Evaluating Energy And Economics Of Paper Machine Clothing

RAY A.K.

ABSTRACT

In this present investigation a brief outline description of all the three types of fabrics employed for formation , pressing and drying of paper is given. Further the available models developed for operations related to paper machine clothing are reviewed for industrial practice with special reference to evaluation of energy consumption,improved performance and economics related to press and dryer fabrics. Some case studies for press and dryer clothings are especially discussed through already developed model based on C++ programming parameter studies and economic evaluation.

Introduction

Average relative cost per ton of paper to dewater the sheet can be of the following order(1).

- **Forming Section 10% 1.0**
- **Press Section 12 % 1.2**
- **Dryer Section 78% 7.8**

In terms of energy consumption it has been estimated that the distribution of energy consumption of paper machine is in the order : forming: pressing: drying =15:20:65(2).

It has also been reported that high dryness after the press is very advantageous because steam consumption for drying of paper is reduced. Removal of water in dryer section by evaporation is 7-10 times costlier than on presses and 60-70 times costlier than the wire part. It depends to a great deal on power and steam cost and felt conditioning.

In forming section itself, the distribution of energy is in accordance with the following in percentages(2) :Hydraulic 1, pressurized air 1,drives 47,vacuum,35,broke collection,6, shower water ,11 and ventilation,4.

It is wellknown(1,3-7) that increased hydrostatic, and mechanical loadings either on wires in forming section or in press section improves water removal. Hydrostatic load and vacuum are employed in forming section whereas vacuum and external mechanical loadings are used in press section. Dryer section uses thermal energy in form of steam. However electrical power is required compulsorily in drives of the machine /felt/ screen or both. It can be shown by simple calculation that 1% change in sheet dryness in press section with 40% B.D.will give 4.2 % reduction in evaporative drying.All the above will depend on the syngergistic efforts of paper machine , machine clothing and fiber stock characteristics. It is evident therefore, paper machine clothing is an integral part of paper machine. It is classed based on its application in the operation such as

- Forming Fabrics (Fourdrinier wire,Twin Wire, Hybrid wire, or multi cylinder machines etc.)
- Press Fabrics(Wet Felts)
- Dryer Fabrics(Felts / Screens)

Felt/ Screen are designed fabrics used synergistically with machine(pressing or drying) in order to do the variety of functions. The properties of the Forming Fabrics, Press Felts and Dryer Felts or Dryer Screens must be characteristically different because of their specific functions in each section and therefore these fabrics must be compositionally and structurally (chemically, mechanically or metallurgical point of view)different. Even for different sections of Press part ; pick-up press, transfer press and the presses in position there are requirements of change in some properties e.g basis weight, porosity ,flow rate etc.

The dryer fabrics have significant influence on drying efficiency. This is shown in the following table.

Effect of drying variables on drying efficiency(1):

Variables	Assume the dryer geometry is fixed and the steam pressure is constant	% influence
Condensate Removal		30
Furnish , Grade and Sheet Properties		25
Dryer Fabric Design,Permeability and Tension		20
Pocket Ventilation		15
Hood and Dryer Air System		5
Others		5

Formation Fabrics

Important properties required are: Dewatering,Retention, Stability-elasticity under tension(12-15 kN/m) in gap formers),stiffness, diagonal stability, good tension profile(P=T/R), wear Resistance(6,8,9,10,11)

Material of Construction

The following materials are used to manufacture synthetic wires in mono or multifilament threads.

Polyethylene,Trevira,terelene,Polyethylene terephthalate(PET), Elana / polyamide fibers, kapron, Nylon, Parlon, Dacron, Orlon, Acrilan, Dynol, Nylon 6,6 etc.

Details of mechanical properties are given (9). Comparison of other

IIT-Roorkee,Saharanpur Campus,
Department of Paper Technology
Saharanpur-247 001

properties are also qualitatively dealt with(9). Generally MD or Warp yarns are made from Poly ester(PET) because of its good tensile strength, and low elongation under load but CD must be prepared from combination of polyester and polyamide(PA)/ other polymers. PA improves wear resistance but absorp water and possesses high elongation under load. Wear resistance can be improved by adding other polymers or additives into polyester polymer before extrusion of filament.

Classification:SL,DL-LWD,-HWD,-EWD,TL,2.5 L,TW,SSB

Some of the specifications are shown below:
Formation Fabric Specifications(6):

Type/Specification	DL 2873	TL 3565	ML 5168
Yarn Density,yarns/cm	72.6 x 51.6	31.9 x 26.8	67.2 x 79.2
Yarn code	15, 16, 19, 19 MD CD CD CD	16 18 16 13 22 22 MD MD CD B CD CD	15 17 15 19 25 25 MD CD CD CD CD CD
Air Permeability,$m^3/m^2/h$	5700	5700	6100
Air permeability,CFM	360	360	390
Thickness,mm	0.62	0.76	0.96
Void Volume,%	49.4	51.5	57.5
Max. Water Content,gsm	260	348	503

Press Fabrics

Composition: Polyamide(Nylon)

High permeability, even under the pressure prevailing in the press nip;physical and good dimensional stability even with exposure of different chemicals

Felt Parameters (1,3-6,11-12)

Basis weight=1000-1800 gsm;thickness:20-100 µm;base textile:200-400 µm;Batt/ Base ratio(mass of batt/ mass of base). Other parameters are :
Felt construction; suction pipe cover;felt water content(moisture ratio);driving force/ vacuum level(mm Hg.);felt basis weight; felt permeability

During designing and manufacturing of felts the following requirements must be kept in mind.
Stiffness and tensile strength ;good runnability; high resistance to wear; good pick-up property; high adhesion between web and felt;texture possessing little clogging tendency;withstand the high pressure showering; good durability; required compression and springback properties; resiliency, compaction pressure resistance; tension tolerance; resistance to puncture , tear and edge cracks; and uniformity of pressure distribution

Modeling Of Some Parameters For Wires And Press Fabrics (Refpaulalapuro)

Permeability refers to the ease with which water (or air) can flow through a material ; it is an expression of the openness of the material to flow.Scanpro FeltPerm is currently being used to measure water permeability during the machine run.

The permeability constant ,K is related to specific cake resistance which can be written in terms of wellknown Kozeny Carmann or Blake Kozeny constant.
Specific cake resistance
$,\alpha=k(1-\varepsilon)S_0^2/\varepsilon^3\rho_s=1/K((1-\varepsilon)\rho_s$
It can also be written as

$K={}^3/k_1S_0^2(1-_t)^2$

Permeability is related to the filtration equation as

$dV/dt=AK\Delta P/\mu$

$L=A[\varepsilon^3/\{k(1-\varepsilon)^2 S_0^2\}(\Delta P/\mu L)$

$v_0=(P_0-P_L)(D_P^2/150\mu)(\varepsilon^3/(1-\varepsilon)^2)$

For cellulose fibres Kozeni's constant is 5.55
For higher porosity (> 0.80), the equation can be modeled according to Davies(13) as

$K=[k_1S_0^2(1-_t)^{3/2}\{1+k_2(1-_t)^3\}]^{-1}$

For cellulosic fibres, the values of the constants are found of the order of 3.5 and 57 respectively as reported by Ingmanson(14).

The equation can be related to basis weight weight of the fibrous mat.
The specific resistance of wires or felts can be used for comparison purposes, The permeability constant of 6 different felts are compared in the following table.

Permeability coefficients of felts (6)

Felt ype	Compressing Pressure, MPa 2.5	 5.0	 10
	Permeability Coefficient,10^{-2} m^2		
F.1(Commercial)	6.9	4.9	2.7
F.2(com.)Old,60day	4.1	2.8	1.8
Felt3*	1.6	0.9	0.4
Felt4**	4.5	2.8	1.4
Felt 5+	18.8	15.5	7.2
Felt 6++	19.4	10.0	3.5

* Batts are made with extraordinary thin fibres; Base is very light and batt is exceptionally heavy

** Batts are made with extraordinary thin fibres, placed on a coarse mesh

\+ Fibres in the batt were very thick.and the felt was the roughest one as it was made from of thick fibes needled to a coarse mesh.

++ Fibres in the batt were very thick and made by using fine mesh a special batt formation technique to develop macroscale nonuniformities.

Compression parameters are important for taking decision when felt could be changed.. The following table depicts some value.

Compression Parameters of new and used felt (6)

A typical set of values put forward by huyck is shown below(11 huyck). More specific data are also available(6).

Properties	New Felt	Old Felt
Nip width,mm	43.0	36.6
Max. pressure,MPa	7.00	9.41
Caliper in mid-nip,mm	1.91	1.60
Moisture Ratio	0.41	0.20

A felt has adequate void volume to absorb water expressed from the sheet in the press nip.

Void Volume(E) is defined as a material's internal void volume divided by its total volume. Void volume needed in a press felt differs from grooved suction or blind drilled roll to plain roll shoe press, increases with the above order(6).

For a felt made of one material , void fraction can be expressed(3)as:

ε== 1-$(m_f/\rho_f)/(m_{fab}/\rho_{fab})$

If the mass of air is neglected, then

$\varepsilon \approx$ 1- (fabric density)/ (fiber density)= $1-\rho_{fab}/\rho_f$

Where m_f ,m_{fab}, ρ_f ,ρ_{fab} represent mass and density of fibres and fabrics respectively(11)

% Felt Void Volume, ε=100-(0.1 x Felt gsm)/t x SG

Where t, is the felt caliper,mm and S.G. , the specific gravity

The specific gravity of Nylon is 1.14 and that of polyester=1.30

$\varepsilon_1/\varepsilon_2 = (t_2 \times SG_2)[100 \times t_1 \times SG_1 - 0.1 \times gsm_1]/[100 \times t_2 \times SG_2 - 0.1 \times gsm_2](t_1 \times SG_1)$

$SG_{av}=100/[(x/SG_A)+(1-x)/SG_B]$

Where SG_A and SG_B represent the specific gravities of the two components of the felt.,x_1 and x_2 are the mass fracrion

Felt Applications - Cleaning And Conditioning

Effective Uhle box dewatering operation depends on the following important factors:

Driving force/ Vacuum Level(mm Hg.)

Air flow(m^3/min)

Dwell time(milliseconds)

MPM	Min. Air Flow,$m^3/min/m^2$	Min. Vacuum,mm
< 450	270	250
450-900	350-440	300
>900	440-660	380

Simple models for Fabric Cleaning and Conditioning:

Details of fabric cleaning and conditioning are detailed elsewhere(8,11).

Oscillator speed V_B (mm/min) must be matched to fabric speed and can be calculated as follows:

$V_B = V_S \times e_b/2 \times S_L = V_S \times p/S_L$

Where V_S= Fabric speed ,MPM

S_L=Fabric length,M

e_b=Width of cleaned strip, mm (approximately 1.9 x nozzle diameter)

p=nozzle pitch

Specifications	Typical Values
Nozzle diameter,mm	0.7-1.2
Distance between nozzles,mm	50-100
Water pressure in shower type,bar	20-30
Distance from Fabric,mm	150-300
Oscillating Width,mm	150-300

The cleaning time, $t_R = S_L \times k/V_s\, e_b$,min

k=Nozzle Spacing,mm=100 mm

g=nozzle distance to fabric(90-100 mm)

α =Approximately 6 bar fan angle

be=2g x Tan(α/2)=2g x Tan(60°/2)

Nozzle quantity=z=b/b_e

Nozzle Spacing k=b/z

Shower volume =110% of fabric volume(fabric caliper/speed/free volume)

Oscillating Rate:2 R=S x 1.9/L x 10

R= Oscillating Rate,cm/min,

S=Speed ,m/min(say 900 mpm)

L=Loop Size,m(25.4 m)

t= Nozzle aperature diameter/ jet imprint dia(1.9 mm@ 150 mm)

R=3.4 cm/min

Felt CFM also depends on the type of paper to be manufacture as shown in the following table.

Type of paper	CFM
Tissue	10-25
Fine Paper	25-80
Newsprint	25-80
Liner/ Corrugating	60-120
Cylinder	70-150

Felt CFM ranges(12)

Alternatively Traversing speed,inches/minute=FPM x 0.04/F.T

FPM =Machine speed ,ft/minute(say 2000 FPM)

F.T.=Fabric speed ,(65 ft.)

0.40= water jet width(inches)

Oscillation speed=2000/65x 0.40=1.23 inch/min.

Running void volume: C x W x S x V

Where C = caliper of fabric,mm

W= fabric width,m;S ,the speed of felt ,m/min ;V,the Void volume

It is very important to use a correct oscillating speed in relation to fabric speed and nozzle diameter(6)

Flooding shower/ Lubricating shower(1,3-6, 8)

Water flow rate=GPM=S x W x C x %RVV x 7.48/144

Where S= machine speed,FPM

W=Machine width,in

C=caliper of clothing,% RVV running void volume

Power Calculations of power due to various components including vacuum pump

Vacuum Pump Drives(1,15,15,)

Power required by vacuum pump of various types(liquid ring) needs data of volumetric capacity,SCFM (standard cubic flow per minute)at 15.55 °C and at 1 atm pressure and acfm(actual volume in cubic feet per minute) at the location.This can be easily calculated by using Boyle's law and Charle's law. The pressure must consider the losses due to skin friction, enlargement, contraction, and fittings.

$P_1V_1/T_1=P_2V_2/T_2$ or using PV=WRT

This calculation can be used for felt suction tube at the press felt,couch roll, This volumetric flow is then used to calculate power.

The theoretical work W_{ad},J/kg for a vacuum pump can be calculated using thermodynamic formula (adiabatic /isoentropic compression) as follows:

$W_{ad}=\{m/(m-1)\}P_1V_1\ [(\ P_2/P_1)(^{m-1)/m}\ 1) ==\{m/(m-1)\}RT_1\ [(\ P_2/P_1)(^{m-1)/m}\ 1) =H_2-H_1$

$T_2/T_1=(\ P_2/P_1)\ (^{m-1)/m}$

$P= G\ W_{ad}/3600*\ 1000$

Where G, the mass of a gas ,kg ; , the overall efficiency,m is the polytropic coefficient which needs to be estimated. The equation can be modified on volume basis also.

How to select the vacuum dewatering profiles?

Two empirical models relating the parameters , namely solid content , vacuum level , residence time are available. These are due to Caufield based on viscoelastic properties and the other due to Neun (10,15,) ; the later being transcendental in nature..

Estimating Driving Power For Forming Fabrics (1,12,16-17)

Model For Power Transmitted Due To Wrap

The power transmitting ability of Fourdrinier rolls can be estimated as follows:

The ratio of tensions on each side of belt (fabric) driven by a roll is given by

$T_t/T_s = e^{\mu\alpha}$

where T_t and T_s are the tight and slack side of felt tensions μ , the coefficient of friction between roll and wire(usually taken as 0.25 for metal to metal),α, the angle of wrap.

The coefficient of friction (μ) between a rubber covered roll and a monofilament fabric is largely determined by the hardness (P & J value) of the rubber covering on the roll. The following equation has been proposed

$\mu = (0.004)\ x\ (P\ \&\ J)^{1.22} + .022$

Considering wrap only, the basic relationship for maximum tension difference across a roll without slippages is given the following equation.

$\Delta T = T_t - T_s = T_s\ (e^{\mu\alpha} - 1)$

The corresponding power can be estimated from the following equation

$HP = Ts\ (e^{\mu\alpha} -1)W_1\ S/33000= Km\ T_s\ (e^{\mu\alpha}-1)\ /330$

where W_1=machine width

If a nip roll is used e.g. lumpbreaker, the nip also adds to the drive ability. With the corresponding power

$HP = PnK_M/\ 330$

The maximum amount of additional tension a suction roll can transmit without slippage is dependent upon the minimum operating vacuum and the machine dimensions

$T_v == (0.4912\ \mu\ v\ W_2$

Where v is the amount of vacuum,W_2, the size of vacuum box, and μ ,is the coefficient of friction between the roll and fabric. . The power is then calculated as

$HP = 0.4912\mu\ v\ W_1\ W_2\ \ (0.4912\mu\ v\ w\ K_M)/330$

The maximum hp the various rolls can supply may be estimated as

$HP_{max} = (T_t - T_s)(W_1)S/33000$

Tension-Power Input Relation ship(5)

$P_{net}=(T_{max}-T_{min})v$

T_{max}= Tension before couch,

T_{min}=Tension in return part

v=velocity,m/s

Pnet=kW/m width(30-110kW/m)

Average tension , $T_{av.}$: $(0.75\ T_{min})+(0.25\ T_{max})$

Models for Power consumption in suction box due to Derrick (17-18)

Typically over a half of the power needed to drive a foudrinier is caused by flat box drag. This drag also has large implicatios for fabric life. The vacuum and air flow used by flat boxes require substantial energy and large, and costly equipment. For just flat boxes,the follwing equation can be used :

NRL = 0.0015ì (box width) (vacuum level)

NRL is horsepower/inchwidth/100 fpm. ì is the box cover, box width is the machine direction width of the box in inches, and the vacuum is inches of Hg. The cover on this machine was all made of alumium oxide. Coefficient of friction for this material is 0.12.

The relationship between fabric life and running horsepower (NRL) may be expressed by the following proposed equation where NRL is in hp/inch/ 100 fpm.

Fabric life (days) = $0.465\ (NRL)^{-2.55}$

Press and Dryer section power requirement

Power Drives for Press and dryer section are based on NRL (normal running load)or RDC(recommended drive capacity) estimation. Each element of these sections has different value of NRL power constant and machine drive constant . When all the NRL constants are added followed by multiplying machine drive constant,k_m=, one can estimate the total NRL HP. A multiplying factor of 1.15-1,35 gives the RDC or RDC HP values. These are well documented in various texts(1,3,5,7) and publications(16-18).

As an example, the application of multinip and multiple felt presses requires the development of component value system based on an actual nip load in the form of:

$HP = Km\ (K_1\ P_n + a)$

and friction leads losses for each roll which are not proportional to nip load, but are dependent upon roll type. The load associated with each felt or fabric in the form:

$HP = K_M\ (K_2P_n + K_3$ (No. of rolls)

Felt Load=[(0.000003)(pli+(0.0007)(No. of felt rolls)]

Adjustable Crown=[(0.000004)(plix ft/min)$^{0.5}$+(0.0060)]

Similar calculations can be made for various elements of presses and dryers.

\Power Drive requirements of the Suction Box due to Neun (15)

$F=0.020U^{0.517}N^{0.622}\,l^{0.325}P^{0.239}m_{pl}{}^{0.139}T^{-0.054}$

$HP=(6.06\ *10^{-7})U^{1.517}N^{0.622}\ l^{0.325}P^{0.239}m_{pl}{}^{0.139}T^{-0.054}$

HP_T=HP * x

Where F =the reaction force, lb_f /in. width,

U, felt speed,ft/min,N=number of slots in suctionbox,

L=MD dimension of slots,in
P=,box vacuum,in hg
M_{P1}= water content of felt before the suction box, kg water/kg of felt
T, single layer felt tension,pli
HP=hp /in.width
HP_T= hp,x=suction box slot CD dimension

Neun(15) also reported experimental data of lube shower flow volume as function of felt speed.

Felt Speed,ft/min	Lube Shower volume,gal/min-in.-width
1000	0.03
2250	0.04
3500	0.05

Press Felt Conditioning:

The conditions for felt cleaning are discussed in great depth(1,3-6,8)
Air flow required for felt dewatering can also be calculated using the DeCrosta equation(1,15-21) based on the variables affecting felt dewaterimg(TIS 0404-27) is reproduced below:
Using a series of equations it is possible to relate specific air flow through the felt at the suction pipe to the resultant felt moisture content. The equation can be used to estimate air flows in felt dewatering. Air flow through a slot on a suction box can also be expressed as,

Air Flow requirement for conditioning of press felts at suction pipes:

Multivariable multiplicative nonlinear regression models:

For specific airflow at the suction box cover

$V^/ = a_o(\Delta P_{sp})^{a1}\ (td)^{a2}\ (V^*)^{a4}/(M_{p,1})^{a}$
$\ln V^/ = a_o + a_1 \ln(\Delta P_{sp}) + a_2(td) + a_4 \ln V^* - a_3 \ln(M_{p,1})$

$V^/ = 0.069(\Delta P_{sp})^{0.476}(td)^{0.110}(V^*)^{0.916}/(M_{p,1})^{0.628}$

For resultant felt moisture content

$\ln m_{p2} = b_0 + b_1 \ln(V^/) + b_2 \ln(\Delta P_{sp}) + b_3 \ln(t_d) + a_4 \ln(m_{p1})$

$M_{p,2} = 1.23(M_{p,1})^{0.819}/(V^/)^{0.024}(\Delta P_{sp})^{0.124}(td)^{0.096}$

Vacuum Pump Capacity:

$^{V}{}_{totalnew}\ V_{vp} = V^/ x\ a_{sp}\ x\ 30/(30 - \Delta P_{sp} + 1)$

Where a_{sp} represents open area , in square inch.
The dwell time of the particle of the fabric as it passes over suction box slot(milli second)
$(td) = n.W_B*60*1000/12*S$

For the drainage rate of the suction box one can use the following equation

$R = (m_{p1} - m_{p2})\ x\ S\ x\ B/198$

Where B is the basis weight of felt or fabric

Shower Water addition Rate(1):

The shower water addition rate can be calculated as
$G = (W_p\ /16)\ U_p\ x_{sp}\ (\Delta m_p/8.35)$

Felt type	Specifications
Triathlon	Caliper: New felt ,mm=2.50;Used felt,mm=1.96;Remaining felt caliper=78.4% Loss of caliper,%=21.6%;Loss of caliper per day=4.3548387 *10^{-3}=1.58 mm/year
Basis weight	New felt,gsm=1135.0;Used felt,gsm=920.52;Remaining weight,%=81.1;Loss of weight %=18.9 Loss of subs.,gsm=214.48 Loss of subs. gsm/day=1.7296774
Compression,%	2.7
Blinding Analysis	Wear %=18.0;Wear,gsm=214.48
Air Permeability	New Felt,l/dm^2,min.=170.0;Used felt,l/dm^2,min.=207.44;Remaining air permeability% =122;Loss of air permeability,l/dm^2,min.=+22.0; Loss of air permability,l/dm^2.min.=+37.44;Loss of air permeability,l/dm^2.min.per day=0.302
Void Volume,ml/m^2	New Felt,ml/m^2=1504;Used felt ml/m^2=1153;Loss of open void volume,ml/m^2=351;Loss of open void volume ml/m^2/day=2.8306451 Open void volume of new felt %=58.7;Loss of open void volume,%=1.3

Where G= Total shower water flow rate
W= Felt basis weight(Oz/ft^2)
U= machine speed,ft/min
x= Felt width,ft
Δm_p=Water removed from felt at suction pipe,kg of water per kg of fabric

Where $V^/$= Specific air flow through the felt/ fabric at the suction tube, scfm/ in^2
ΔP_{sp} = Pressure drop across the felt at the suction tube, in.Hg.
Td = Dwell time of a particle of felt at the suction tube , milliseconds(ms)
V^* = Felt permeability , cfm/ sq ft. at 0.5 inch water

$M_{p,1}$= Felt moisture content approaching suction tube, lb water/ lb of felt
$M_{p,2}$= Felt moisture content leaving suction tube , lb water/ lb of felt
n= number of slots in suction box
W_B=Width of each slot
S=Machine speed
N=Number of slots in suction box

The permeability will decrease through the life of the felt to about 20% of the original value of a new felt. With that information , one can calculate the new and the old felt vacuum requirements. Typical inlet moisture values are 0.8 lb water /lb felt for the first press , 0.7 for the second and 0.6 for the third.
The following is a case study of an Indian mill for laboratory assessment of felt conditions:

Felt Specification Running Period=155 days , effective period =124 days:

Suction box dewatering

For good operation in general the hydraulic capacity has been recommended by DeCrosta(19-21).
Typical Felt moisture contents and recommended shower water addition rate

Press Position	Hydraulic load,kg water/kg Fabric ,m_{p2}	Recommended shower water rates,kg water/kg of felt
First	0.6-0.8	0.1
Second	0.5-0.7	0.08
Third	0.4-0.6	0.06

Case A and B:

Assumed Values for press position-second/First bottom

U_p, machine speed, ft/min	5000/3000	V^*, felt permeability,$ft^3/min/ft^2$ At 0.5 in. of water	45/50
L, slot width,in	2 x 1/0.75	W_p, felt basis weight,oz/ft^2	4.5/3.5
t_d dwell time,milliseconds	2/1.25	Assume m_{p1}	0.70/0.9
x_{sp} ,slot length,in	300/300	Desired m_{p2}	0.62/0.8
a_{sp} , open area,in^2	600/225	? m_p	0.08/0.1

Calculation for new felt

ΔP,in Hg	2	5	10	15	20	25	30
$V^/$	4.2/3.8	6.6/5.9	9.1/8.1	11.1/9.9	12.7/11.3	14.1/12.5	- /13.7
M_{p2}	0.76/0.98	0.67/0.87	0.61/0.79	0.58/0.75	0.56/0.72	0.54/0.70	-/0.68
V_{Total}	2800/-	4950/-	8621/-	14271/-	25400/-	63450/-	-/-

Calculation for old felt

ΔP,in Hg	2	5	10	15	20	25	30
$V^/$	0.97/0.87	1.5/1.34	2.1/1.86	2.5/2.26	2.9/2.59	3.2/2.89	-/3.14
M_{p2}	0.77/1.02	0.70/0.90	0.63/0.82	0.60/0.77	0.58/0.74	0.56/0.71	-/0.70
V_{Total}	647/-	1125/-	1989/-	3214/-	5800/-	14520/-	-/-

Case Study B (23):

Parameters:

Shower water addition rate: 0.1 kg water/kg of felt;Felt=1000gsm; speed=300 m/min;fabric width=3.5 m;permeability of new felt=45 $ft^3/min/ft^2$ at 0.5 inch W.G.;
Old felt permeability= 0.2 new felt permeability;dwell time=5.08 milliseconds;slot width =1inch; machine speed=1000 ft/min;open area, a_{sp}=600 ft^2
Assume m_{p1}=0.5 and m_{p2}=0.4

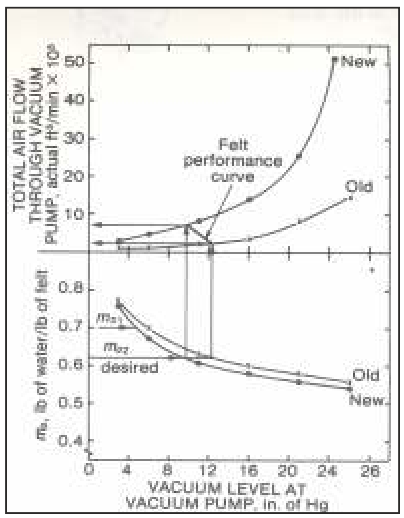

Fig. 1 Sizing a suction pipe felt conditioner

Calculation for new felt

Calculation for old felt

ΔP,in Hg	2	5	10	15	20	25
$V^/$	5.876	8.949	12.447	15.897	17.313	19.253
M_{p2}	0.524	0.477	0.429	0.4012	0.385	0.360
V_{Total}	15641	17446.15	21600	28350	41236	75600

ΔP,in Hg	2	5	10	15	20	25
$V^/$	1.327	2.053	2.855	3.629	3.971	4.416
M_{p2}	0.543	0.498	0.437	0.413	0.398	0.386
V_{Total}	3128.27	4361.53	5400	7057.50	10309.1	18900

The results are plotted in Fig.1 DeCrostra has demonstrated how to use this curve and at what conditions the felt will be replaced. It has also been how to use the curve to estimate the air flow requirement.
From the data which has been calculated we can get the air flow through pump of the order of 26,000 $ft^3/min/inch$ and vacuum requirement is 15 inch.

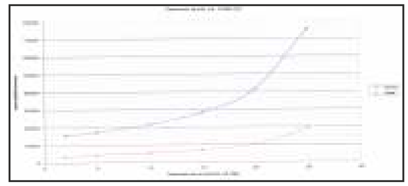

Fig.2. Relation between vacuum level and total air

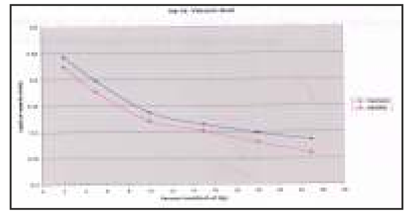

Fig. 3 Relationship between Vacuum level and water holding capacity

Figures 2 and 3 are also drawn to find the relation between vacuum level and total air and between vacuum level and water holding capacity.

The values obtained from the graphs are now added in the programs to solve the objective function for optimization.

Dryer Felts / Screens (1, 2-7,11)

The dryer fabrics must work synergistically with the machine part to provide desired machine production with reasonable heat transfer efficiency and maintains the requisite paper quality. Dryer fabrics has dramatic effects on the overall performance of machine.

Material of construction:

Natural:Cotton,Wool and Asbestos
Synthetic includes Acrylics, Polyamide (Nylon), Nomex,Polypropylene ,Poly-phenylene sulfides (PPS), Aramid, Kevlar, Fiberglass etc.

Degradation from moisture and heat

The order of strength retained with the days exposed is

Fibre glass> PPS> Polyamide> Aramid> Acryalic> Polyester Cotton> Wool

The polyester,cotton and wool can retain almost 30%(on 10 days exposure) and 0.0 (6 days exposure) and 0.0 for nearly 3 days exposure respectively.
The dry heat degradation (after exposure to elevated temperatures in a forced draft ,hot air oven) polyester retains nearly 70% of their original strength.

Monofilament polyester type, Acrylics, Fiber Glass can not stand 150^{0}C

MD multifilament (Combination of multifilament and spin)

Polyester , Nylon, Nomex or Homoacrylic can make-up yarns

Relative degradation resistance of yarn to heat and moisture(12,16)

Type of materials	Low temp./low moisture	High temp/high moisture	Low temp/high moisture	High temp/moisture
Nylon	E	P	VG	F
Polyester	E	VG	G	F
Nomex	E	E	E	E
Fiberglass	E	E	E	E
Acrylic	E	VG	VG	G
Kevlar	E	F	Vg	P
PPS	E	E	E	E

E = Excellent, VG = Very good, G = Good, F = Fair and P = Poor

Air Permeability values are shown in the following table.

Comparison of Air Permeability values of different fabrics(1)

Type	Cfm/sq.ft at 0.5 in. water pressure	m/h
Cotton or woolen felt	0-2	0-33
Needled fabrics(100% synthetic),batt-on-base or batt-on-mesh	40-100	650-1630
Open-mesh dryer fabrics	30-400	490-6500
Monofilament dryer fabrics	30-1000	490-16300

With monofilament and multi-filament dryer clothing ,it is possible to achieve much higher permeabilities than with cotton felts .

Overall, polyester has the best balance of characteristics for modern dryer clothing though it is susceptable to moist heat degradation which decreases running time under extreme conditions. Materials more resistant to hydrolysis , such as acrylic, polyamide, and aramid are being used in such cases. The monofilament fabrics must be heat set and may be chemically treated to add stability.The fabrics are made of flat instead of round monofilaments.

From the repairability point of view Aramid multi-filament thread must be there.

Dryer Felt Tension

Tappi has given guidelines for predicting in an approximating manner the most efficient static tension for dryer felts and fabrics(TIS 0404-04,1989). It is well known that the object of felt or fabric tension is to squeeze air out from the space between the paper and dryer. This is shown in Fig. 4.

It is established that dryer felts are used on paper machines to force the paper into close contact with the dryers in order to increase the rate of heat transfer with certain amount of tension. However, it increases heat transfer rate up to a certain value beyond which the gains are reduced. The condensing rates, a direct measure of heat transfer increases with felt tension to a certain level beyond which very little or no further gains could be measured. Tension is falling within a range of about 10% of the recommended tension which should provide optimum heat transfer without being wasteful. Higher felt tensions have certain limitations.

Use of higher tensions needlessly shortens felt life, increases bearing loads and drive loads, and causes excessive deflection of felt rolls

The boundary film conditions in the ingoing wedge shaped space between a smooth roll and a smooth impermeable web under tension have been described by Riddiford(16).

The residual thickness of the air film between roll and web beyond the wedge area is

$$H=1.51\,R[(\mu U/T)(3/4\,\pi\,\sqrt{2}/4)]^{2/3}$$

Where R, the roll diameter,μ, the viscosity of air, U , the machine speed, and T , the tension. The theoretical tension required to reduce the air film to a given value can be obtained by rearranging equation as under:

$$T=6.2\,\mu U(R/H)^{1.5}$$

This relationship shows that the tension needed to produce a fixed air film is directly proportional to machine speed and varies with roll size to the 1.5 power. Thus a 1.52 m roll should need about 40% more tension than a 1.22 m roll, and a 1.83-m roll needs about 31% more than a 1.52 m roll.

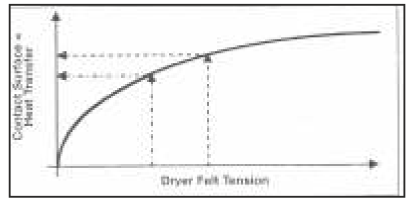

Fig. 4 Influence of dryer felt tension on contact surface between cylinder and paper and heat transfer.

Most machines were used to run between 3 to 8 PLI(0.5 to 1.5 kg/cm) earlier with 6 pli being the average. This is shown in Fig.5

However, newer machines now a days run at 10 to 15 PLI(1.8 to 2.7 kg/cm). Reports are also available that application of synthetic fabrics and use of larger diameter lead rolls in a single felted design have allowed an increase in fabric tension on new machines to approximately 4 kN/m(7).

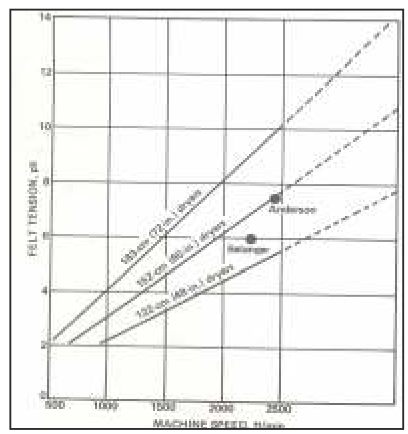

Fig.5 Recommended static tensions for the dryer felts

Effect of Felt Tension on Drying Rates:

According to Belanger, there is little increase in drying rate above 6 pli felt tension whereas according to Anderson there is a significant increase in drying rates up to 10pli(obtained by repeated experiments). Suppliers today are designing dryer sections for felt tensions of 10 to 17 pli. The best recommendation would be to run the design allowed felt tension and not limit to 6 pli . Dryer felt tensions should also be designed for a minimum of 15 pli tension.

Steam Consumption with various dryer fabric tension(7)

1.5 kN/m		2.2 kN/m	
Shift 1	40.1 t/h	Shift 7	36.3 t/h
Shift 2	38.2 t/h	Shift 8	34.7 t/h
Shift 3	40.2 t/h	Shift 9	34.2 t/h
Shift 4	37.6 t/h	Shift 10	34.9 t/h
Shift 5	40.1 t/h	Shift 11	35.4 t/h
Shift 6	39.0 t/h	Shift 12	35.4 t/h
Average	39.2 t/h	Average	35.1 t/h

Mathematical Model For Optimization Of Press And Dryers

To evaluate the performance of press section and dryers in terms of economics Tappi (TIS 0404-22) documented the following procedure in order to provide uniform results from mill-to-mill comparisons. The procedure lay emphasis on the evaluation of machine clothing.

In view of the high capital investment in the paper industry, production rate on a given paper machine is of prime concern. It is therefore important in any economic evaluation to tie the result as closely as possible to the production rate.In view of the fact that production rate often varies with the grades being produced , it is desirable to determine an average daily production rate , P_d, normalized over a suitable period of time , say one month or the life of a press (L_{fp},days) or drier fabric(L_{fd}) in days. The average daily theoretical production rate can be computed as:

Case study : Production Rate Calculations of mill A(5,23)

P_{th} = 60 B_{max} V_{max} GSM *24/1000 TPD=60 x 3.5 x 300x 80/1000 x 24/1000=120.96 tonnes/day=121 TPD

Deckle of paper machine can not be utilized completely and machine does not operate at maximum speed,rather it works at average speed of machine,V If the machine utilization factor for design speed of machine ,$K_V=V/V_{max}$, varying K_V=0.9-0.95

Machine does not run without stoppage . If t_o, be the total stoppage time and t_w, theworking time=$t_P + t_{unprod.}$, the factor for machine runnability, defined as $K_R=(24-t_o)/24$

During working machine does not produce paper always. If t_P, production period per day, $t_{unprod.}$,$t_W=24-t_o=t_P+t_{unprod}$

The time utilization factor,$K_P=t_P/t_W$

Now the gross production,$P_b= P_{th}\ K_V\ K_R\ K_P= B_{max}\ V_{max}$ GSM*(60/1000)*24* $K_V\ K_R\ K_P$

2. Estimation of B_{Max}, the trimmed deckle of Pope Reel :

The width of the wire is calculated from the final trimmed width of the paper, B_p taking into consideration of the shrinkage in press and dryer part, trimming at the couch,a (0.025-0.05 m) and cutters and distance of deckle strap,e,(0.005-0.05) , and free portion of wire required to move in lateral direction for guiding the wire,f,(0.02-0.05 m)

$B_s=B_n$ x 100/(100- %shrinkage) + 2 (a+e+f) = (B_p +22)x 100/(100- % shrinkage) +2(a+e+f)

Where Bs,Bn,B_p= width of the web at the wire , of the paper at pope reel, at the cross cutter. Approx. a=0.03 m,e=0.01m,f=0.035 m, total a+e+f=75 mm and % shrinkage ≈6% are assumed from practical considerations.

3. Estimation of Wire length,

L=A/B=(P_{th} /Kx B)(2.1 to 2.3), A being cross sectional area and K ,the loading factor; depends on the type of paper produced and many other factors such as gsm and speed of machine..

3.Empirical model for estimation of dryness of paper leaving press/ dryer

Fiber content at the exit

$$F_2 = K_1 K_2 K_3 (P/100)^{\alpha} (S_P)^{\beta} (Spf)^{\gamma}(gsm)^{\delta}/(v/60)^{\nu}(SR)^{\varphi}$$

Where K_1,a constant depends on designing of press=$B^{0.047}$ * $H^{0.023}$;B=width of suction box=120 mm;K_2,constant depending on type of press=0.73;K_3, constant depending on condition of press=17 ;S_P,dryness of web before press(17%);S_{pf} ,the dryness of felt after press(69 %);SR, degrees SR(say 45);α,β,γ,δ,ν,φ ,the factors obtained from experiments (0.123,0.07,0.127,0.026,0.145,0.06 respectively).

Using the above values of the constants one can determine the value of F_2=31.2%

In this particular case D was found of the order of 121 TPD and taking 20,000 per tonne of kraft paper , D was found to be 151200 Rs and K_f=55.55 Rs/tonne.

Further calculation shows that K_m=Rs.15/tonne of paper.

Water cost has been calculated with the data from table for pick up felt=0.1* kg of felt

=0.1 * 1000 x 10^{-3} x 300 x 60 *3.5=6300 m^3/h

Water cost is taken as Kw=Rs.10/tonne of paper produced.

Cost of lost production=121 x 2 x20,000/24=201600

K_{lp}=74.0 Rs./tonne

The total cost still requires many other costs including the cost of dewatering in Uhle box and cost due to shower water addition .

These are evaluated from DeCrosta equation. The shower water can also be found out from respective equation. All terms must be calculated at different production capacities.

Based on the computer program in C++,the total costs per tonne basis as objective function all the cost contributing equations have been evaluated for various production capacities. These are tabulated below:

Production vs Press section cost:

Production Rate,tones /day	Press section cost, Rs./tonne
100	646.0
150	475.0
200	389.5
250	338.3
300	304.0

The cost of press section , Rs/tonne as a function of production rate have been plotted in Fig.6

. The data are fitted to a polynomial equation as

$$Y=0.0149X^2-8.7412X+1715$$

Y =cost of press section

X=production rate

Cost of press section vs. Life of felt(23):

Fabric cost calculated from the respective equation is plotted as a function of production rate and fabric life(Fig.7).The data for fabric life have been collected from mill (for 100-121 tonnes per day). The operating cost of press section is a function of life of felt. If life of felt decreases the overall cost of the press section decreases according to the linear regression equation as under:

$Y=-0.0162-4.591\,X+0.885$
Where Y= cost of press section
X= Production rate.

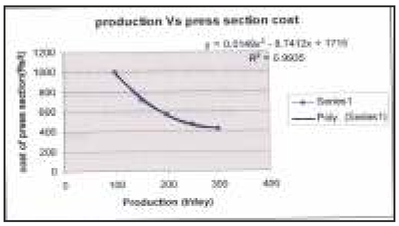

Fig. 6 Relation between production rates and cost of press section

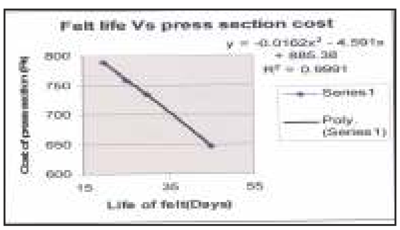

Fig.7 Relation between cost of press section and life of felt

Economic Evaluation (Nomenclature are given in Tappi Information sheet ,16,23-24)

I.Primary Paper Related Variables

A.Production Rate: $P_d=P/L_f=P/T$

B.Sheet Dryness

C.Downtime including any loss production time

II Operating Costs

The calculations considered here for both pressing and drying operations in this sample calculation is a general technique. The costs of various components given in Tappi information sheets revised in 1984 have just converted at the rate of 43 rupees per USD. No time value of money ,

Items	Press Fabrics	Dryer Fabrics
A. Clothing Costs		
1. Fabric cost	$K_f=C_f/P_d\,L_f$	$K_f=C_f/P_d\,L_f$
2. Fabric Installation cost	$K_{fi}=D\,t_i/P_d\,L_f$	$K_{fi}=D\,t_i/P_d\,L_f$
3. Cleaning cost	$K_{fc}=C_c/P_d + D\,t_cN/P_d\,L_f$	$K_{fc}=C_c/P_d + D\,t_cN/P_d\,L_f$
4.Fabric maintenance cost	Certain percentage of Fabric cost	Certain percentage of Fabric cost
5. Conditioning cost	Mill specific, depends on type of felts and contaminants	Mill specific, depends on type of felts and contaminants
B. Equipment Maintenance cost	$K_m=D\,t_m/P_d\,t + C_Lt_m/P_d\,t$,Rupees/tonne	$K_m=D\,t_m/P_d\,t + C_Lt_m/P_d\,t$,Rupees/tonne
C. Water cost	$K_w=C_{fc}U_{fw}/P_d +C_{ww}U_{ww}/P_d$	
D. Cost of loss of production	$K_{lp}=D\,t_d/P_d\,t$	$K_{lp}=D\,t_d/P_d\,t$
Downtime cost	$D=P_d\,t_i/24$ Cost(Rupees/tonne)	$D=P_d\,t_i/24$ Cost(Rupees/tonne)
Operating Cost, $C_{op}=K_f+K_{fi}+K_{fc}+K_m+K_w+K_{lp}$		
III. Energy Costs		
A. Drive System of machine/Electrical Power	K_{dc}=? $E_{dc}\,24\,C_c/1000\,P_d$	$E_{dc}=VI$ K_{dc}=? $E_{dc}\,24\,C_c/1000\,P_d$
B. Vacuum Pump Drives/Fan drives(DS)	$E_{ac}=VI\,Cos\varphi$ $E_v=0.334\,Q_f[1-(P_2/P_1)^{0.287}]W_s$ K_{ve}==? $E_v\,24\,C_c/P_d$	$E_{ac}=VI\,Cos\varphi$ K_{ve}==? $E_v\,24\,C_c/P_d$
C. Water Pump drives/ Condensate pump(DC)	K_{pc}==? $E_p24\,C_c/\,P_d$	K_{pc}==? $E_p24\,C_c/\,P_d$
D. Heat input to Sheet/Thermal Energy costs	$K_{tc}=E_t\text{-}E_s.24.C_t\ /P_d$	$K_{tc}=E_t\,24\,C_t/P_d$
Total Energy Costs= $K_{dc}+K_{vc}+K_{pc}+K_{tc}$		
IV. Potential Savings/ Cost reduction		
A. Saving in steam costs	$K_s=2\,d_s$? $M^*C_s^*\,e$	A.Reduce evaporation load
B. Savings due to increased production(dryer limited machines)	$K_p=24\,D$? $M\,e\,f/P_d$	B.Tune the dryer section
Saving due to quality improvement	$K_f=(C_{ca})(F_a)+(C_{cb})(F_b)+$………	C.Cost reduction through increased productivity D.Recover Waste Heat
Total potential savings=$K_s+K_r+K_f$		

Sample Calculation For Econo-mic Evaluation (based on the cost basis assumed in TIS 0404-22)

Wire, cost/m^2=4075-4200For single- double wire 2.5 layer= Approx.Rs.6000/m^2	Press Fabrics 100% synthetic: Depends upon gsm; 1100gsm, Rs.2587 /kg	Dryer Fabrics 100% synthetic Mono up to Rs.2400/m^2

escalation of costs, inflation , and scale ratio are considered. The costs may be thus hypothetical in Indian conditions.In actual practice,the following procedure available in all standard texts of plant design must be used. For example,

Power of Pumps:P=QρgH/1000η, Q, the volumetric flow rate, m^3/s; ρ, the density , kg/m^3,H, the total equivalent height of transport of fluids,m, η,the overall efficiency which can be defined as $\eta = \eta_p \eta_t \eta_m$ where ,p,t, and m indicate for pump, transmission as well as motor. The efficiency of motor can be assumed of the order of 93-95%. H_p can be estimated from curve plotted for efficiency vs. volumetric flow rate. In absence of the data the following equation can be used:

η_p=-0.01(lnQ)^2+0.15lnQ+0.3

For motor Curve for efficiency of motor as a function of Brake Power,kW can be used . In absence of data , the following table can be used

Approximate efficiencies of electric motors

Size,kW	Efficiency,%	Size,kW	Efficiency,%
5	80	200	92
15	85	750	95
75	90	>4000	97

Cost, $C_A=C_B(S_2/S_1)^M$ x (I_p/I_{old}) x f_mxf_Tx f_P x f_{type} index at present/Index value at thetime original cost was obtained)

Cost exponent of the equipment, M, must be considered from the designer's handbook. For example the exponent M for centrifugal pump with motor, is 0.55, vacuum pump including motor,0.44 and electric motor alone,0.85. The exponent values however changes from designer to designer. The base cost also varies. The multiplying factors fi represent for material of construction, temperature, pressure and types. To calculate present cost of the equipment or item like felts or screens , the chemical engineering plant cost index may be considered. Alternately the cost due to inflation at an appropriate rate (averaged over certain period) in any country may be employed.

For economic comparison among several alternatives for higher efficiency design an investment analysis is made considering time value of money and escalating costs of materials, energy etc. Standard method for evaluating an investment in high efficiency equipment at a price premium can be used as follows:

NPV, Net present value, a discounted cash flow methods determines the net present value of all cash flows by discounting them by the required rate of return (known as the hurdle rate or cutoff rate and similar terms

$NPV=A_0+\sum_{t=1}^{n}(ACF)_t/(1+r+p_t)^t$

Where ACF , the net cash flow in period t, r, the required rate of return,A_0 ,the intial cash investment (because this is an outflow, it will be negative),p_t, the predicted rate of inflation or deflation during the period t.

The project will successful and thus acceptable if the sum of the net present values of all estimated cash flows over the life of the project is positive. The concept must be used for allminvestment decisions.

Economic Evaluation Of Press Section

Case 1: First considering a hypothetical third press

Fabric cost= Rs.258000; Fabric Life=45 days and average daily production rate=282 TPD(O.D. Basis);fabric Installation time , T_i= 1 h; hourly cost of downtime, D=Rs 86000/h

Typical sheet dryness during run: Out of press section=42%(moisture ratio=1.38) and at reel=6%(moisture ratio=0.064).

Cost of steam, C_s=Rs. 107.5 /1000 lb steam;Dryer efficiency=1.5 lb steam/ib water evaporated; production efficiency factor, e = 0.04;cost of fabric cleaning chemicals , C_c=Rs 2580/day;power input to drive, E_{dc}=89.5 kW; power input to vacuum pump , E_v=78 kW;Cost of electricity, C_e=Rs 1.29/ kWh; eight wash ups of 15 min each were required in 45 days;cost of maintenance, k_m=Rs 9.03/ton; cost of Shower water, K_w=9.89/ ton;total downtime at press section=2.75 h

Operating costs

A. Press clothing costs

1. Press Fabric costs, $K_f=C_f/(P_d*L_f)$ = 258000/282*45= Rs.20.33 /ton

2. Fabric Installation costs= K_{fi}=D t_i/P_d L_f=86000*1/282*45=Rs.6.77698

3.Fabric Cleaning Costs=$K_{fc}=C_c/P_d$ + D t_cN/P_d L_f=2580/282 + 86000 *8* (15/60)/282*45=9.14893617+13.5539795=Rs. 22.703/ton

Total Fabric related costs=20.33 +6.77698+22.703=Rs. 49.80998/ton

4. Maintenance costs, K_m=D t_m/P_d t + $C_L t_m/P_d$ t=86000*…..= Rs.9.03/ton

5. Cost of Shower water,K_w = Rs.9.89/ ton

6.Cost of lost production= K_{lp}=D t_d/P_d t=86000*2.75/282*45=Rs.18.63672 /ton

D=(P_d t_i/24)Cost(Rupees /tonne) = 282*1 /24

Total Operating Costs = 20.00 + 6.77698 +22.703 + 9.03 + 9.89 + 18.63672 = Rs. 87.0367/ton

B. Energy Costs:

1. Drive costs= $K_{dc}=\sum E_{dc}$ 24 C_e/1000 P_d=89.5 kW x 24 x 1.29/282 = Rs. 9.82595/ton

2. Vacuum Costs= E_{ac}=VI Cosφ

$E_v=0.334\,Q_f[1-(P_2/P_1)^{0.287}]W_s$

K_{ve}==$\sum E_v$ 24 C_e/P_d=78 kW * 24 * 1.29/ 282 = Rs.8.5634/ton

Total cost = 87.0367 + 9.82595 + 8.5634 = 18.38935=Rs.105.42605/ton

Potential Savings

Drying Costs(steam): Specific steam demand=, d_s =1.5 kg of steam/kg water evaporated(1.38-0.064)=1.974 kg steam/kg of paper

B. Cost Steam = (1.974*107.5/1000) * 2000 = Rs. 424.41/ton

Case 2 : Installation of a new fabric

New Style of Press Fabric of higher costs, 1.5 times the former is installed. As a result production capacity is increased by 5% to 210 tonnes but the fabric life,2/3 rd of the earlier one, is reduced to 30 days. The new fabric installation increased the dryness by 1.5 % more. All other costs are assumed to remain the same on a cost per ton basis. The lost time was reduced to 2 hours. Should we go ahead with the new fabric installation?

Simple calculations show the following changes without going for more accurate estimation using NPV based on discounted cash flow and inflation rate.

The net savings compring of steam savings ,increased production down time saving,increased pressing cost and less longevity of the order of Rs. 315.6 per tonne will be anticipated.

Economic Evaluation Of Dryer Section

Dryer Fabric cost=Rs.2580000;fabric life , L_f=180 days; average daily production rate=282 TPD; fabric Installation time , T_i=18h;hourly cost of downtime, D=Rs.86000/h

Typical sheet dryness during the run:

Entering dryer section=42%(moisture ratio=1.38); at reel=6%(M.R.=0.064)

Cost of steam,C_s=Rs.172/1000 lb steam;production Efficiency=90%;cost maintenance=Rs.10.75/tonne;down time for dryer section=3h/month;steam energy,E_t=45000 lb/hr

Operating costs

Dryer Fabric costs

1.Press fabric costs= $K_f = C_f/(P_d * L_f)$ = 2580000/282 * 180 = Rs. 50.827 /ton

2. Fabric Installation Costs :K_{fi}=D t_i/P_d L_f=86,0000*18/282*180=30.4964539

3.Fabric Cleaning Costs: = 0.0 = K_{fc}= C_c/P_d + D $t_c N/P_d L_f$

4. Maintenance costs: K_m= D t_m/P_d t + $C_L t_m/P_d$ t = 86000/282

5.Cost of lost production dryer section= K_{lp}=D t_d/P_d t=Rs.30.496/ton

6.Cost of lost productivity(efficiency loss):24(1-0.9)=2.4 h/day; 2.4 * D/P_d = Rs. 731.915/ton

7. Thermal Energy costs = K_{te}= 45 * 24 * 4/282=Rs.15.319/ton

K_{tc}(water)=15.319/{(94/42)-1} * D = Rs. 0.000144/lb of water

Conclusions

In this present investigation various mathematical models are attempted to apply in practical calculation of energy estimation , specifically electrical energy in relation to paper machine clothing. Detailed calculations are made for vacuum pump , suction roll and drive power requirements. DeCrosta equations have been used for various case studies of Indian mill. Economic evaluations of both press and dryer fabrics are made with some assumed data used abroad. Case studies for press and dryer clothings are especially discussed through already developed model based on C++ programming for parameter studies and economic evaluation as a function of production rates. More extensive work should be carried out with more authentic economic data from paper mill.

References

1. Pulp and Paper Manufacture, Vol. 7, Paper Machine Operations,edited by B.A.Thorp and M.J.Kocurek,The joint textbook committee of the paper Industry, TAPPI and CPPA,1991, Third Edition,pp 563-593
2. Leigh Ged,,ipw 6/2009
3. Pulp and Paper- Chemistry and chemical Technology, Edited by J.P.Casey, Vol. II,Third Edition,1960,pp 1076-1090, 1096-1099.
4. Pulp and Paper Manufacture,Vol.3, edited by Macdonald R.C. and J.N.Franklin,399-401,,380-382,428-436
5. Kikiewicz,Z and R.S.D.Pandey, Theory and Design of Paper Machines, Vol.1 and II,Tara Book Agency, 1983 and 1990
6. Hannu Paulapuro-Papermaking Science and Technology, Book 8, papermaking Part 1, Stock preparation and Wet End, Finish Paper Engineers' Association and Tappi ,2000
7. Markku karlsson-Papermaking Science and Technology, Book 9, papermaking Part 2, Drying, Papet Oy,Finish Paper Engineers' Association and Tappi ,2000
8. Mukherjee Ashish and Naveen Srivastava, IPPTA Workshop, 18-19 Dec, Rajahmundry
9. Rao N.J. & Ray A.K., IPPTA, Vol.20(4), 1983,1-15
10. Pandey Ravi, Dissertation submitted to DPT,IITR,2004
11. Phamplets of Felt manufacturing company of India and Abroad(Voith fabrics, Wire and Fabrieks , Shalimar Wire, Shri Dinesh mills, huyck, Nippon ,heimbach Ippolito & Pisani S.p.A etc
12. Practical Aspects of Pressing and Drying Short Course-Ta[ppi Press,1995
13. Davies C.N.,1952, Proc. Inst Mech.Engrs(London),1B,pp. 185.
14. Ingmanson W.L., Andrews B.D. and Johnson R.L., 1959, Tappi, 42 (10) , pp.840-849.
15. John A. Neun J.A.-Tappi Sept. 1981, Vol.64(9), pp 123-127
16. Technical Information Sheets TIS 0404-17,-21,-22 ,-26,-27and 0404-30
17. Derrick, R.P., Tappi J., Vol.60,1977
18. Derrick R.P., P.T. McNulty, and W.F. Robertson, Tappi, Vol.64(9), 117119
19. DeCrosta E.F., Tappi, Vol. 56 (11),1973,100-106
20. DeCrosta E.F., Pulp & Paper Canada (1),1980,pp.97-102
21. DeCrosta E.F., Tappi, Vol. 63 (5),1980,93-95, 97-101
22. Ravi Pandey ,Paper Machine drive load calculations,Project Report, DPT,IITR,2003
23. Puri M.K.,Optimization of press section,Project report submitted to DPT, IITR,,2005
24. Hemant Kishore, Nikhil Kumar and S.Amit, Project report , submitted in IPT, University of Roorkee,2000