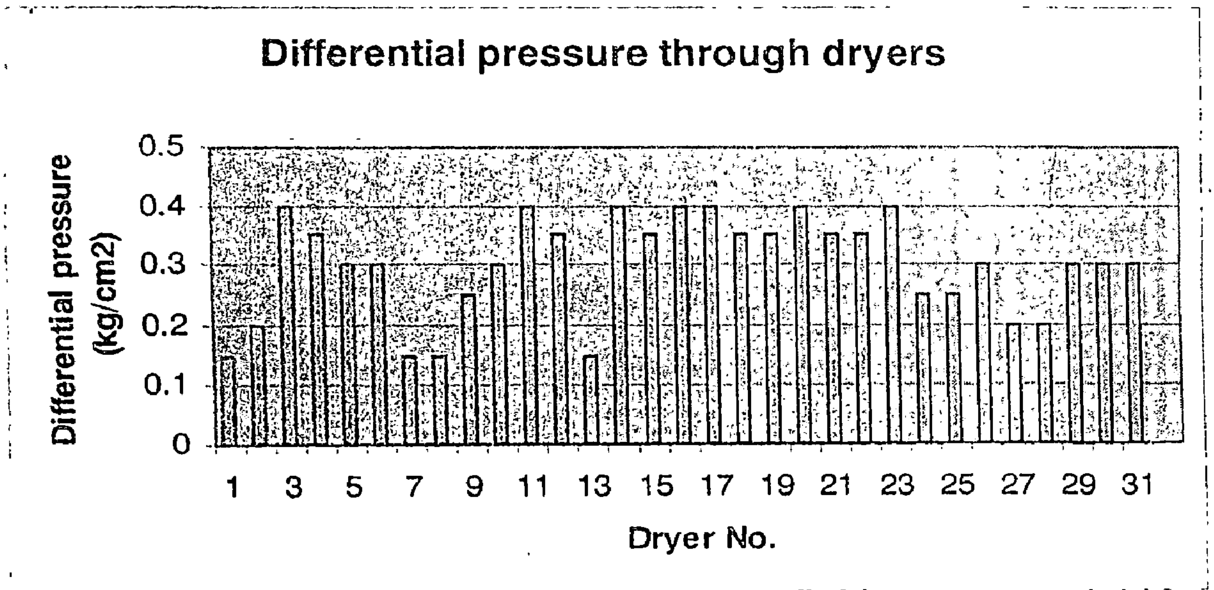


Fig. 23 Differential pressure between steam header and condensate header

3.4.2 Energy Balance over Dryers:

Table 8 shows the machine condition during energy balance. The energy balance of the dryers was evaluated by conducting test during load periods and trials at various intervals. The objective of the trial was to evaluate the fixed and variable loss components and thereby identify energy saving opportunities.

The parameters measured and monitored are:

- Steam consumption
- Steam pressure and temperature
- Exhaust gas flow and temperature
- Pocket ventilation air flow and temperature
- Surface heat losses of dryers
- Recovered and non recovered condensate flow and condensate temperature
- Flash steam loss
- Heat loss in vacuum condenser
- Moisture percentage at inlet to the dryers
- Moisture percentage at various levels
- Dry bulb temperature and relative humidity of pocket ventilation zones
- Temperature of ex-filtered air
- Temperature of out going material

The complete energy balance of paper machine 4 dryer is given in Tables 9 & 10.

From the energy balance it is very clear that increasing the production rate by increasing the speed helps in reducing the specific steam consumption in terms of tons of steam used per ton of paper drying. Trials can be conducted to increase the production to reduce the specific steam consumption after rectifying the present vibration problems. The detailed evaluation is given in Appendix-5-6

Table 9 - Energy Balance on Paper machine 4 for 60 GSM

Particulars	Paper machine # 4	
	kW	%
Energy Input		
Total input heat as steam	9244.9	100.0
Energy output		
Total heat required to evaporate water	3388.4	36.7
Heat required to heat the fibers	81.7	0.9
Heat required to dry felt	423.6	4.6
Heat loss through exhaust fan	211.1	2.3
Heat recovered through condensate recovery	627.7	6.8
Heat loss through escaping flash	142.3	1.5
Heat loss through let out condensate	313.8	3.4
Total surface heat loss	11.1	0.1
Other losses (blow through steam +condensate tank + condensate return line)	4045.2	43.8

Table 10 - Energy Balance on Paper machine 4 for 70 GSM

Particulars	Paper machine # 4	
	kW	%
Energy input		
Total input heat as steam	9472.2	100.0
Energy output		
Total heat required to evaporate water	3541.6	37.4
Heat required to heat the fibers	83.3	0.9
Heat required to dry felt	442.7	4.7
Heat loss through exhaust fan	211.1	2.2
Heat recovered through condensate recovery	724.8	7.7
Heat loss through escaping flash	145.8	1.5
Heat loss through let out condensate	243.3	2.6
Total surface heat loss	12.5	0.1
Other losses (infiltration air + blow through steam +condensate tank + condensate return line)	4067.1	42.9

After the detailed study of energy consumption in paper machine dryer part it was observed that:

- The higher unaccounted losses indicate the overall surface heat losses from the steam and condensate distribution system. If we see in table 8 & 9 around 40 % of energy is going as loss from this head only.
- Dryer surface temperature is on the lower side (85-90 °C) which means dryers are flooded and most of steam is coming out without giving its latent heat. If we observe the passage of paper on the dryers, it is thus coming in contact with condensing steam with upper set of dryers at higher temperature and at lower temperature with steam condensate in lower set of dryers. Thus it appears that more convective, condensing heat transfer at higher temperature in upper set of dryers in comparison to conductive heat transfer at lower temperature in lower set of dryers.
- Specific steam consumption was near 3.9 tons/ ton of dry paper produced which is on the very high side.
- Pocket humidity level is very high (150-175 gm/kg of dry air) which slow down the mass transfer rate of evaporated moisture.
- Flexibility in the steam pressure control is minimum because there are only two groups pre dryer and post dryer, which leads to energy waste in the first five cylinders and last cylinders where high pressure steam is not required.
- Conventional dryer felt should be removed because of their small life and lot of steam is consumed for their drying.
- Quality of paper produced is not uniform. In every shift there is a lot of variation in final moisture level, and GSM in cross direction and as well as in machine direction which should be controlled.
- Condensate recovery is only 70% and most of the condensate is leaking from different joints. Structure of steam and condensate piping is in very poor condition.

3.5 Energy Conservation and Other Proposals for PM-4 Performance Improvements:

3.5.1 Proposal #1 Conversion of Two-Group Steam Supply System to Six Groups Steam Supply System:

Background

Initially there is no size press so amount of water, which is to be evaporated, is not so high. After renovation we shall have to start size press so we shall have to increase water evaporating capacity of the machine. For this either we add extra cylinder or we could increase the steam pressure. Second option appears to be economical one.

According to drying curve, first stage is warming up stage. In this stage we do not require high cylinder temperature and virtually no evaporation takes place in this zone. After warming up stage constant rate period comes where maximum evaporation takes place. So steam pressure should be on the higher side. Final stage of drying is falling rate period where water removal is difficult so steam temperature should be maximum here.

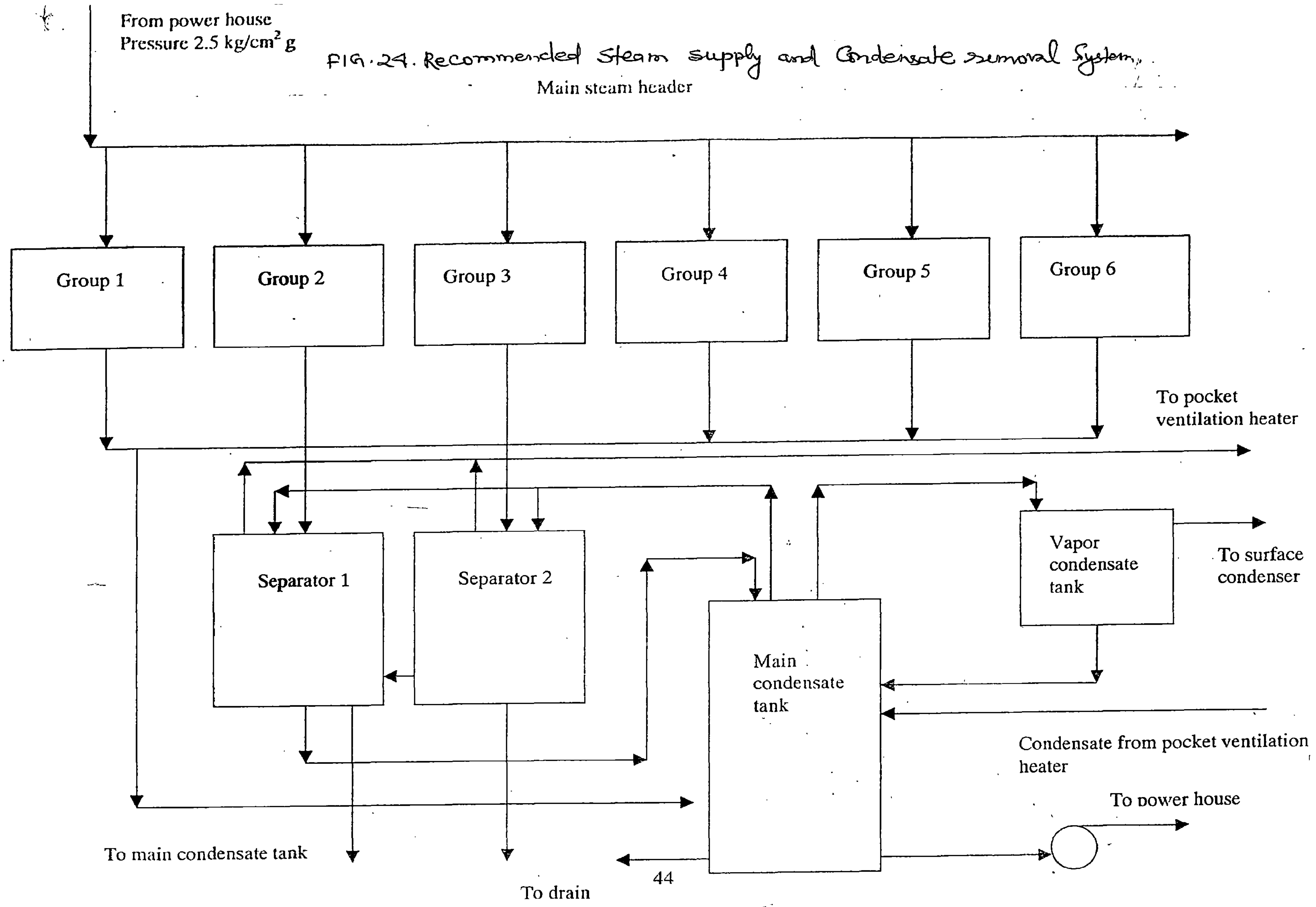
By regrouping of dryer cylinders we could reduce steam demand, increase in drying capacity of the existing system and also control over steam distribution system.

Recommendation:

- Divide pre dryer group into four groups and post dryer group into two groups.
- Add two extra cylinders in the post dryer group. These cylinders are felt dryer cylinders.
- Steam supply should be from main steam header and six pneumatic control valves for better control should control the steam distribution.
- Condensate from group 2 & 3 can be fed to two-separator tank S_1 & S_2 then to main condensate tank and flash vapors generated are sent to pocket ventilation heater.
- Condensate from rest of the groups can be fed directly to the main condensate tank and from the main condensate tank the condensate should be sent to the Power house.

Recommended steam and condensate distribution system is shown in fig. 24

FIG. 24. Recommended Steam supply and Condensate removal System.



ng Production Increase Calculations:

Being able to accurately predict production increase or decrease as a result of easing or decreasing the dryer pressure is very important. In order to do this, we need know what the equivalent steam pressure is on a machine, not the average steam pressure.

Equivalent pressure calculation with the help of dryer capacity factor (DCF) for present system are shown in Table 11. Equivalent pressure calculation for recommended system is shown in Table 12. Drying capacity factor (DCF) for equivalent pressure is given in Appendix- 12.

Table 11 - Equivalent pressure calculation for the existing system[18]

Basis weight gm/m^2	60	70
Pre dryer pressure kg/cm2	0.5	1.0
Post dryer pressure kg/cm2	0.3	0.6
Pre dryer DCF	11.3	12.6
Post dryer DCF	10.8	11.89
System DCF	11.21	12.42
Corresponding pressure kg/cm2	0.42 (41.19)	0.81 (79.43)

Table 12 - Equivalent pressure calculation for the Recommended system[18]

Basis weight gm/m^2	60	70
Group 1 pressure kg/cm^2 g	0.5	1.0
Group 2 pressure kg/cm^2 g	0.6	1.2
Group 3 pressure kg/cm^2 g	0.8	1.25
Group 4 pressure kg/cm^2 g	0.9	1.4
Group 5 pressure kg/cm^2 g	1.7	2.1
Group 6 pressure kg/cm^2 g	1.6	2.0
Group 1 DCF	11.64	12.6
Group 2 DCF	11.89	13.29
Group 3 DCF	12.4	13.39
Group 4 DCF	12.6	13.67
Group 5 DCF	14.22	14.89
Group 6 DCF	14	14.74
System DCF	12.64	13.65
Corresponding pressure kg/cm^2 g (kpa)	0.91(89.24)	1.39(136.31)

Percentage increase in drying capacity for 60 gsm	:	12.64/11.21 =1.12
So drying capacity increase is 12.7 %.		
Percentage drying capacity for 70 gsm	:	13.65/12.42 =1.099
So drying capacity increase is 9.9 %.		

Fig. 25 shows that with the increase of steam pressure, specific evaporation rate will increase. After this change expected specific evaporation rate will be 12-13 kg/hr m^2.

Initial water removal capacity	:	5000 kg/hr
Expected increase in capacity	:	12 %
Investment required	:	30 lakhs

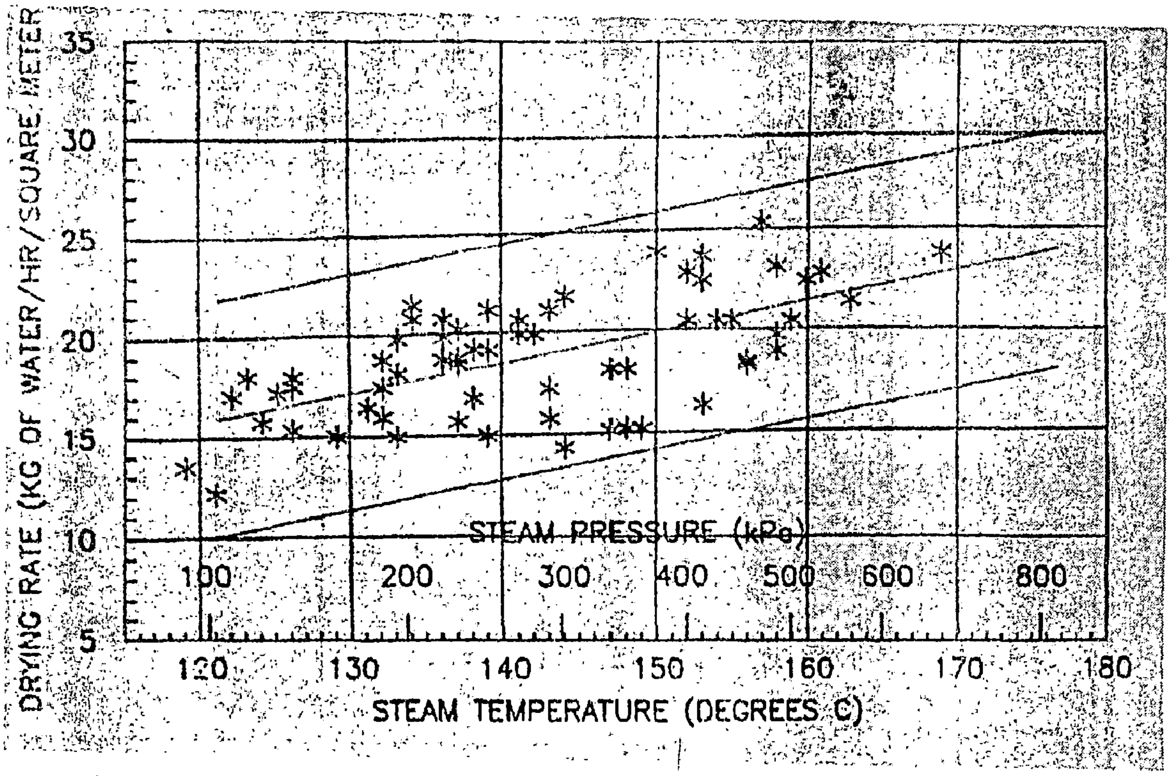


Fig 25 shows dryer capacity increase with the increase in steam pressure.[11]

Advantage of Recommendation:

- Steam pressure in different groups is according to the drying curve.
- Now system is more flexible than the previous system.
- Control of steam pressure is easier.
- Proper utilization of flashed vapor and blow through steam.
- Increase in water evaporation capacity up to 12 %.

3.5.2 Proposal # 2 Installation of Three Groups Heating Pocket Ventilation System:

Background:

- The water evaporated in the dryer section was allowed to simply migrate into the room where it would be removed using room exhaust fans. There is no pocket ventilation system for the removal of vapors from pockets. So very high humidity in pockets, increase the mass transfer resistance. This will reduce the drying capacity, increase the steam requirement and also affect the product quality. That's why pocket ventilation is a primary necessity. This will reduce profile variation, increase the capacity, and reduce the steam requirement.
- Effect of pocket humidity on drying rate is shown in Fig.26, from Fig. It is clear that with decrease of pocket humidity drying rate increases. If we increase the flow rate of dry air per unit flow area it also helps in increasing the drying rate.
- Enthalpy of flash vapors from the condensate header is going as waste. This vapor could be used to heat PV supply air.

EFFECT OF POCKET HUMIDITY ON DRYING RATES

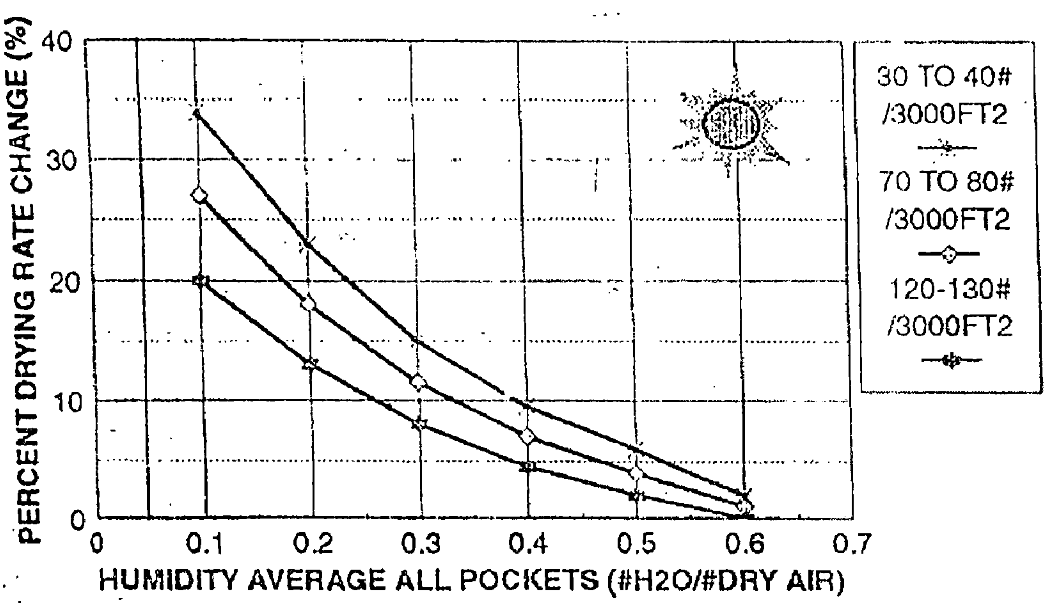


Fig. 26 shows the effect of Pocket Humidity on change in drying rate[11]

Recommendation:

- Install three groups of steam coils for the hot air generation chamber and feed this hot air inside the pockets by five pocket ventilation fans.
- Live steam should be supplied at the side close to the outlet side and return flash vapor and blow through steam. After removing, the condensate can be used in the first stage heating.
- The temperature of air can be raised to 70 to 80 °C in the first two groups of steam coils and the required temperature of 110 °C for the hot air can be achieved in the final group of Infrared heater. Exhaust air temperature level should be around 85 ^{0}C.
- The nozzles should be designed for the highest drying zone on the machine. The amount airflow will vary from 12 m^3 /min/m of machine width per nozzle. Approximately 10 kg of air is exhausted for every kg of water evaporated. Exhaust humidity level should be between 0.1-0.12 kg/kg of dry air.
- There should be five ID fans and five exhaust fans. Three ID fans in pre dryer section and two for post dryer section. They should be connected with six pocket ventilation nozzles.

Recommended three group heating pocket ventilation system shown in fig. 27.

Table 13 Process data for Recommended Pocket Ventilation system[23]

Description	Closed hood
Exhaust,	
No. of exhausts fans	5
Flow rate, kg/hr	80000
Temperature, ^{0}C	78
Humidity, kg/kg of dry air	0.12
Supply,	
No. of inlet fan blowers	5
No. of pocket ventilation nozzles	6
Flow rate, kg/hr	60000
Temperature, ^{0}C	110
Humidity, kg/kg of dry air	0.018

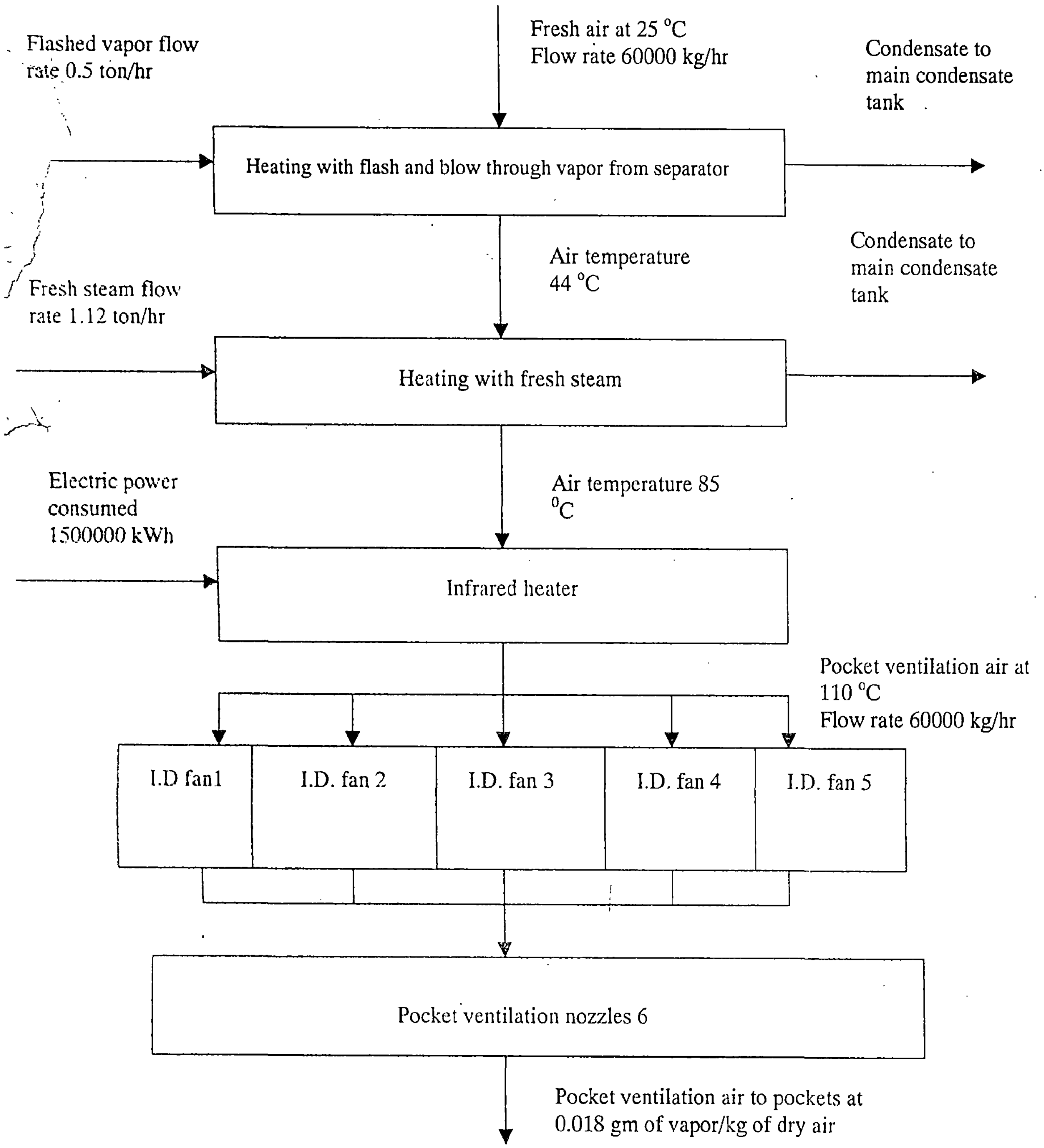


Fig. 27 Shows Recommended pocket ventilation system

Advantage of Recommendation:

- Increase in water evaporation capacity of dryer.
- Cross direction profile will be uniform.

Present water evaporation capacity	:	5000 kg/hr
Expected increase in water evaporation capacity	:	2-3 %
Investment required	:	40 lakhs

3.5.3 Proposal #3 Energy Saving by Proper Moisture Control:

Background:

Increasing the reel moisture while holding the basis weight constant contributes to energy saving in two ways.

First, less water has to be evaporated. Second, less pulp has to be manufactured and processed. If moisture is increased from 3% to 6% on an average paper machine producing 30000 tpy,

Energy saving by increasing moisture of paper on pope reel,

$$\frac{30000 * 0.97}{0.39} = 74615 \text{ tpy fiber and water entering dryer}$$

- 30000

44615 tpy water evaporated in dryers at 3% reel moisture

$$\frac{30000 * 0.94}{0.39} = 72307 \text{ tpy fiber and water entering dryer}$$

- 30000 tpy fiber/water leaving dryers

42307 tpy water evaporated in dryers at 6% reel moisture

where,

0.97 – fractional dry weight at 3% moisture
0.94 – fractional dry weight at 6% moisture
0.39 – fractional dry weight entering dryers.

Amount of less water to evaporate =44615-42307= 2308 tpy

To determine the energy savings associated with the 2308 tpy less water evaporated; the energy required per unit of water evaporated must first be estimated.

To evaporate one ton of water amount of energy required = 3000 kJ/kg of water Evaporated approximately)

Amount of energy saved by

Evaporating 2308 tpy less water = (3000 * 1000) * 2308 = 6924 GJ/year.

The second energy savings benefits of moisture increase are the savings associated with less pulp being manufactured and processed. A 3% increase in reel moisture at a constant basis weight means a 3% decrease in pulp. Thus, for the 30000 tpy machine, 900 tpy less pulp have to be manufactured and converted into paper.

A 30GJ of energy are required to produce a ton of paper from wood chips. However, the energy saving in the drying process has already been taken in to account. Thus, 12.6 GJ/ton (used in drying section) must be subtracted from the savings of 17.4 GJ/ton. Therefore, the 900 tpy reduced pulp demand results in an annual saving of energy as detailed below.

Annual saving of energy by demanding

900 tpy of less pulp = 900* 17.4 = 15660 GJ / year

Total annual energy savings associated with 3% moisture increase are 22524 GJ/year approximately.

The paper machine has to take care with proper process control, for maintaining exact moisture percentage in sheet at the reel. Where, too low moisture content gives lower smoothness and gloss while too high moisture content can cause dark spots in the paper. Best surface smoothness and gloss is obtained with moisture content of 7-8% approximately.

Table 14, 15 & 16 shows GSM, moisture & ash variation in machine direction respectively. By analyzing GSM variation it was find out that maximum variation of 14 GSM was present in different sample and minimum variation from desired GSM was 4. and it was in only two samples and in all other sample it was out of limit. Average range is 8 which is on the higher side.

In case of moisture variation by analyzing table 15 it was find out that average moisture level is very low i.e. 2.5 %. So lot of energy is going as waste and it also deteriorates the paper properties. The reason for dampness and dimensional un-stability is improper drying. So it is necessary to control final moisture level from quality point of view and also for energy saving.

Table 14 GSM variation before installation of QCS for 70 GSM paper

Five different interval	1	2	3	4	5	Maximum	Minimum	Average	Range
Sample no.									
1	70	69	67	65	63	70	63	66.8	7
2	69	68	70	72	72	72	68	70.2	4
3	70	72	63	72	74	74	63	70.2	11
4	76	69	76	70	68	76	68	71.8	8
5	69	70	62	76	73	76	62	70.0	14
6	70	74	71	72	74	74	70	72.2	4
7	70	69	63	71	72	72	63	69.0	9
8	64	70	62	65	62	70	62	64.6	8
9	69	77	78	72	73	78	69	73.8	9
10	68	64	64	65	70	70	64	66.2	6
Average								69.5	8

Table 15 Moisture variation before installation of QCS for 70 GSM paper

Five different interval	1	2	3	4	5	Maximum	Minimum	Average	Range
Sample no.									
1	2.5	3	3.5	2.7	2.6	2.5	3.5	2.9	1
2	2.1	2.7	3	2.5	2.6	2.1	3	2.6	0.9
3	2.4	3.6	2.5	3.3	2.6	2.4	3.6	2.9	1.2
4	2.2	2.5	3	3.2	2.1	2.1	3.2	2.6	1.1
5	2.1	2.8	3.2	1.9	2.4	1.9	3.2	2.5	1.3
6	1.9	2.2	2.5	1.8	2	1.8	2.5	2.1	0.7
7	1.8	2.2	2.8	2.2	2.4	1.8	2.8	2.3	1
8	2	2	3.2	1.8	2.8	1.8	3.2	2.4	1.4
9	2.2	2.8	3.5	2.4	2.6	2.2	3.5	2.7	1.3
10	2.1	3.5	3.9	3.1	2.4	2.1	3.9	3.0	1.8
AVERAGE								2.5	1.1

Table 16 shows the ash variation in different sample of paper, average ash content was 12.8 % and average range is 2.2 %. And set point for ash content is 12 %. Uniformity in Ash content is important for uniformity in quality of paper produced. Other wise there will be huge variation in quality and reject rate in finishing section will be higher.

Table 16 Ash variation before installation of QCS for 70 GSM paper

Five different interval	1	2	3	4	5	Maximum	Minimum	Average	Range
Sample no.									
1	14	12.5	13.2	12.4	13.4	12.4	14	13.1	1.6
2	13.5	15	14.5	13.8	13.2	13.2	15	14.0	1.8
3	13	14	12.5	15	14.6	12.5	15	13.8	2.5
4	13.5	11	12.8	13.4	13.9	11	13.9	12.9	2.9
5	12.8	13.5	14.2	12.8	14.1	12.8	14.2	13.5	1.4
6	15	13	13.6	12.4	13.1	12.4	15	13.4	2.6
7	13	11.4	11.5	12.5	13.4	11.4	13.4	12.4	2
8	10.5	13	12	10.9	11	10.5	13	11.5	2.5
9	10.1	12	10.4	11.6	12.1	10.1	12.1	11.2	2
10	11.4	12.5	13.6	11.7	11.9	11.4	13.6	12.2	2.2
AVERAGE								12.8	2.2

Recommendation:

- Install a BM (Beta Ray Meter) meter as a sensing element for measuring moisture, ash, caliper and GSM.
- Install a controller to regulate the steam pressure in the final group which will control the final moisture level.
- Install a display unit to display the Ash, GSM and caliper variation in paper at pope reel and variation will be controlled manually.

Advantages of the Recommendations made:

- Less water to be evaporated.
- Less paper to be processed.
- Proper control of final moisture and GSM of paper result in better properties of paper.
- Lower the rejection rate of the paper in the finishing section.
- Reduced consumption of steam.

Investment required	:	50 lakhs
Energy saved	:	22524 GJ/year
Cost of steam saved	:	28.89 lakhs/year

3.5.4 Proposal #4 Replacing The Present Bucket Type Siphons With Cantilevered Siphon For PM-4:

Background:

The condensate removal rate is poor and the blow through steam quantity is high due to poor performance of the siphons in the cylinders of PM-4. Due to this live steam demands is increased and hence blow through quantity also increased. In order to meet the drying rate with increase in speed, the steam pressure and flow is increased keeping the same conditions of siphon in the cylinder. High blow through steam leads high flash at the condensate tank. Presently more flash steam loss is happening in the condensate tank. More draining is occurring from the condensate tank due to mismatch of steam pressures used in subsequent sections to increase the drying rate. The present situation of drains makes us to think that the condensate header size is not adequate, but it is not so. The problem is mainly mismatch of steam pressure and steam flow to the different groups.

Recommendation:

- Stationary siphons operate in a stationary mode. The siphon shoe and pipe are always in the 6 o'clock position. This orientation assures evacuation of condensate at all operating conditions including loss of differential pressure at speed. The retrofitted stationary siphons eliminated flooding. The tendency to flood during the sheet break also decreased. This reduced time spent in returning to the desired grade.
- Replacing the present siphons with Rotary siphons for PM-4 cylinders shall reduce the steam demand, less pressure drop, low blow through rate, chances of flooding of dryer are also reduced. Typical cantilevered stationary siphon is given in Fig.13. If we look at Table 4 this siphon has good performance for every machine speed.

- Maintain the 15 % blow through rate and differential pressure between steam header and condensate header should not be more than 0.4 kg/cm^2.

Advantages of the Recommendations Made:

- Maximize the heat transfer to reach maximum drying rate on dryer limited grades.
- Minimize cross-machine temperature deviation to attain as flat a moisture profile as possible to improve sheet quality.
- Provide a system requiring minimal energy to evacuate condensate, eliminating dryer flooding and avoiding production losses and quality defects.
- Simplify the operation and control of the dryer drainage system.
- Minimize the residual condensate inside the dryers to reduce the drive torque energy requirements and potentially eliminate the related mechanical problems.
- Provide a siphon system to ensure mechanical reliability to reduce maintenance costs.

Possible reduction in steam consumption	:	2 tons/hour
Steam saving	:	15840 tons/year
Cost savings	:	Rs.55.44 lakhs/year
Investment required	:	Rs 150 lakhs

3.5.5 Proposal #5 Installation of Size Press for Improving Paper Quality:

Background:

The purpose of surface sizing is to provide resistance to penetration of liquids, to give better surface properties of the paper sheet such as surface strength and internal bond. Objective of size press is to flood the entering nip with sizing solution; the paper absorbs some of the solution, and the balance is removed in the nip. Conventional size press configuration are generally categorized as vertical, horizontal or inclined.

At paper machine #4 horizontal size press is installed but is not in use, so to make it operational no investment is required. Only requirement is to increase the water removal capacity of post dryer. Horizontal size press is shown in fig. 28.

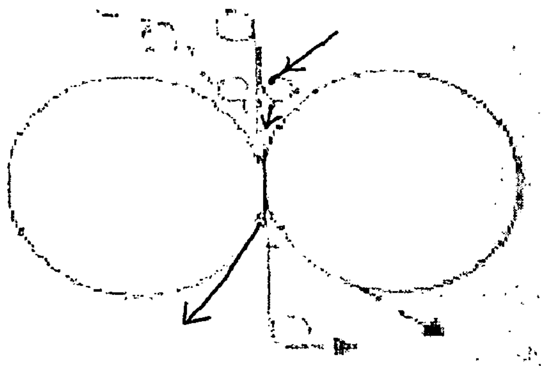


Fig. 28 shows the horizontal size press[22]

Recommendation:

- A low viscosity starch solution of 3 to 9 % solids should be used at the size press to achieve the pick up in the range of 30-50 kg of dry starch per ton of paper produced.
- Increase the water evaporation capacity of dryers by increasing the steam pressure in post dryer section and adding extra cylinder. Installation of pocket ventilation system also increases the capacity of dryers.

Advantage of Recommendation:

- Improvement in paper quality such as cobb, smoothness, opacity etc.
- Cost of paper will increase due to improved quality.

Investment required	Rs 5 lakhs
Total cost/ton of paper	Rs 1000
Increase in annual cost of paper	Rs 24750000

3.5.6 Proposal # 6 Replacement of Conventional Dryer Felt With Monofilament Dryer Fabrics:

Background:

- To increase the drying capacity of the dryers, we have to increase the steam pressure and temperature, which will result in increase in dryer temperature. The conventional cotton felts tends to degrade and is weakened by high cylinder temperatures and high humidity in dryer pockets. New heat resistant materials (i.e., polyphenylene sulfides and araminds) and fabric construction have been designed to greatly increase the fabric life compared to that of conventional cotton felts.
- These monofilament dryer fabrics absorb very little water or condensed steam from paper, felt dryer often be by-passed, thus the running size of fabric can be shortened and common sizes can be interchanged, reducing the fabric cost by 10-30 percent. Appreciable steam savings are made possible by eliminating the felt dryer.
- Higher drying rates made possible with modern drying fabrics, by leading to increased production.
- Monofilament dryer fabrics also assist in leveling the cross machine moisture profile of the web.
- Increased production resulting from less down time associated with fewer dryer fabric changes is also possible.

Recommendation:

- Replacement of dryer felt with monofilament dryer fabric which has longer life time and which save production down time.
- Bypassing the felt dryer which shorter the length of dryer fabric and also reduce the steam consumption.
- Removal of felt dryer from the present system so that the steam consumption can reduce.
- Use the synthetic felt in first group and in last group because the evaporation rates are lower in these groups.

Advantages of Recommendations Made:

- Increase in water removal capacity is expected.
- Life of monofilament dryer fabric is more than conventional felt.
- Felt dryer are removed from dryer section.
- Steam requirement is likely to reduce.

Table 17 - Specification of dryer felt presently used

Particular	Size	Life days	Cost Rs	Total cost (Rs/Year)
1st Uni-Run	43*3.55	180	347000	694000
2nd top	27.8*3.55	180	224322	448644
2nd bottom	27.8*3.55	180	224322	448644
3rd top	21.8*3.55	180	175907	351814
3rd bottom	21.8*3.55	180	175907	351814
4th top	30*3.55	180	242074	484148
4th bottom	32*3.55	180	258212	516424
5th top	29.9*3.55	180	241267	482534
5th bottom	29.9*3.55	180	241267	482534
6th top	12.5*3.55	180	100864	201728
6th bottom	12.5*3.55	180	100864	201728
Total			2779809	4664012

Table 18 - Specification of Recommended monofilament Dryer felt

Particular	Size	Life days	Cost Rs	Total cost (Rs/Year)
1st Uni-Run	43*3.55	180	347000	694000
2nd top	27.8*3.55	365	278110	278110
2nd bottom	27.8*3.55	365	278110	278110
3rd top	21.8*3.55	365	215724	215724
3rd bottom	21.8*3.55	365	215724	215724
4th top	30*3.55	365	294752	294752
4th bottom	32*3.55	365	315259	315259
5th top	29.9*3.55	365	294752	294752
5th bottom	29.9*3.55	365	294752	294752
6th top	12.5*3.6	180	100864	201728
6th bottom	12.5*3.6	180	100864	201728
Total			2735911	3284639

Table 17 & 18 show the comparison of previous dryer felt and recommended Monofilament cost data.

By comparison we can observe we will save around Rs.1379373 per year. Other advantage is less down time due to felt change and increase in water removal capacity by 2-3 %.

3.5.7 Recommendation for Better Process Control:

- Conduct routine operational inspections of the steam system (tanks, pressure gauges, pumps).
- Check vacuum condenser (receiver) to ensure that adequate vacuum levels are being achieved.
- Turn down steam temperatures during sheet breaks (automated systems for turn-down are most effective). Turn-down adjustments should be based on the required change in dryer surface temperature, not fixed adjustments in steam pressures.
- Adjust steam pressures in advance of grade changes, to reduce the delay in establishing the new dryer surface temperatures.
- Monitor valve and transmitter condition (calibration, response, accuracy)
- Check transmitter connections (inspect lines). Properly operating transmitters are critical for good system performance.
- Maintain records of steam system operation as a benchmark for performance monitoring. Include operating steam pressures, differential steam pressures, separator rise time times (condensing loads), machine speeds, sheet weight, and sheet trim.
- Monitor steam system to be sure that vent valves are not open during normal operation and have limited venting during sheet breaks. In a good steam system, there is no steam venting, during sheet breaks, grade changes, and particularly not during normal operation.
- For stationary siphons dryer differential steam pressures (inlet-to-outlet) should be in the range of 0.15-0.4kg/cm^2, depending on the machine speed and dryer condensing load.

- Dryer surface temperature should be checked periodically, particularly before and after major dryer section modifications. The dryer surface temperature should normally be less than 5-10 °C below the steam temperature in effective dryers.
- Dryer head temperatures should be checked with an infrared sensor on a periodic basis, to determine if any of the dryers are flooded. This is particularly important if the dryer drive loads are found to be running higher than normal.

3.6 Machine Condition after Renovation:

After renovation of PM-4, the machine conditions are shown in Table 19. The detailed evaluation is given in Appendix 7 - 9.

Table 19 - Paper machine conditions maintained during energy balance after renovation

Particulars	Units	60 GSM	70 GSM
Machine speed	m/min.	315	275
Deckle	M	3.2	3.2
LP Steam consumption	Tons/hr	13.2	14.3
LP steam pressure	Kg/cm^2 g	2.5	2.5
No. of Pre dryer group		4	4
No. of cylinder in pre dryer section		26	26
Specific evaporation rate of pre dryer	Kg/m^2. hr	14.02	12.9
No. of post dryer group		2	2
No. of cylinders in post dryer section		8	6
Specific steam consumption	tons/ton of O. D. Paper	3.6	3.9
Specific steam consumption	tons/ton of water evaporated	1.8	1.8

The following graphs 29-33 depict the variation of cylinder surface temperature, moisture level in pocket ventilation above the cylinders and differential temperature of supply steam and top surface of the cylinder.

3.6.1 Observed Dryer Surface Temperature Profile after Renovation:

Observed dryer surface temperature is shown in Fig. 29.After renovation dryer surface temperature is more uniform then in the past and also is in increasing order as the steam pressure is higher in the later cylinders.

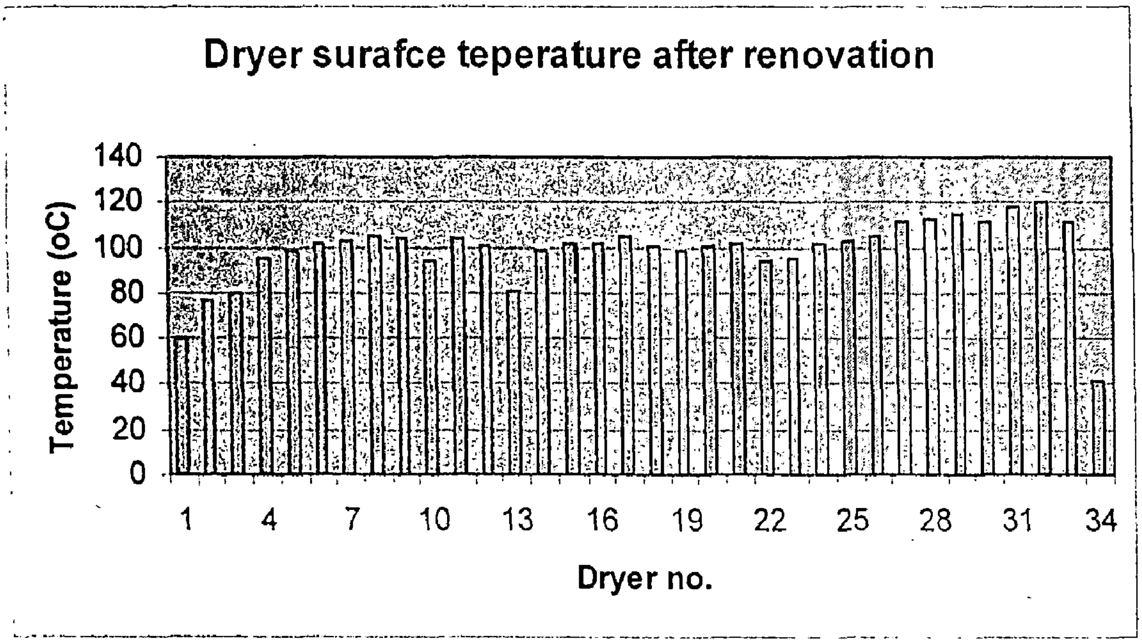


Fig. 29 Dryer surface temperature after renovation

3.6.2 Observed Dryer Pocket Humidity Profile after Renovation:

Observed dryer pocket humidity profile is shown in Fig. 30. The moisture removal rate behavior is also matching with the temperature pattern, which indicates the improved performance of the system.

3.6.3 Observed Pocket Temperature after Renovation:

Observed pocket temperature after renovation is shown in Fig. 31. The pocket ventilation temperature is gradually increased from one end to the other. In between fall in temperature indicates the size press area when moisture is added to the paper surface.

3.6.4 Observed Differential Temperature of Inlet Steam and Dryer Surface Temperature after Renovation:

Observed differential temperature of inlet steam and dryer surface temperature is shown in Fig. 32. The difference in temperature above 30 °C shows poor condensate removal from the dryer. But now difference in differential temperature is reduced which shows better condensate removal rate. So better heat transfer rate is observed after renovation.

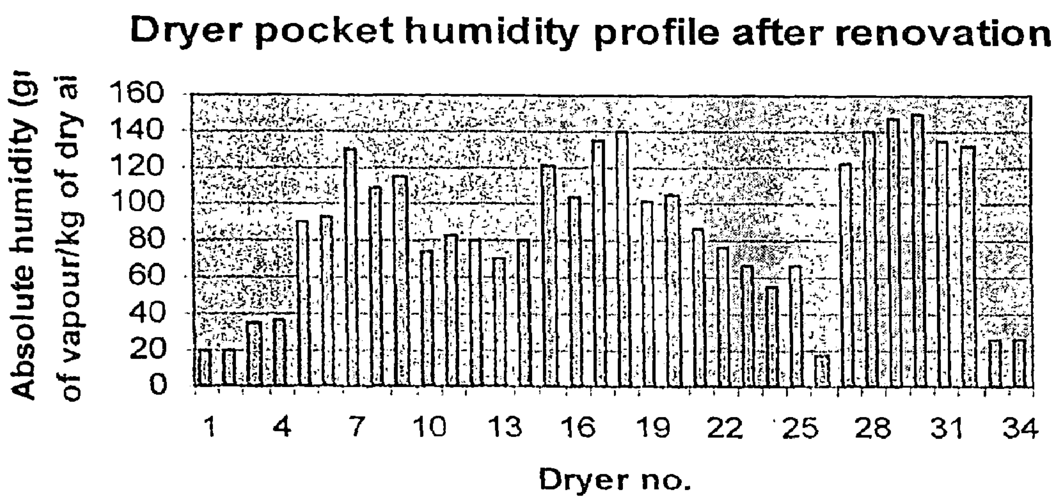


Fig. 30 Dryer pocket humidity profile after renovation

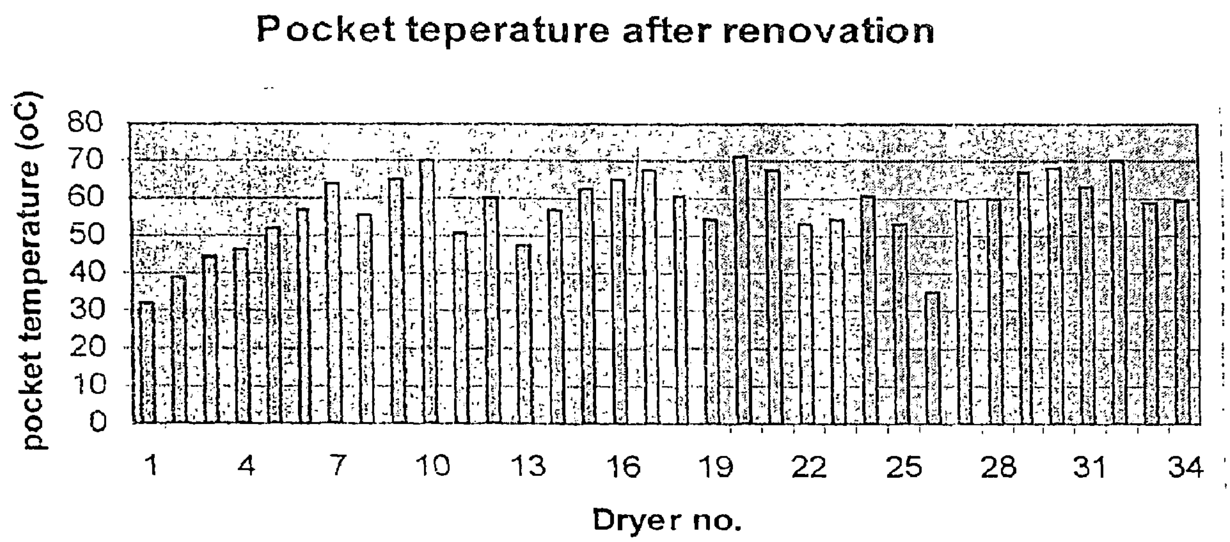


Fig. 31 Pocket temperature after renovation

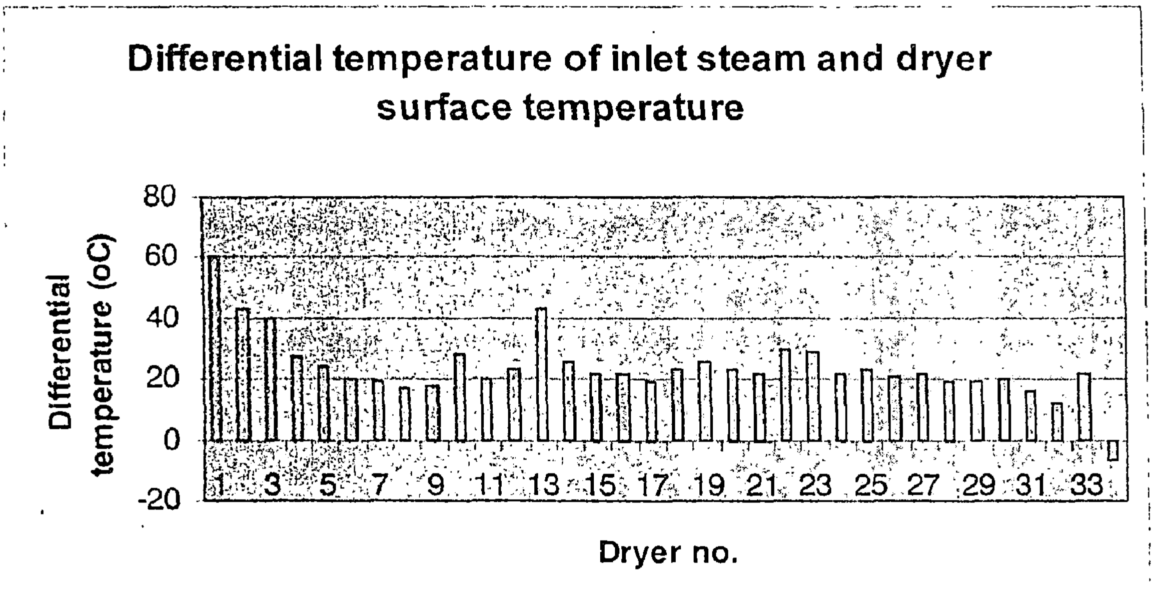


Fig. 32 Differential temperature of inlet steam and dryer surface temperature

3.6.5 Observed Differential Pressure after Renovation:

Fig. 33 shows the differential pressure after renovation between steam header and condensate header. This include pressure drop due to siphon, line drop, drop to evacuate the condensate. In most of the dryers the differential pressure is between 0.2-0.35 kg/cm^2.

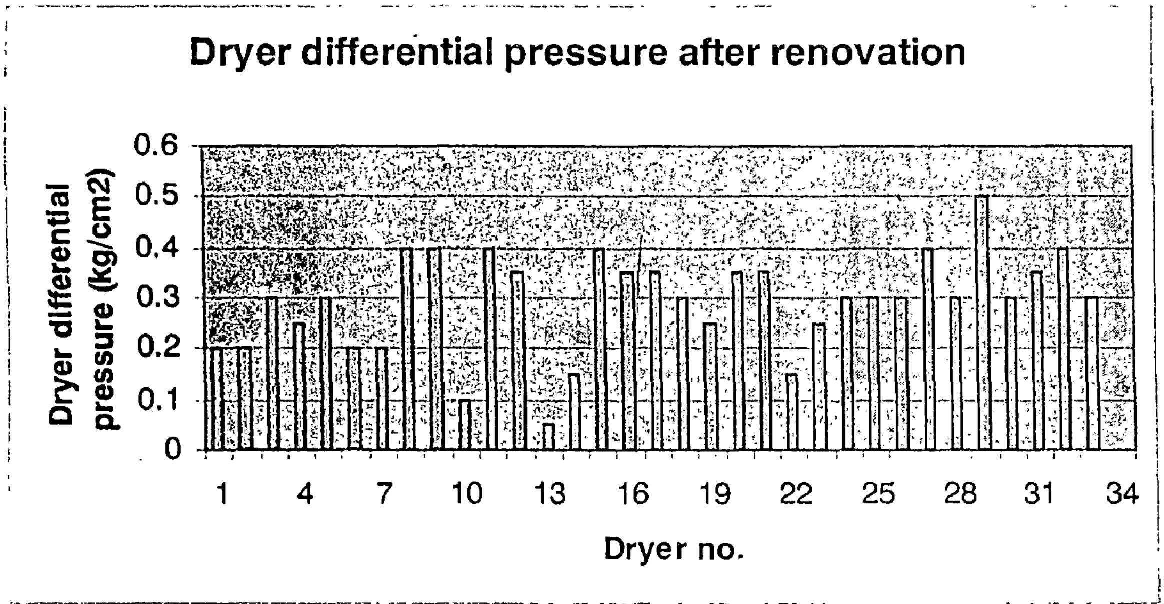


Fig. 33 Dryer differential pressure after renovation

3.7 Energy Balance after Renovation:

The summary of the energy balance of PM-4 after renovations is given in Table 20 & 21 and the detailed evaluation is given in Appendix 10 & 11

. From the energy balance, it is clear that 60-65 % of the energy is going to evaporate the water and the rest is going as waste, which is lower than the previous figure of 45 %. Now with the replacement of dryer siphon, installation of pocket ventilation, grouping of dryers, installation of BM meter, heat which is going as waste is reduced and the capacity of the paper machine is also increased

Table. 20 Energy balance for PM-4 at 60 gsm after renovation

Particulars	Paper machine # 4	
	kw	%
Energy input		
Total input heat as steam	9169.1	100.0
Energy output		
Total heat required to evaporate water	4447.4	48.5
Heat required to heat the fibers	74.4	0.8
Heat required to heat pocket ventilation air	944.4	10.3
Heat recovered through condensate recovery	851.9	9.3
Heat loss through escaping flash	141.2	1.5
Heat loss through let out condensate	150.3	1.6
Total surface heat loss	16.8	0.2
Other losses (infiltration air + blow through steam +condensate tank + condensate return line)	2542.6	27.7

Table 21 Energy balance for PM-4 at 70 gsm after renovation

Particulars	Paper machine # 4	
	kw	%
Energy input		
Total input heat as steam	9775.3	100.0
Energy output		
Total heat required to evaporate water	4830.0	49.4
Heat required to heat the fibers	75.7	0.8
Heat required to heat pocket ventilation air	1062.5	10.9
Heat recovered through condensate recovery	908.3	9.3
Heat loss through escaping flash	150.5	1.5
Heat loss through let out condensate	160.3	1.6
Total surface heat loss	16.8	0.2
Other losses (infiltration air + blow through steam +condensate tank + condensate return line)	2571.2	26.3

3.8 Quality Analysis after Renovation:

After implementation of QCS if we look at GSM variation in processed sheet, the maximum range of GSM variation is 5 GSM and average of GSM range is 3.8. Average of all the sample is 70.5 GSM which under control range.

In table 23 moisture variation after installation of QCS is given, average moisture content is 5.5 % and maximum range of moisture variation in sample is 1.2 and average variation in range is 0.9.

Table 24 shows ash variation after installation of QCS average ash content is 9.4 % and average range is 1.28.

Table 22 GSM variation after installation of QCS for 70 GSM paper

Five different interval	1	2	3	4	5	Maximum	Minimum	Average	Range
Sample no.									
1	66	69	70	69	70	70	66	68.8	4
2	74	70	71	72	73	74	70	72.0	4
3	70	72	73	69	69	73	69	70.6	4
4	70	70	70	73	73	73	70	71.2	3
5	69	71	71	72	72	72	69	71.0	3
6	72	68	68	70	70	72	68	69.6	4
7	69	71	72	70	69	72	69	70.2	3
8	74	70	70	70	70	74	70	70.8	4
9	70	72	72	74	71	74	70	71.8	4
10	72	69	69	70	67	72	67	69.4	5
Average								70.5	3.8

Table 23 Moisture variation after installation of QCS for 70 GSM paper

Five different interval	1	2	3	4	5	Maximum	Minimum	Average	Range
Sample no.									
1	4.8	5.5	5.5	5.1	4.9	4.8	5.5	5.2	0.7
2	5	5.8	6	6.1	5.2	5	6.1	5.6	1.1
3	4.8	5.5	5.8	5.3	5.2	4.8	5.8	5.3	1
4	5.2	6.2	6.3	5.8	5.2	5.2	6.3	5.7	1.1
5	5.6	5.5	6.2	5.6	5.4	5.4	6.2	5.7	0.8
6	4.8	5.2	5.4	5.1	4.9	4.8	5.4	5.1	0.6
7	4.6	4.5	5	5.2	5.5	4.5	5.5	5.0	1
8	5.5	5	6.2	6	5.5	5	6.2	5.6	1.2
9	5.8	6.2	6	5.7	5.2	5.2	6.2	5.8	1
10	5.6	5.8	6	5.8	5.6	5.6	6	5.8	0.4
AVERAGE								5.5	0.9

Table 24 Ash variation after installation of QCS for 70 GSM paper

Five different interval	1	2	3	4	5	Maximum	Minimum	Average	Range
Sample no.									
1	9.5	10	9.7	8.8	9.1	8.8	10	9.5	1.2
2	8.4	9.6	8.4	8.6	8.8	8.4	9.6	8.8	1.2
3	8.7	7.4	8.6	7.4	7.8	7.4	8.7	8.0	1.3
4	9.1	10	9.4	9	8.8	9	10	9.4	1
5	9.9	10.2	9.3	9.6	9.4	9.3	10.2	9.8	0.9
6	10	10.2	11	9.5	10.1	9.5	11	10.2	1.5
7	9.9	11	10	10.2	10.4	9.9	11	10.3	1.1
8	8.8	9.5	10.8	9.4	9.2	8.8	10.8	9.6	2
9	8.6	9	8.9	9.7	8.7	8.6	9.7	9.1	1.1
10	8.5	9.8	8.3	9.7	8.4	8.3	9.8	9.1	1.5
AVERAGE								9.4	1.28

If we compare GSM, moisture and ash variation before and after installation of QCS now paper quality is more uniform and reject rate in finishing section has been reduced, energy consumption is reduced due to increase in final moisture content.

Chapter 4- Conclusion and Further Recommendation

4.1 Conclusion:

After making a study of energy consumption and implementing the process modification in PM-4 of the BILT Yamunanagar. This implemented have led to the greater reduction in energy consumption, and greater utilization of the capacity of the paper machine.

The calculated results after process modifications show that modified processes are more energy efficient compared to the previous process.

Comparison of Table 19, 20 & 21 with the Table 8, 9 & 10 shows that in the previous process only 50 % of heat content of steam was used to evaporate the moisture and the specific steam consumption was 3.8 tons/ ton of dry paper produced. Specific steam consumption per ton of water evaporate was 2.32 tons/ ton of water evaporated. Specific evaporation rate was only 12.5 kg of water evaporated/ m^2 hr.

After process modification and installation of size press, more than 60 % of heat is going to evaporate the water and specific steam consumption rate is 3.9 tons/ton of dry paper produced which is almost equal. This increase in specific steam consumption is because of the size press. Now we are evaporating 8000 kg/ hr water while in the previous system it was 5500 kg/hr. Now specific steam consumption per ton of water evaporated is 1.8 tons/ton of water evaporated. Specific evaporation rate in renovated system is 14.5 kg of water evaporated/ m^2.hr.

If we compare the paper properties before and after renovation, by table 25 & 26, we will find a drastic difference in two. Reasons behind this are external sizing of paper and installation of quality control system. There is drastic change in Cobb value so water resistance is higher in surface sized paper, opacity, smoothness, gloss has been increased. So this increased the cost of paper.

Table 25 Properties of paper before renovation

Properties	60 gsm	70 gsm
Bulk (cc/gm)	1.4	1.3
Thickness (micron)	84	91
Tear factor	18 (md) 55 (cd)	28 (md) 86 (cd)
Breaking length (m)	4000 (md) 2000 (cd)	4185 (md) 2648 (cd)
Burst factor	18.2	19.4
Double fold	10 (md) 5 (cd)	12 (md) 6 (cd)
Porosity (sec/100 ml)	7.9	15.2
Cobb (gm/m^2) 1 min.	21.4(felt) 22 (wire)	23.2 (felt) 25.3 (wire)
Ash (%)	11	10
Smoothness (ml/min)	140 (wire side) 100 (felt side)	130 (wire) 240 (felt)
Brightness (%)	84.1	85.4
Opacity(%)	86	87.6

Table 26 Properties of paper after renovation

Properties	60 gsm	70 gsm
Bulk (cc/gm)	1.57	1.4
Thickness (micron)	94	98
Tear factor	69.2 (md) 78.3 (cd)	67 (md) 78.7 (cd)
Breaking length (m)	4007(md) 3157 (cd)	4589(md) 3900 (cd)
Burst factor	16	20.1
Double fold	10 (md) 8 (cd)	16 (md) 8 (cd)
Porosity (sec/100 ml)	10.2	18.2
Cobb (gm/m^2) 1 min.	19 (Felt) 20.2 (wire)	18.5 (felt) 19.8 (wire)
Ash (%)	9.2	8.3
Smoothness (ml/min)	98 (wire side) 81 (felt side)	105 (wire) 82 (felt)
Brightness (%)	84.2	84.9
Opacity(%)	88.5	91.96
Pick	6	7

After making a study of energy consumption in the dryer section of paper machine-4 we come to the following conclusion:

Now we are producing the sized paper with almost the same specific steam consumption. The market value of sized paper is more than the previous produced paper.

The detailed study of energy consumption and quality improvement recommendation and their implementation shows, annual savings of 401.97 lakhs. The cost of implementation required for the proposals have been worked out to be Rs 265 lakhs. Detail evaluation of all the implementation is given in table 27.

Table 27 - Comparison of the entire proposal made

Proposal	Cost of implementation (Lakhs)	Percentage increase in capacity	Amount of energy saved GJ/Year
Conversion of two-group steam supply system to six group of steam supply	30	10-12	
Installation of three groups heating pocket ventilation system	40	2-3	
Energy saving by proper moisture control	50	1-2	22524
Replacing the present bucket type siphons with stationary siphon for PM-4	150	5	43211
Installation of size press for improving paper quality	5		
Replacement of conventional dryer felt with Monofilament dryer fabrics	Nil	1-2	
Total	275	19-24	65735

Increase in steam used per ton of paper	:	0.1 ton
Total increase in steam consumption	:	2475 tons
Cost of steam	:	350 Rs/ton
Total increase in cost	:	8.66 lakhs
Cost of surface size require annually	:	24.75 lakhs
Cost of energy saved	:	84.33 lakhs
Money saved by Changing Dryer felt	:	13.8 lakhs
Cost of unsized paper (60 gsm)	:	Rs 38/kg
Cost of unsized paper (70 gsm)	:	Rs 38.3/kg
Cost of sized paper (60 gsm)	:	Rs 41.5/kg
Cost of sized paper(70 gsm)	:	Rs 41.1/kg
Annual production	:	25000-30000 ton

Expected sized paper production	:	12500-15000 ton
Expected unsized paper production	:	12500-15000 ton
Approximate benefit	:	Rs.2500 / ton of paper
Saving due to quality improvement	:	312.5 lakhs
Total saving	:	377.22 lakhs
Total investment	:	275 lakhs
Payback	:	0.73 years

4.2 Recommendation for Future Work:

There should be work on the following potential areas:

- DCS control system for the steam and condensate control.
- The cross direction moisture control with the help of pocket ventilation duct.
- Thermocompressor system should be installed because we are getting condensate at 0.6-0.8 kg/cm^2 which can be reused by the thermocompressor.
- Machine trial can be taken to increase the machine speed.

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APPENDIX

Appendix-1

m_e = $w\ u\ l\ \{(100-d_1)/d_1-(100-d_2)/d_2\}$ *1000/60

m_f = w u l *Þ*1000/60

Q_e = $m_e c_w (T_e-T_1) + m_e ë_v$

Q_f = $m_f c_p (T_e-T_1)$

Q_a = $m_a c_a (T_p-T_a)$

F = $(S_1 - S_2)/ ë_2$*100

Q_h = $m_s F ë_2$

Q_r = $å\, ë_s A (T_s^4 - T_2^4)$

Q_c = $h_i A (T_s-T_2)$

Q_t = $Q_r + Q_c$

A_h = $ð\ d\ l_d$

A = $2*ð\ d^2/4$

S_e = m_e * 3600/ A_h

S_s = m_s/m_f

m_e = Mass of evaporated water from dryer group (kg/sec.)

m_f = Mass of fiber dried or production of machine

w = Basis weight of web (gm/m^2)

u = Machine speed (m/min.)

l = Width of paper produced (m)

d_1 = Sheet dryness before the dryer group (%)

d_2 = Sheet dryness after the dryer group (%)

Þ = Machine efficiency (%)

Q_e = Heat required to heat the the evaporating water to evaporation temperature and to evaporate the water (kW)

c_w = Specific heat of water, (4.2 kj/kg ^oC)

T_e = Temperature of evaporating water (^oC)

T_1 = Temperature of paper sheet before drying group (^oC)

$ë_v$ = Latent heat of evaporation (kj/kg)

Q_f = Heat required to heat the fiber (kW)

c_p = Specific heat of fibers, (1.4 kj/kg °C)

Q_a = Heat required to heat the pocket ventilation air (kW)

m_a = Mass flow rate of pocket ventilation air (kg/sec.)

c_a = Specific heat of air, (1 kj/kg °C)

T_p = Temperature of pocket ventilation air after heating (°C)

T_a = Temperature of fresh air (°C)

F = % of flash steam produced

S_1 = Sensible heat of higher pressure condensate (kj/kg °C)

S_2 = Sensible heat of steam at lower pressure at which it has been Flashed (kj/kg°C)

$ë_2$ = Latent heat of flash steam at lower pressure (kj/kg)

Q_h = Heat loss due to flash steam loss (kW)

m_s = mass flow rate of steam (kg/sec)

Q_r = Heat loss from surface due to radiation (kW)

å = Emmisivity of dryer surface (0.25)

$ë_s$ = Steafan Boltzman constant ($5.67*10^{-8}$ kW/m^2 K^4)

T_s = Temperature of dryer surface (°C)

T_2 = Temperature of surrounding (°C)

Q_c = Heat loss from surface due to convection (kW)

h_i = Heat transfer coefficient for dryer surface (0.0003 kW/m^2 °C)

Q_t = Total surface Heat loss (kW)

A = Area from which surface heat loss takes place (m^2)

A_h = Total heat transfer area available (m^2)

d = Dia. of dryer cylinder (m)

l_d = Width of dryer cylinder (m)

S_e = Specific evaporation rate (kg/hr m^2)

S_s = Specific steam consumption (ton/ton of paper produced)

Appendix-2

Dryer operating parameters- steam in/ out conditions & pocket ventilation conditions for PM-4

Particulars	Dryer surface Temp.	Steam inlet condition		Stream outlet condition		Pocket DBT	Relative humidity	Absolute humidity
		Sat. temp of steam inlet to cylinder	Inlet pr.	temp of outlet stream to cylinder	Outlet Pr.			
	^{0}C	^{0}C	kg/cm^2 g	^{0}C	kg/cm^2 g	^{0}C	%	gm/kg
Dryer # 1	61	120	1	117	0.85	32	62	18.74
Dryer # 2	75	120	1	116	0.8	40	96.2	47.1
Dryer # 3	91	120	1	112	0.6	45.6	95.3	64.2
Dryer # 4	92	120	1	113	0.65	49	90.8	73.6
Dryer # 5	88	120	1	114	0.7	48	94.8	73
Dryer # 6	96	120	1	114	0.7	53.5	90.2	94
Dryer # 7	80	120	1	117	0.85	49.9	94.6	81
Dryer # 8	85	12	1	117	0.85	55.8	92	109.3
Dryer # 9	86	120	1	115	0.75	55.8	93.3	109.8
Dryer # 10	91	120	1	114	0.7	62	78	125.8
Dryer # 11	94	120	1	112	0.6	50.4	94.7	83
Dryer # 12	93	120	1	113	0.65	48.7	94.7	75.9
Dryer # 13	96	120	1	117	0.85	47.2	94.8	69.8
Dryer # 14	96	120	1	112	0.6	60.2	91.7	139.5
Dryer # 15	93	120	1	113	0.65	58.9	93.8	133.3
Dryer # 16	96	120	1	112	0.6	68.2	68	150.5
Dryer # 17	97	120	1	112	0.6	65.8	74	146.5
Dryer # 18	93	120	1	113	0.65	60.4	91.8	139.8
Dryer # 19	93	120	1	113	0.65	64	91.8	173.6
Dryer # 20	96	120	1	112	0.6	66.3	91	196.1
Dryer # 21	93	120	1	113	0.65	61.8	91.8	158
Dryer # 22	94	120	1	113	0.65	55.6	94.6	111.7
Dryer # 23	96	120	1	112	0.6	55	94.5	107.9
Dryer # 24	91	120	1	115	0.75	54.1	94.7	102.8
Dryer # 25	93	120	1	115	0.75	45.6	95.3	64.2
Dryer # 26	90	120	1	114	0.7	43.5	95.6	57.2
Dryer # 27	82	113	0.6	109	0.4	51.7	94.8	90
Dryer # 28	86	113	0.6	109	0.4	51	94.5	86.3
Dryer # 29	85	113	0.6	106	0.3	56.5	65	75.1
Dryer # 30	85	133	0.6	106	0.3	56.1	52	58.3
Dryer # 31	82	113	0.6	106	0.3	64	28	33.3
Dryer # 32	45	48	Atm.	42	Atm.	58.7	22	26.8

Appendix-3

Surface heat losses from the front side surface of the dryer cylinders for paper machine –4 (front side)

Particulars	Area, m^2	Temp. °C	Radiation loss, Kw	Forced convection loss, kw	Total heat loss, kw
Dryer # 1	1.77	61	0.0391451	0.0165	0.0556
Dryer # 2	1.77	75	0.0948804	0.0239	0.1188
Dryer # 3	1.77	91	0.1673649	0.0324	0.1998
Dryer # 4	1.77	92	0.1722251	0.0329	0.205147
Dryer # 5	1.77	88	0.153023	0.0308	0.1838
Dryer # 6	1.77	96	0.192069	0.035	0.2271
Dryer # 7	1.77	80	0.1164883	0.0266	0.143
Dryer # 8	1.77	85	0.1390341	0.0292	0.1682
Dryer # 9	1.77	86	0.1436582	0.0297	0.1734
Dryer # 10	1.77	91	0.1673649	0.0324	0.1998
Dryer # 11	1.77	94	0.1820659	0.034	0.216
Dryer # 12	1.77	93	0.1771253	0.0335	0.2106
Dryer # 13	1.77	96	0.192069	0.035	0.2271
Dryer # 14	1.77	96	0.192069	0.035	0.2271
Dryer # 15	1.77	93	0.1771253	0.0335	0.2106
Dryer # 16	1.77	96	0.192069	0.035	0.2271
Dryer # 17	1.77	97	0.1971319	0.0356	0.2327
Dryer # 18	1.77	93	0.1771253	0.0335	0.2106
Dryer # 19	1.77	93	0.1771253	0.0335	0.2106
Dryer # 20	1.77	96	0.192069	0.035	0.2271
Dryer # 21	1.77	93	0.1771253	0.0335	0.2106
Dryer # 22	1.77	94	0.1820659	0.034	0.216
Dryer # 23	1.77	96	0.192069	0.035	0.2271
Dryer # 24	1.77	91	0.1673649	0.0324	0.1998
Dryer # 25	1.77	93	0.1771253	0.0335	0.2106
Dryer # 26	1.77	90	0.1625447	0.0319	0.1944
Dryer # 27	1.77	82	0.1253926	0.0276	0.153
Dryer # 28	1.77	86	0.1436582	0.0297	0.173394
Dryer # 29	1.77	85	0.1390341	0.0292	0.1682
Dryer # 30	1.77	85	0.1390341	0.0292	0.1682
Dryer # 31	1.77	82	0.1253926	0.0276	0.153
Dryer # 32	1.77	45	-0.016521	0.008	-0.009
Total			4.5685742	0.9845	5.553048

Appendix-4

Surface heat losses from the back side surface of the dryer cylinders for paper machine –4(back side)

Particulars	Area, m^2	Temp. $^{\circ}C$	Radiation loss, Kw	Forced convection loss, kw	Total heat loss, kw
Dryer # 1	1.77	61	0.0391451	0.0165	0.0556
Dryer # 2	1.77	75	0.0948804	0.0239	0.1188
Dryer # 3	1.77	91	0.1673649	0.0324	0.1998
Dryer # 4	1.77	92	0.1722251	0.0329	0.205147
Dryer # 5	1.77	88	0.153023	0.0308	0.1838
Dryer # 6	1.77	96	0.192069	0.035	0.2271
Dryer # 7	1.77	80	0.1164883	0.0266	0.143
Dryer # 8	1.77	85	0.1390341	0.0292	0.1682
Dryer # 9	1.77	86	0.1436582	0.0297	0.1734
Dryer # 10	1.77	91	0.1673649	0.0324	0.1998
Dryer # 11	1.77	94	0.1820659	0.034	0.216
Dryer # 12	1.77	93	0.1771253	0.0335	0.2106
Dryer # 13	1.77	96	0.192069	0.035	0.2271
Dryer # 14	1.77	96	0.192069	0.035	0.2271
Dryer # 15	1.77	93	0.1771253	0.0335	0.2106
Dryer # 16	1.77	96	0.192069	0.035	0.2271
Dryer # 17	1.77	97	0.1971319	0.0356	0.2327
Dryer # 18	1.77	93	0.1771253	0.0335	0.2106
Dryer # 19	1.77	93	0.1771253	0.0335	0.2106
Dryer # 20	1.77	96	0.192069	0.035	0.2271
Dryer # 21	1.77	93	0.1771253	0.0335	0.2106
Dryer # 22	1.77	94	0.1820659	0.034	0.216
Dryer # 23	1.77	96	0.192069	0.035	0.2271
Dryer # 24	1.77	91	0.1673649	0.0324	0.1998
Dryer # 25	1.77	93	0.1771253	0.0335	0.2106
Dryer # 26	1.77	90	0.1625447	0.0319	0.1944
Dryer # 27	1.77	82	0.1253926	0.0276	0.153
Dryer # 28	1.77	86	0.1436582	0.0297	0.173394
Dryer # 29	1.77	85	0.1390341	0.0292	0.1682
Dryer # 30	1.77	85	0.1390341	0.0292	0.1682
Dryer # 31	1.77	82	0.1253926	0.0276	0.153
Dryer # 32	1.77	45	-0.016521	0.008	-0.009
Total			4.5685742	0.9845	5.553048

Appendix-5

Temperature Of Paper Sheet Before Dryer	^0C	34.0	
Average LP Steam Used For The Dryers	t/hr	12.2	
LP Steam Pressure At The Main Inlet Line	kg/cm2	2.5	
LP Steam Saturation Temperature	^0C	141.0	
Enthalpy Of LP Steam	kj/kg	2728.0	
Latent Heat	kj/kg	2156.0	
Total Heat Input	kw	9244.9	100.0
Paper Machine Speed	m/min.	325.0	
Basis Weight Produced	gm/m2	60.0	
Deckle At Pope Reel	m	3.2	
Weight Of Paper Produced	kg/hr	3182.4	
Specific Steam Consumption	tons/ton of paper	3.8	
No. Of Pre Dryers		26	
No. Of Post Dryers		6	
No. Of Felt Dryer		4	
Dia.Of Dryer	m	1.5	
Evaporation Area Of Predryer	m2	391.9	
Evaporation Area Of Post Dryer	m2	90.4	
Evaporation Area Of Felt Dryer	m2	60.3	
Paper Dryness At The Entry Of First Dryer	%	39.0	
Paper Dryness Inlet To Size Press	%	87.0	
Moisture Evaporated By The Dryers Before Size Press	kg/hr	4502.1	
Paper Dryeness After Size Press	%	87.0	
Paper Dryeness At Pope Reel Size Press	%	98.0	
Moisture Evaporated By The Post Dryers	kg/hr	410.6	
Total Moisture Evaporated During Process	kg/hr	4912.7	
Specific Steam Consumption	tons/tons of water evaporated	2.5	
Specific Evaporation Rate Of Predryer	kg/hr.m2	11.5	
Specific Evaporation Rate Of Post Dryer	kg/hr.m2	4.5	
Specific Evaporation Rate	kg/hr.m2	10.2	
Temperature Of Paper Sheet Before Dryer	^0C	34.0	
Average Temperature Of Paper Sheet At Predryer	^0C	92.0	
Latent Heat Required To Evaporate Water	kj/kg	2257.0	
Specific Heat Of Water	kj/ kg.^0C	4.2	
Specific Heat Of Fibers	kj/ kg.^0C	1.4	
Heat Required To Evaporate The Moisture In Pre Dryer	kw	3127.2	
Temperature Of Paper Sheet Before Post Dryer	^0C	80.0	
Temperature Of Paper Sheet At Post Dryer	^0C	88.0	
Heat Required To Evaporate The Moisture In Post Dryer	kw	261.2	
Total Heat Required To Evaporate Water	kw	3388.4	36.7
Heat Required To Heat The Fibers	kw	81.7	0.9
Heat Required To Dry Felt	kw	423.6	4.6
Heat Loss Through Exaust Fan	kw	211.1	2.3
Quantity Of Recovered Condensate	kg/hr	8540.0	
Condensate Temperature	^0C	88.0	
Heat Recovered Through Condensate Recovery	kw	627.7	6.8
Flash Steam Produced	t/hr	0.2	
Heat Loss Through Escaping Flash	kw	142.3	1.5
Heat Loss Through Let Out Condensate	kw	313.8	3.4
Total Surface Heat Loss	kw	11.1	0.1
Other Losses (Blow Through Steam +Condensate Tank + Condensate Return Line)	kw	4045.2	43.8

Appendix-6

Temperature Of Paper Sheet Before Dryer	^0C	34.0	
Average LP Steam Used For The Dryers	t/hr	12.5	
LP Steam Pressure At The Main Inlet Line	kg/cm2	2.5	
LP Steam Saturation Temperature	^0C	141.0	
Enthalpy Of LP Steam	kj/kg	2728.0	
Latent Heat	kj/kg	2156.0	
Total Heat Input	kw	9472.2	100.0
Paper Machine Speed	m/min.	280.0	
Basis Weight Produced	gm/m2	70.0	
Deckle At Pope Reel	m	3.2	
Weight Of Paper Produced	kg/hr	3198.7	
Specific Steam Consumption	tons/ton of paper	3.9	
No. Of Pre Dryers		26	
No. Of Post Dryers		6	
No. Of Felt Dryer		4	
Dia.Of Dryer	m	1.5	
Evaporation Area Of Predryer	m2	391.9	
Evaporation Area Of Post Dryer	m2	90.4	
Evaporation Area Of Felt Dryer	m2	60.3	
Paper Dryness At The Entry Of First Dryer	%	38.0	
Paper Dryness Inlet To Size Press	%	85.0	
Moisture Evaporated By The Dryers Before Size Press	kg/hr	4654.5	
Paper Dryeness After Size Press	%	85.0	
Paper Dryeness At Pope Reel Size Press	%	98.0	
Moisture Evaporated By The Post Dryers	kg/hr	499.2	
Total Moisture Evaporated During Process	kg/hr	5153.7	
Specific Steam Consumption	tons/tons of water evaporated	2.4	
Specific Evaporation Rate Of Predryer	kg/hr.m2	11.9	
Specific Evaporation Rate Of Post Dryer	kg/hr.m2	5.5	
Specific Evaporation Rate	kg/hr.m2	10.7	
Temperature Of Paper Sheet Before Dryer	^0C	34.0	
Average Temperature Of Paper Sheet At Predryer	^0C	90.0	
Latent Heat Required To Evaporate Water	kj/kg	2257.0	
Specific Heat Of Water	kj/ kg.^0C	4.2	
Specific Heat Of Fibers	kj/ kg.^0C	1.4	
Heat Required To Evaporate The Moisture In Pre Dryer	kw	3222.2	
Temperature Of Paper Sheet Before Post Dryer	^0C	78.0	
Temperature Of Paper Sheet At Post Dryer	^0C	89.0	
Heat Required To Evaporate The Moisture In Post Dryer	kw	319.4	
Total Heat Required To Evaporate Water	kw	3541.6	37.4
Heat Required To Heat The Fibers	kw	83.3	0.9
Heat Required To Dry Felt	kw	442.7	4.7
Heat Loss Through Exaust Fan	kw	211.1	2.2
Quantity Of Recovered Condensate	kg/hr	8750.0	
Condensate Temperature	^0C	96.0	
Heat Recovered Through Condensate Recovery	kw	724.8	7.7
Flash Steam Produced	t/hr	0.2	
Heat Loss Through Escaping Flash	kw	145.8	1.5
Heat Loss Through Let Out Condensate	kw	243.3	2.6
Total Surface Heat Loss	kw	12.5	0.1
Other Losses (Blow Through Steam +Condensate Tank + Condensate Return Line)	Kw	4067.1	42.9

Appendix-7

Dryer operating parameters- steam in/ out conditions & pocket ventilation conditions for PM-4 after renovation

Particulars	Dryer surface Temp.	Steam inlet condition		Stream outlet condition		Pocket DBT	Relative humidity	Absolute humidity
		Sat. temp of steam inlet to cylinder	Inlet pr.	temp of outlet stream to cylinder	Outlet Pr.			
	^0C	^0C	kg/cm^2 g	^0C	kg/cm^2 g	^0C	%	gm/kg
Dryer # 1	60	120	1	116	0.8	32	62	19.96
Dryer # 2	77	120	1	116	0.8	38.5	46	19.9
Dryer # 3	80	120	1	114	0.7	44.5	57	34.7
Dryer # 4	95	122	1.2	119	0.95	46.5	53	35.8
Dryer # 5	98	122	1.2	118	0.9	51.7	94.8	90
Dryer # 6	102	122	1.2	120	1	56.8	76	92.5
Dryer # 7	103	122	1.2	120	1	63.7	74	130.6
Dryer # 8	105	122	1.2	116	0.8	55.8	92	109.3
Dryer # 9	104	122	1.2	116	0.8	65	63	115.5
Dryer # 10	94	122	1.2	121	1.1	70	80	73.23
Dryer # 11	104	124	1.25	117	0.85	50.4	94.7	83
Dryer # 12	101	124	1.25	118	0.9	60.1	57	79.5
Dryer # 13	81	124	1.25	122	1.2	47.2	94.8	69.8
Dryer # 14	98	124	1.25	121	1.1	56.7	67	79.8
Dryer # 15	102	124	1.25	105	0.85	62.5	74	121.7
Dryer # 16	102	124	1.25	118	0.9	65.1	56	103.3
Dryer # 17	105	124	1.25	104	0.9	67.8	63.5	135.5
Dryer # 18	101	124	1.25	119	0.95	60.4	91.8	139.8
Dryer # 19	98	124	1.25	109	1	54.5	92.8	101
Dryer # 20	101	124	1.25	118	0.9	71.3	44	104.8
Dryer # 21	102	124	1.25	118	0.9	67.5	43.8	86.2
Dryer # 22	94	124	1.25	121	1.1	53.1	76	75.7
Dryer # 23	95	124	1.25	112	1	54.3	64	66.7
Dryer # 24	102	124	1.25	119	0.95	60.7	73	54.5
Dryer # 25	103	126	1.4	121	1.1	53.4	66	65.7
Dryer # 26	105	126	1.4	121	1.1	35.2	48	17.5
Dryer # 27	112	134	2.1	129	1.7	59.5	85	122.4
Dryer # 28	113	132	2	129	1.7	60.2	91.7	139.5
Dryer # 29	115	134	2.1	128	1.6	67.1	70	147
Dryer # 30	112	132	2	129	1.7	68.2	68	150.5
Dryer # 31	118	134	2.1	130	1.75	63.2	78	135.4
Dryer # 32	120	132	2	128	1.6	70.2	56	131.9
Dryer # 33	112	134	2.1	131	1.8	58.7	22	26.8
Dryer # 34	42	35	atm	39	atm	59.6	20.9	26.3

Appendix-8

Surface heat losses from the front side surface of the dryer cylinders for paper machine –4 (front side) after renovation

Particulars	Area, m^2	Temp. °C	Radiation loss, Kw	Forced convection loss, kw	Total heat loss, kw
Dryer # 1	1.77	60	0.04	0.02	0.05
Dryer # 2	1.77	77	0.10	0.02	0.13
Dryer # 3	1.77	80	0.12	0.03	0.14
Dryer # 4	1.77	95	0.19	0.03	0.22
Dryer # 5	1.77	98	0.20	0.04	0.24
Dryer # 6	1.77	102	0.22	0.04	0.26
Dryer # 7	1.77	103	0.23	0.04	0.27
Dryer # 8	1.77	105	0.24	0.04	0.28
Dryer # 9	1.77	104	0.23	0.04	0.27
Dryer # 10	1.77	94	0.18	0.03	0.22
Dryer # 11	1.77	104	0.23	0.04	0.27
Dryer # 12	1.77	101	0.22	0.04	0.26
Dryer # 13	1.77	81	0.12	0.03	0.15
Dryer # 14	1.77	98	0.20	0.04	0.24
Dryer # 15	1.77	102	0.22	0.04	0.26
Dryer # 16	1.77	102	0.22	0.04	0.26
Dryer # 17	1.77	105	0.24	0.04	0.28
Dryer # 18	1.77	101	0.22	0.04	0.26
Dryer # 19	1.77	98	0.20	0.04	0.24
Dryer # 20	1.77	101	0.22	0.04	0.26
Dryer # 21	1.77	102	0.22	0.04	0.26
Dryer # 22	1.77	94	0.18	0.03	0.22
Dryer # 23	1.77	95	0.19	0.03	0.22
Dryer # 24	1.77	102	0.22	0.04	0.26
Dryer # 25	1.77	103	0.23	0.04	0.27
Dryer # 26	1.77	105	0.24	0.04	0.28
Dryer # 27	1.77	112	0.28	0.04	0.32
Dryer # 28	1.77	113	0.28	0.04	0.33
Dryer # 29	1.77	115	0.30	0.05	0.34
Dryer # 30	1.77	112	0.28	0.04	0.32
Dryer # 31	1.77	118	0.31	0.05	0.36
Dryer # 32	1.77	120	0.33	0.05	0.37
Dryer # 33	1.77	112	0.28	0.04	0.32
Dryer # 34	1.77	42	-0.03	0.01	-0.02
Total			7.16	1.24	8.40

Appendix-9

Surface heat losses from the back side surface of the dryer cylinders for paper machine –4 (front side) after renovation

Particulars	Area, m^2	Temp. ° C	Radiation loss, Kw	Forced convection loss, kw	Total heat loss, kw
Dryer # 1	1.77	60	0.04	0.02	0.05
Dryer # 2	1.77	77	0.10	0.02	0.13
Dryer # 3	1.77	80	0.12	0.03	0.14
Dryer # 4	1.77	95	0.19	0.03	0.22
Dryer # 5	1.77	98	0.20	0.04	0.24
Dryer # 6	1.77	102	0.22	0.04	0.26
Dryer # 7	1.77	103	0.23	0.04	0.27
Dryer # 8	1.77	105	0.24	0.04	0.28
Dryer # 9	1.77	104	0.23	0.04	0.27
Dryer # 10	1.77	94	0.18	0.03	0.22
Dryer # 11	1.77	104	0.23	0.04	0.27
Dryer # 12	1.77	101	0.22	0.04	0.26
Dryer # 13	1.77	81	0.12	0.03	0.15
Dryer # 14	1.77	98	0.20	0.04	0.24
Dryer # 15	1.77	102	0.22	0.04	0.26
Dryer # 16	1.77	102	0.22	0.04	0.26
Dryer # 17	1.77	105	0.24	0.04	0.28
Dryer # 18	1.77	101	0.22	0.04	0.26
Dryer # 19	1.77	98	0.20	0.04	0.24
Dryer # 20	1.77	101	0.22	0.04	0.26
Dryer # 21	1.77	102	0.22	0.04	0.26
Dryer # 22	1.77	94	0.18	0.03	0.22
Dryer # 23	1.77	95	0.19	0.03	0.22
Dryer # 24	1.77	102	0.22	0.04	0.26
Dryer # 25	1.77	103	0.23	0.04	0.27
Dryer # 26	1.77	105	0.24	0.04	0.28
Dryer # 27	1.77	112	0.28	0.04	0.32
Dryer # 28	1.77	113	0.28	0.04	0.33
Dryer # 29	1.77	115	0.30	0.05	0.34
Dryer # 30	1.77	112	0.28	0.04	0.32
Dryer # 31	1.77	118	0.31	0.05	0.36
Dryer # 32	1.77	120	0.33	0.05	0.37
Dryer # 33	1.77	112	0.28	0.04	0.32
Dryer # 34	1.77	42	-0.03	0.01	-0.02
Total			7.16	1.24	8.40

Appendix -10

Temperature Of Paper Sheet Before Dryer	°C	34.0	
Average LP Steam Used For The Dryers	t/hr	12.1	
LP Steam Pressure At The Main Inlet Line	kg/cm2	2.5	
LP Steam Saturation Temperature	°C	141.0	
Enthalpy Of LP Steam	kj/kg	2728.0	
Latent Heat	kj/kg	2156.0	
Total Heat Input	kw	9169.1	100.0
Paper Machine Speed	m/min.	315.0	
Basis Weight Produced	gm/m2	60.0	
Deckle At Pope Reel	m	3.2	
Weight Of Paper Produced	kg/hr	3084.5	
Specific Steam Consumption	tons/ton of paper	3.9	
No. Of Pre Dryer Groups		4	
No Of Dryers In 1st Group		3	
No. Of Dryers In 2nd Group		7	
No. Of Dryers In 3rd Group		14	
No. Of Dryers In 4th Group		2	
No Of Post Dryer Groups		2	
No Of Dryers In 5th Group		4	
No. Of Dryers In 6th Group		4	
Dia.Of Dryer	m	1.5	
Evaporation Area Of Predryer	m2	391.9	
Evaporation Area Of Post Dryer	m2	120.6	
Paper Dryness At The Entry Of First Dryer	%	39.0	
Paper Dryness Inlet To Size Press	%	90.0	
Moisture Evaporated By The Dryers Before Size Press	kg/hr	4481.7	
Paper Dryeness After Size Press	%	57.0	
Paper Dryeness At Pope Reel Size Press	%	94.0	
Moisture Evaporated By The Post Dryers	kg/hr	2130.0	
Total Moisture Evaporated During Process	kg/hr	6611.7	
Specific Steam Consumption	tons/ton of water evaporated	1.8	
Specific Evaporation Rate Of Predryer	kg/hr.m2	11.4	
Specific Evaporation Rate Of Post Dryer	kg/hr.m2	17.7	
Specific Evaporation Rate	kg/hr.m2	12.9	
Temperature Of Paper Sheet Before Dryer	°C	34.0	
Average Temperature Of Paper Sheet At Predryer	°C	88.0	
Latent Heat Required To Evaporate Water	kj/kg	2257.0	
Specific Heat Of Water	kj/kg.°C	4.2	
Specific Heat Of Fibers	kj/kg.°C	1.4	
Heat Required To Evaporate The Moisture In Pre Dryer	Kw	3092.1	
Temperature Of Paper Sheet Before Post Dryer	°C	85.0	
Temperature Of Paper Sheet At Post Dryer	°C	93.0	
Heat Required To Evaporate The Moisture In Post Dryer	Kw	1355.3	
Total Heat Required To Evaporate Water	Kw	4447.4	48.5
Heat Required To Heat The Fibers	Kw	74.4	0.8
Heat Required To Heat Pocket Ventilation Air	Kw	944.4	10.3
Quantity Of Recovered Condensate	kg/hr	10285.0	
Condensate Temperature	°C	96.0	
Heat Recovered Through Condensate Recovery	Kw	851.9	9.3
Flash Steam Produced	t/hr	0.2	
Heat Loss Through Escaping Flash	Kw	141.2	1.5
Heat Loss Through Let Out Condensate	Kw	150.3	1.6
Total Surface Heat Loss	Kw	16.8	0.2
Other Losses (Blow Through Steam +Condensate Tank + Condensate Return Line)	Kw	2542.6	27.7

Appendix-11

Temperature Of Paper Sheet Before Dryer	°C	34.0	
Average LP Steam Used For The Dryers	t/hr	12.9	
LP Steam Pressure At The Main Inlet Line	kg/cm2	2.5	
LP Steam Saturation Temperature	°C	141.0	
Enthalpy Of LP Steam	kj/kg	2728.0	
Latent Heat	kj/kg	2156.0	
Total Heat Input	Kw	9775.3	100.0
Paper Machine Speed	m/min.	275.0	
Basis Weight Produced	gm/m2	70.0	
Deckle At Pope Reel	M	3.2	
Weight Of Paper Produced	kg/hr	3141.6	
Specific Steam Consumption	tons/ton of paper	4.1	
No. Of Pre Dryer Groups		4	
No Of Dryers In 1st Group		3	
No. Of Dryers In 2nd Group		7	
No. Of Dryers In 3rd Group		14	
No. Of Dryers In 4th Group		2	
No Of Post Dryer Groups		2	
No Of Dryers In 5th Group		4	
No. Of Dryers In 6th Group		4	
Dia.Of Dryer	M	1.5	
Evaporation Area Of Predryer	m2	391.9	
Evaporation Area Of Post Dryer	m2	120.6	
Paper Dryness At The Entry Of First Dryer	%	38.0	
Paper Dryness Inlet To Size Press	%	91.0	
Moisture Evaporated By The Dryers Before Size Press	kg/hr	4815.1	
Paper Dryeness After Size Press	%	55.0	
Paper Dryeness At Pope Reel Size Press	%	94.0	
Moisture Evaporated By The Post Dryers	kg/hr	2369.9	
Total Moisture Evaporated During Process	kg/hr	7184.9	
Specific Steam Consumption	tons/ton of water evaporated	1.8	
Specific Evaporation Rate Of Predryer	kg/hr.m2	12.3	
Specific Evaporation Rate Of Post Dryer	kg/hr.m2	19.7	
Specific Evaporation Rate	kg/hr.m2	14.0	
Temperature Of Paper Sheet Before Dryer	°C	34.0	
Average Temperature Of Paper Sheet At Predryer	°C	88.0	
Latent Heat Required To Evaporate Water	kj/kg	2257.0	
Specific Heat Of Water	kj/kg.°C	4.2	
Specific Heat Of Fibers	kj/kg.°C	1.4	
Heat Required To Evaporate The Moisture In Pre Dryer	Kw	3322.1	
Temperature Of Paper Sheet Before Post Dryer	°C	85.0	
Temperature Of Paper Sheet At Post Dryer	°C	93.0	
Heat Required To Evaporate The Moisture In Post Dryer	Kw	1507.9	
Total Heat Required To Evaporate Water	Kw	4830.0	49.4
Heat Required To Heat The Fibers	Kw	75.7	0.8
Heat Required To Heat Pocket Ventilation Air	Kw	1062.5	10.9
Quantity Of Recovered Condensate	kg/hr	10965.0	
Condensate Temperature	°C	96.0	
Heat Recovered Through Condensate Recovery	Kw	908.3	9.3
Flash Steam Produced	t/hr	0.2	
Heat Loss Through Escaping Flash	Kw	150.5	1.5
Heat Loss Through Let Out Condensate	Kw	160.3	1.6
Total Surface Heat Loss	Kw	16.8	0.2
Other Losses (Infiltration Air + Blow Through Steam +Condensate Tank + Condensate Return Line)	Kw	2571.2	26.3

Appendix-12

Typical drying capacity factor table of data, providing equivalent steam pressures.

Equiv Psig=	DCF	Equiv Psig=	DCF	Equiv Psig=	DCF	Equiv Psig=	DCF	Equiv Psig=	DCF	Equiv Psig=	DCF	Equiv Psig=	DCF
-14	1.115	11	12.336	36	15.531	61	17.627	86	19.226	111	20.537	136	21.655
-13	3.059	12	12.504	37	15.629	62	17.699	87	19.284	112	20.585	137	21.696
-12	4.288	13	12.668	38	15.726	63	17.770	88	19.340	113	20.632	138	21.738
-11	5.206	14	12.827	39	15.822	64	17.839	89	19.396	114	20.680	139	21.779
-10	5.946	15	12.981	40	15.915	65	17.909	90	19.452	115	20.727	140	21.819
-9	6.571	16	13.132	41	16.008	66	17.977	91	19.507	116	20.773	141	21.861
-8	27.113	17	13.278	42	16.099	67	18.046	92	19.562	117	20.819	142	21.901
-7	7.593	18	13.421	43	16.189	68	18.113	93	19.617	118	20.866	143	21.942
-6	8.026	19	13.560	44	16.278	69	18.179	94	19.671	119	20.912	144	21.981
-5	8.420	20	13.696	45	16.366	70	18.246	95	19.725	120	20.958	145	22.021
-4	8.782	21	13.829	46	16.452	71	18.311	96	19.778	121	21.003	146	22.061
-3	9.118	22	13.959	47	16.537	72	18.376	97	19.832	122	21.049	147	22.101
-2	9.431	23	14.086	48	16.620	73	18.440	98	19.884	123	21.093	148	22.140
-1	9.725	24	14.210	49	16.703	74	18.504	99	19.936	124	21.138	149	22.180
0	10.002	25	14.332	50	16.786	75	18.567	100	19.988	125	21.182	150	22.219
1	10.265	26	14.451	51	16.867	76	18.630	101	20.040	126	21.226	151	22.257
2	10.514	27	14.569	52	16.947	77	18.691	102	20.091	127	21.270	152	22.296
3	10.751	28	14.683	53	17.026	78	18.753	103	20.141	128	21.314	153	22.334
4	10.977	29	14.796	54	17.104	79	18.813	104	20.192	129	21.357	154	22.373
5	11.195	30	14.907	55	17.181	80	18.874	105	20.242	130	21.401	155	22.411
6	11.403	31	15.015	56	17.258	81	18.934	106	20.292	131	21.443	156	22.448
7	11.603	32	15.121	57	17.334	82	18.993	107	20.342	132	21.486	157	22.486
8	11.796	33	15.227	58	17.408	83	19.052	108	20.391	133	21.529	158	22.524
9	11.982	34	15.330	59	17.481	84	19.110	109	20.439	134	21.571	159	22.561
10	12.162	35	15.431	60	17.555	85	19.169	110	20.488	135	21.613	160	22.599