Selection of clothing at the wet end and its impact on economy

RAO, N. J.* & RAY, A. K.**

Cost reduction in the manufacture of Pulp and Paper has now become an imperative necessity under the prevailing uncertain condition of cost of energy. This fact alongwith sudden depletion of conventional raw-materials has caused the Paper Industry to have decelerated productivity. To maintain the uniformity in production, various ingredients known as filling and loading are usually added alongwith the pulp. Inspite of this the profitability of paper Industry is now comparatively low (around 3%) in comparision to 9.7 for other industries as a whole[25]. Keeping all these in mind, The National Planning Commission expects that in the ensuing plans the growth rate of Paper Industry would be in the order of 7. percent per annum[4].

This calls for allround efforts to identify areas of cost reduction to bring about an economy in manufacture and increase in profitability. Apart from direct economisation of energy in the form of steam/fuel, electricity, the other important considerations for reduction of cost of manufacture are the proper choice of materials pertaining to the process of conversion, its efficient utilization and optimum performance of the processing equipment.

One of the most important items for cost reduction in the forming section of Paper Machine is machine clothing. This imparts a significant contribution towards operating cost for production of paper. (An cost of all wet and dry clothing is 2% of the cost of tonne paper produced).

According to LINDEROT[17] the clothing costs based on European mill data comprise appreciable part of operating cost around 20 percent or more, but these costs are regarded as isolated operating costs. During the last decade a lot of improvements have been made In the innovation of machine clothing either in the web forming section as wires or in the press or drier section as felts, the object is to reduce the overall manufacturing cost. The historical step by step evolution, development and its utilisation has been discussed in greater depth by MACDONALD[22]. Recent development of synthetic fibres have made possible a substantial increase in the production of paper. Still much more new type of machine clothing are coming up at a very fast rate, particularly in the forming section with the advancement of technology, research or methods in the areas of high polymer with a view to reduce the cost of manufacture, to save energy or to improve quality of product. The overall object is to increase the productivity at the minimum cost. According to Linderot[17], there is a decline in the cost of clothing per ton of paper defined as specific clothing cost and became almost one-fouth of its consumption of what it was in 1960.

The machine clothing as already described have its own domain of application and varies in behaviour from sheet forming section to the dryer section. The gain of any desired variables either in the form of economy or in the form of productivity in any section will be reflected in subsequent section in succession and the cumulative effect will be implemented in the final output, Linderot[17] referred qualitatively that with an increase of 1 percent dryness content, the capacity of the dryer section would be increased by almost 4 percent. In fact by using of fabric more dryness of web has been noticed after couch (1-2%)[16]. leading to increase in machine speed and productivity.

Clothing at web and its selectivity:- Wire is indispensable for formation of paper web, the

*Professor in Chemical Engineering and Director,
**Lecturer in Chemical Engineering,
Institute of Paper Technology. Saharanpur

function of which is not only to support the sheet of paper at wet stage but also helps in water drainage, imparts surface finish to the paper web The choice of wires depends upon many factors. The wire should be such as to give high operatioal raliability, efficient drainage, minimum bleeding, uniform sheet formation, casy control & easy cleaning. It should be cheap both in first cost and maintenance. Other cost contributing factors such as Installation, repair, cleaning and replacement should also be lower. It must have lower down time, reasonable salvage and long life.

The above mentioned criteria are very much essential or to be developed either prior to design stage or during application in real situation so that it will yield the best performance. In other words maximum Productivity will be achieved with minimum investment and time with maximum efficiency. Unfortunately in reality no such clothing exists which has all the advantages as cited above. Futhermore these factors in turn depend upon its various mechanical, chemical and physical properties. The information in these fields are meagre and proprietary in nature. Due to inadequate information about these aspects the processing Engineers find it difficult to choose the proper materials. In this paper an attempt is made to describe a systematic approach of design, selection and economic feasibility for machine clothing in the forming section of a paper machine.

ECONOMICS IN SELECTION OF MATERIALS

The fourdrinier wire is usually made of conventional type of material such as Brass in the weft and phosphor bronze or bronze in the warp. The primary consideration for these material was high mechanical strength, resistance to abrasion, free from aqueous, galvanic and stress corrosion, either resulting from paper making liquors or from the operating temperature level. Monmohan etal[21] discussed in detail about the application of these wires and compared the feasibility of brass, phosphor bronze and steel wires to high speed machines in relation to durability and mechanical properties particularly fatique, stiffness, reselience etc. The application of plated wires with metals like Nickel, Chromium, Tin or plastic etc. and Aluminium bronze, silicon bronze, chemically treated wires were also discussed by them conventional wires with wire life extenders such as marcapto-benzothiozole admixed with Sulphur has also been used in Industry to reduce the metal failure by fatique and wear. It has been reported[21] that increase in wire life upto 50-200 percent has been achieved with the addition of extenders. Goyal etal[9] discussed about the contribution of alloying components in developing the various mechanical properties needed in a wire. But all these metallic wires are unsuitable for fast machines. Search for a new type of material led to the development of synthetic polymeric fabrics. Out of many types of polymeric materials, only alkene base thermoplastic such as polyethylene or polypropylene and polyester/polyamide base fibers such as Dacron, Nylon, Orlon etc. have been successfully used either alone or in combination. The use of stainless steel in the cross-direction for stiffness and synthetic polyester in the machine direction for abrasion resistance and flexibility has also been reported in literature, synthetic fabrics have the advantages of light weight (Sp. gr. 85-2 5), weatherability i.e., excellant moisture resistance (0.4-1.5 % water absorption in case of Nylon), ease of fabrication and installation, resistance to chemical and biochemical attack, good dimensional stability, high tensile strength and low coefficient of friction (0.03-0.12). But they suffer from greater stretch (2.5%), liability to wrinkle, sensitive to temperature changes[24] ($>250^{\circ}C$) and have the risk of being punctured during operation. The materials like Nylon, Acrylonitrile-butadiene-styrene (ABS), Epoxide (EP), polycarbonates (PC), Dacron (polyesters), polyethyline (PE) etc. have varying properties and selection should be carefully made. The various machanical and physical properties of plastics and metal-alloys are given in table I and II.

It is evident from the table I that the mechanical properties of plastics (Thermoplastic) are not constant but varies with stress. Tensile strengths are significantly affected by the rate of loading and the temperature. The elongation at rupture often varies considerably. These are also subject to creep at all practical temperature. From Table-2 it is evident that stainless steel is having low coeff. of friction, and high module of elasticity and rigidity. The elastic modulus of phosphor bronze[14,15] (85.5%Cu, 12.5%Sn,10%zn) lies within the range of 10.5×10^3 to 10.2×10^3 kg/mm^2 and that for commercial Brass(66%Cu, 34%zn) is 9.8×10^3 to 9.6×10^3 kg/mm^2 within the same range of temperature 20°C - 100°C. It is also evident that addition of small amount of the alloying elements (such as P, Si, Cr, Sn, Fe) changes the mechanical properties of wire significantly[15]. The material should be such that

TABLE—1 MECHANICAL PROPERTIES OF PLASTIC MATERIALS AT 25°C

Property	Nylon (Polyamide)	ABS (Acrylo-nitrile Butadiene Styrene)	EP (Epoxi-des)	PC (Poly-Corbo-nates)	DACRON/ Terylene (Polyesters)	PE (Polye-thylene)	PP (Polyp-ropy-lene)
1	2	3	4	5	6	7	8
A- DENSITY (Kg/m³)	1090-1140	1050-1200	—	—	1380-1410	920-930(L.D.) 940-970(H.D.)	900-910
B- Tensile Strength (Kg/cm²)	476-741	281-563	281-2109	563-1406	56-3515	70-387	>PE —
C- Elongation (%)	5.0-155	2-300	0.5-70	0.9-1.30	0.5-310	15-1000	>PE —
D- Tensile Modulus 10^3kg/cm²	18-27.2	16-72	0.07-214	25-130	21-140	0.98-13.0	>PE —
E- Compressive Strength Kg/cm²	—	492-1547	70-2812	879-1336	844-3515	– to 387	>PE —
F- Compressive modulus 10^3 Kg/cm²	—	12-27	—	21-32.0	—	– to 11.0	>PE —
G- Flexural modulus 10^3kg/cm²	—	1.4-91.0	—	24.0-84	– to 141.0	– to 25.0	>PE —
H- Impact Strength Kg-m/cm.	0.106-0.702	0.0108-0.544	0-0.544	0.0652-0.952	0.0108-87	0.0272-0.1088	>PE —
I- Flextural Yield Kg/cm²	646-993	352-1898	70-4218	949-2106	563-5624	– to 49	>PE —
J- Shear Strength Kg/cm²	571-653		—	—	—	—	— —
K- Coeff. of friction.	0.08-0.12	—	—	—	—	—	— —

TABLE—2 CHEMICAL COMPOSITION AND PHYSICAL AND MECHANICAL PROPERTIES OF METALLIC WIRES

Name of the alloys.	Chemical composition.	Average Modulus of Elasticity (E) Kg/cm²	Tensile Strength Kg/cm²	Average modulus of rigidity (G) Kg/cm²	Poisson's ratio. —(μ)	Density (Kg/m³) (ρ)	Coefficient of friction.
1.	2.	3.	4.	5.	6.	7.	8.
Phosphor Bronze	Cu 91-93 Sn 6-8, PO 2-1	1.132×10^{6}	4200-4500	0.422×10^{6}	0.349	8160	—
Stainless Steel	12-15% Cr	1.940×10^{6}	5500*-8000**	0.745×10^{5}	0.305	7750	0.10-0.15
Brass	Cu 70-80 Zn 30-20	0.970×10^{6}	200-3400* 5500***	0.350×10^{6}	0.30-0.40	8450	—
Bronze	Cu 92, Sn8	1.110×10^{6}	1800-2000	—	—	8730	—
Silicon Bronze	Cu 97.5 Sn 1, zn 1 Si .5	—	3000-7000	—	—	—	—
Aluminium Bronze	Cu 88, Al-8 Mn 4	—	5000-5300 (6000-7000) (by heat-treatment)	—	—	—	—
German Silver	Ni 25, Cu 60 Zn 15	—	1700-4500	—	—	—	—
Monel Metal	Ni 60, Cu 33, traces of Fe, Mn, Si, c.	—	2700 (at 600°c) 4500 at 20°c	—	—	—	—

*Annealed.
**Unannealed.
***Hardened

it should have an unique combination of tensile, fatigue, wear, corrosion and abrasion resistance. Although stainless steel is better in respect of high tensile strength and low density but is inferior in other respects. Addition of iron (0.02-0.04%) to phosphor bronze improves the behaviour in respeet of life, elasticity, fatigue, wear and tear. The Breaking Strength of such material is 50-52 kg/mm² 16. Aluminium bronze is superior 30 to commercial bronze in respect of atmospheeric corrosion, resistance due to shock and tensile strength. From table I it is also evident that between the alkene base thermoplastic, polypropylene is superior to polythene in all respects and among the other polymeric fibres polyesters are superior to polyamide in respect of all mechanical properties. From comparison of Fabrics with metallic wires, polymers are having comparatively lower mechanical Strength than metallic. But these properties can be developed by reinforcing the fibres with other fibres (5-30%) glass, asbestos, jute, sisal, carbonate Cl,P etc.)[15]. Mechanical impact and service temperature should be taken care of From table-III it is clear that Nylon in respect of hydrolysis resistance, hardness, rigidity is superior to polyesters but inferior in respect of dimensional stability, wrinkling and abrasion resistance, polythene is not a good matererial as far as heat/temperature resistance is concerned.

COST OF MATERIAL

The price of synthetic fibres[5] is less than that of wool, over four times that of cotton and normally2½-3 times[2,16] as much as a metal wire depending upon the type of alloys in metal wire. Table-IV reflects the approximate ralative cost of all the polymeric materials. Costwise polythene is the cheapest whereas Dacron is the costliest. But due to the poor mechanical properties and temperature sensitivity of polythene its use has been discarded. Higher temperature resistance and greater resistance of polypropylene that polythene has led to its greater use as wire. But due to accute shortage of petro-chemicals the manufacture of polypropylene is limited in our country. Therefore in Indian conditious polyamide and polyester fibres are more popular.

LIFE OF A WIRE

The life of a wire depends upon the factors like Improper Installation, Faulty operation Mechanical damage such as bursting, Abrasion, sudden change of PH, corrosion, Inadequate cleaning and fatique etc. This aspects has been dealt in great detail in literature. A brief review is outlined below :

TENSION

Tension on a wire is not uniform and varies around the wire run. Garg etal[6] reported the distribution of tension at each points, based on the Loyall's mathematical expression[19]. These are

Couch	24467.00	Kg/m^2
Wire roll	42.21	,,
Breast Roll	224.90	,,
Table Roll	14.10	,,
Apron drug	513.10	,,
Rotabelt Unit	675.01	,,

of three boxes.

The proper running tension will be needed to overcome slippage on the couch roll and should be maintained constantly. Streching is maintained in such a way[20] so that it should not go beyond elastic limit or to the extent of slippage. The elongation of bronze wire is around 0.2 to 0.25% while the same for duble layer fabric and mono-fabric are 0.5% and 1.0% respectively. The little advantage of using bronze in this connection may be ignored if the initial stretch for the case of fabric, is taken into consideration prior to installation. Alternatively a combination of fabrics may be useful.

ABRASION

Abrasion deteriorates the life of the wire It results mainly due to vacuum applied at the suction box, resence of abrasive materials in the stock (loading and filling materials[11] such as Talc, clay, TiO_2, $CaCO_3$, diatomaceous earth, asbestos, Al_2O_3, synthetic silica and silicates etc.), size of the particles in the loading materials (filler clay) presence of other extraneous materials either formed during chemical transformation or transported alongwith pulp.

The fabric wire is more susceptible to damage from localized abrasion. The abrasion in the stationary elements can be reduced to a very low level by replacing the wooden covers with hard ceramics, high density polythene, poly-tetra-fluoro-ethylene, polythene. These materials have low coefficient of friction high moisture and corrosion resistance, high density and high toughness. The coefficient of friction, temperature stability, density and corrosion resistance are indicated in the table–V.

γ-irradiated polythene[24] seems to be promising material from cost point of view but suffers from temperature susceptibility, only TFE is the favourable material property-wise but is expensive. Sarang[2] found HDPE to be a material.

CLEANING

Fabrics are most susceptible to dirt deposi-

TABLE NO.—III. COMPARISION OF FABRIC WIRES.

Material	Crease/ wrinkling resistance	Stretch resis tance	Abrasion resis-tance	Dimensi-onal stability under stress	Heat/temp resistance	Wear resis-tance	Moisture ubsorp-tion resistance	Hydrolyis resistance	Resistance to low pH	Hardness/-Rigidity
1	2	3	4	5	6	7	8	9	10	11
1. Polythene	good	good	Fair	good	Not good (above 50°C)	good	good	good	very good (except oxidis-ing acids)	good
2. Poly-propylene	good	good	very good	good	good (upto 100-120°C)	good	good	very good	very good	very good
3. Nylon	good	fair	good	fair	fair	good	good	good	poor (good for high-H	very good
4. Acrylics	Fair	Fair	Fair	—	good	moderate	—	very good	good	fair
5. Decron & Terylene.	very good	very good	very good	good	very good (upto 95°C	very good	good	poor	good (fair for high pH)	good
6. Acryloni-trile	—	—	—	—	good (upto 65°C	—	—	—	—	—
7. Polytetra fluero ethylene	—	—	—	—	very good* (upto 327°C)	—	very good	very good	very good at low as well as at high pH	good
8. Polycarbonate	—	—	—	—	good upto 150°C	—	—	good	good	—

(Note :—Item 1 to 5 are normally used as wires. Items 6 to 8 and 1-2 are normally used as cover in stationary elements)
*Safely upto 260°C

tion and need more attention to cleaning than metallic wires. High pressure needle jet (at a pressure of 15-40 Kg/cm^2 installed[8] at 10°-15°) oscillating shower will be the most appropriate cleaning system for the shower systems with fully automatic and semi-automatic devices.

TABLE—IV. APPROXIMATE RELATING COST OF POLYMERIC MATERIALS

Trade Name	Chemical Name	Relative Costs
Polythenc	Polyethylene	1.0
—	Mothecrylate	1.38
Profax Parlon	Polypropylene	3.0
Nylon—6	Poly-Caprolactam	3.2
Nylon—6, 6	Polyamide	3.4
Dynoi	Vinyl-acrylo-nitrile copolymer	3.5
Acrilan	Acrylic-Copolymer	3.7
Orlon	Poly acrylonitile	4.50
Dacron	Polyester	4.60

For Chemicai cleaning the machine is normally shut resulting into production loss. Therefore this cleaning can be performed only when it is desirable at long intervals. Dil. HCl (10%), H_2SO_4, NaOH (7%) are the usual cleaning agents for both metallic and fabric wires. Strong acid and base should be avoided otherwise heat of dilution may affect the fabric life. For polyamide, it is better to use alkaline solution whereas for polyesters it is better to use for low PH acids. Organic solvents like Xylone, CCl_4, trichloroethylene, acetone, petrol and Kerosene may be used to remove pitch and similar substances. Steam through the shower can also be used for cleaning the fabric wire. MACDONALD[22] suggested the use of chemical cleaners such as Na floc N 228, Diadavin E. P. etc. for cleaning fabric during running conditions and Brilltak 5%, Hostapal, D.L. 10%, solugan 10% for general cleaning at shut down time. He also discussed at length about the cleaning solvents for removal of soiled spots, oil and grease, pitch, resin, tar, latex, Rosin size and hard water deposits.

TABLE—V. PROPERTIES OF COVER MATERIALS

	Heat/temporature and moisture resistance.	Coefficient of friction	Donsity	Resistmco to aids, alkali a etc.
Carborundum	Very good	0.10—0.15	—	—
PTFE	Very good upto 260°C good (upto 327°C)	0.08—0.12	2200	Totally unaffected
Polyurathane	—	0.03—0.06	—	—
Ceramic Materials γ—Irandiated		0.03—0.05	—	—
Polythene	Poor (>50°C)	—	920-930	Good at low temp.
HDPE	,,	—	940-970	Good
PVC	good	—	1650-1750	Very Good

CORROSION

The corrosion may be due to any one or combination of the following factors : acidity giving rise to aqueous corrosion, presence of disimilar metals, i. e. Galvanic Corrosion, due to presence of temp. and stress i. e. stress corrosion, rusting and allied phenomena due to air saturation. Presence of air accelerate all the corrosion proc sses. The conventional metal wires are corroded by all the above mentioned factors. It has been found that about 20% of their strength is lost due to corrosion (chemical as well as galvanic) in Fourdrinier metal wire during their normal life. Due to dezincification of Cu, Zn alloy in warp and weft wire corrosion cracking takes place. Fabrics can be successfully used within the PH range 3.0 to 10.0. By periodical Spraying of corrosion inhibitors on metal polymeric combinations pitting can be reduced. Garg etal reported[6] that the increase of pH of machine white water from 5 to 6 almost doubles the wire life. However at higher pH the filling and plugging of wires may be pronounced.

CREASING, EDGE CRACKING, WRINKLING, PATCHING

The filament in synthetic fabric can withstand a greater degree of bend without permanent deformation than the metallic wires. As a result the fabrics are more crease resistant. Wrinkles if present can be, removed by ironing. Wrinkling occurs due to machine misalignment. Close observation can minimise the damage of fabric due to wrinkling. Fabric filament are heat fused at edges during, manufacturing process and further reinforced with plastic coating. Low melting point polyethylene is unsuitable for heat setting. Polyvinyl-di chloride at a temperature of 170°C may be used as reinforcing material at the edge of fabric wire[16]. This fusion coating plus flexibility and toughness of the synthetic filament reduces the tendency of edge cracking. However edges if required can be trimmed and can be fused again with the help of portable electric soldering iron, synthetic forming fabric can be patched more easily and effectively than the metallic wires and is accomplished with a specially designed patching equipment. This techniques provide move durability to the wires.

FAT QUE

Bronze wires are permanently deformed even at moderate elongations. Thickness is usually kept minimum in order to resist fatique. Deformation and fatique resistances of plastic wires can be developed to the need by using different weaving techniques.

DRAINAGE CHARACTERISTICS

The drainage characteristics or permeability is comparable in the case of metallic as well as monofabrics, and it differs with the weaving pattern. The double layer fabric is the most preferred one. The detailed weaving pattern has been discussed by Manmohan etal[21], Gune[7], MACLONALD[21] Britt[12], MACDONALD G.R.[23]. Halle[11] has given emphasis on the analytical expression of Kozeny Carman and Ergun[3] to calculate the permeability or drainage free area.

The equation in dimensionless form can be written as :

$$\left(\frac{\triangle P}{G_o^2}\right)\left(\frac{DP}{L}\right)\frac{\epsilon^3}{1.\epsilon)} = A_1 \frac{Cu}{D_p G_o^2}(1-\epsilon) + B_1 \quad -(1)$$

The influence of specific surface area S_v or Particle size D_p and the Porosity (ϵ) are the main factors to decide about the pressure drop. The more simplified equation can be derived from modified Hagen Poiseuille equation.

$$S_v^2 = \frac{(\triangle P)\, g_c\, \epsilon^3 A}{\left(2\frac{L_a}{L}\right)\bar{v}/^u\,(1-\epsilon^2)LA} \quad -(2)$$

$$= \frac{(h\ pL)\, g_c \epsilon^3\, A}{2\,\frac{L_a}{L}\,(v/o)\,/u(1-\epsilon^2)L} \quad -(3)$$

$$= \frac{h\ pL\ g_c}{\alpha a} = \frac{t^3\, A}{v^2/u(1-\epsilon^2)L} \quad -(4)$$

where a is known as Aspect factor, for fibre the value is between 3.07 to 6.04. The simplified expression for water ($\mu = 1$ CP) are as below—

$$S_v = \frac{180}{(1-\epsilon)}\sqrt{\frac{h\ \epsilon^3\ A}{v^1.\ L}} \quad -(5)$$

$$S_v = \frac{128}{1-\epsilon}\sqrt{\frac{h\ \epsilon^3\ A}{v^1.\ L}} \quad -(6)$$

The specific surface area is related to D_p as

$$S_v = \frac{6}{D_p} \quad -(7)$$

These equations can be effectively utilized for comparing the porosity or drainage area under any given set of conditions. But these equations are limited to static conditions. For steady state dynamic conditions experiments are needed to predict suitable dimensionless expressions based on proper Mathematical models.

WIRELIFE

The absolute value of wire life depends upon the Speed of the machines apart from the considerations as already explained. It has been seen that even for the same machines having the same speed the values widely differ due to many complexities involved in the operation. The life of bronze wire in a well maintained machine for low speed, medium speed and the high speed are around 3 months, 30-60 days and 1-30 days[33] respectively. For most modern machines it has been obtained from practical observation that the life of the bronze wire hardly exceeds 10 days. The life of the fabrics in the same operational environment is 1-10 times of that of metallics. According to KIKIEWCH[16] the life of the bronze wirs is 4-8 days and the same for fabric is 2-8 times on most modern machines. The same auther[16] cited that life of plastic wire would become 3-10 times than that of bronze wires if G.S.M. exceeds 80. According to MACDONALD[22], the monofilament fabric life is 3 to 6 times that of metal wire Gune[7] based on factory trials with indigenously fabricated phosphor bronze and synthetic fabrics found that while metallic wire had life of 1-2 days due to creasing, the latter had a life of 60 days Bradshaw[2] found the life of bronze wire to be 20 days in comparision to 100 day for fabric i.e. 5 fold increase in life. Garg etal[6] discused that the life of bronze averaged 6 to 8 days in comparision to that of fabric wire running time 9 to 10 times longer on the same machine. Combination of synthetic in warp and phosphor bronze in weft gives 3 times more life[16] than Phosphor Bronze and brass combination.

From the above mentioned reviews it can be concluded that the synthetic fabrics are having approx. 6 times durability even for same kind of machine and for high speed machine there is no other alternative, except synthetic fabric of any combination otherwise there is huge loss of investment due to very short life of bronze wire. However it seems to be a common practice in the mills to assume the life of a syntheic wire to be three times that of a metallic wire as a synthetic wire is 3 times costilier than the metal wire. This procedure does not seem logical as the actual life of a synthetic wire is much more than 3 times that of metal wire.

ECONOMIC FEASIBILITY

For making economic feasibilty each and every cost component contributing to total cost is needed. Followings[32] are the criteria for comparing economic features of apparently suitable materials. material costs, production costs, probable life, lost time costs, liability at special hazards.

RAW MATERIAL COSTS

The cost of raw material includes the freight and transporation charges and it comes under the manufacturing costs. Bradshaw[2] referred that cost of fabric would be approximately 2.5 times that of a metal wire. Similar value (2.5-3 times) is incorporated in literature[1,5]. In Indian conditions, a standard bronze wire costs Rs. 350/m^2 and the same for fabric is Rs. 1000-1050/m^2 [33]. The other manufacturing costs[32] are operating labour and supervision, maintenance and repair, operating supplies, utilities, (Power, steam, water, fuel), periodic cleaning and installation.

OPERATING LABOUR

Irrespective of production (15 tonnes-60 tonnes/day/machine) the labour requirements are same (10-15 persons) excepting during installation. Therefore, expenses for labour are constant for any kind of wires plastic or metallic within the moderate range of production rate labour costs varies from time to time and place to place. The man day costs may be approximated at present time anywhere in India from Rs. 10-30.

Maintenence and rapairs

A considerable amount of expense is necessary for maintenance and repair[1,18,29] if a plant is to be kept in efficient operation condition. These expenses include the cost of labour, material and supervision. Annual cost for maintenance and rapair may range as low as 2 % for light services to 20% for severe cases. In process industries that the total plant cost per year for maintenance and repair is roughly, equal to an average of 6% of the fixed Capital investment, out of which 1-3% are for wages and 1-3% are for material. For severe corrosion these figures are 3-5% and 4-6% respectively. As a rough approximation the Price Formula may be used for maintenance cost evaluation[1,32].

$$C_{main} = x\,(a_1 + b_1 y) \quad (8)$$

In Paper Industry this cost is generally more in case of metallic wire installation. Further more the cost of labour and material for mending and patching etc. will add to this cost. This maintenance and repair may be accomplished during planned shut down time or may be non-planned. Generally 7-10 days/year are planned or scheduled maintenance and repair time. In absence of absolute data the repair and maintenance charges can be expressed in the form of a fixed percentage of base cost.

CLEANING COSTS

For chemical cleaning there is practically no difference between these two types of items. But for mechanical cleaning the fabric wire needs high pressure oscillating shower jets and consumes more power. It has been estimated that the total cleaning cost is approx. 1.1–1.2 times in case of fabric in comparision to metallic wires. Make up water cost may be negligible. During mechanical cleaning, of course, there is no revenue loss due to production in both the cases. As patching problem is less in case of synthetic wire this extra cost due to water may be balanced off. Normally 2 man hours are needed for patching and 10-15 min. with 2 persons for chemical cleaning.

UTILITY COST

The cost for utilities such as steam, electricity, process water, fuel varies widely depending upon the amount of consumption, plant location and source[32]. Water consumption is higher in case of synthetic fabrics due to high pressure water shower. More power consumption in couch roll has been noticed, trimming cost is appreciable in case of metallics. This may be cancelled out with water cost. It has been found out from practical observation[23] that power consumption is around 1.33–2.0 times higher in case of synthetic wire installation.

INSTALLATION AND REPLACAMENT

For equipment and allied materials it is normally found to be 5-30% of the purchased cost in chemical process Industries[24,32]. For Paper Industry with run out or cantilever system replacement time is 4-8 hrs. It includes the total change over time (dismantling, idle and reassembling). For the same system fabric wires takes 1.5 – 3 hrs. For manual system it needs 8 hrs. with simultaneous working of 10-12 persons for metal and 5 hrs. for fabric. The cost factor may be conservative. But it is sure that the installation of fabric is easier and less time consuming. The cost terms involved here are mainly due to labour and power.

FIXED CHARGES AND DEPRECIATION

This costs are invarient with the amount of production[24]. This includes property taxes, insurance & depreciation. Fixed charges excluding depreciation amount to about 10-20% of the total manufacturing cost as a rough approximation. This cost is usually ignored in case of web-forming section because of the consumable nature of wires and felts and fixed Capital investment predominates. Depreciation term which is normally (10% of the fixed capital) in other Industry is not also taken into consideration. The other important cost related term involved here is scrap value or Salvage value. For metallic wire salvage value is roughly one fifteenth to one-twentieth of the initial base cost but for synthetic wire this value may be neglected.

DEVELOPMENT OF COST EQUATION RELATING TO MANUFACTURE

The total manufacturing cost as already described in these two alternate situations comprise of the following breakups : Raw material costs, operating costs such as operating labour, operating supervision, maintenance and repair, operating supplies, utilities (steam, fuel, water and electricity) over-head costs, fixed charges.

Therefore total manufacturing cost/unit of production[1] for metal (bronze) wire installation $= C_{Tm} =$ Raw Material cost $(C_m) +$ Fixed charges $(C_F) +$ cost due to maintenance and repair (Cr-m) $+$ cost for installation and replacement $(C_{IR}) +$ cost for utilities $(C_u) +$ cost for cleaning $(C_c) +$ cost for direct labour and supervision (C_L) ....(9)

The raw material cost C_m is related to the base cost for unit/area which depends upon the length and width of the wire. Length is related to product.on according to the following equation[21]

$$L = K\sqrt{\rho} \qquad \text{.............(10)}$$

If we represent the first four terms in terms of the raw material cost/base cost, the total manufacturing cost equation becomes

$$\begin{aligned} C_{T(m)} &= C_B\ A\ n_m\ (1 + f_1 + f_2 + f_3) + C_u + C_c + C_L \\ &= C_B\ L_x W\ n_m\ (1 + f_1 + f_2 + f_3) + C_u + C_c + C_L \\ &= C_B\ WK\sqrt{\rho}\ n_m\ (1 + f_1 + f_2 + f_3) + \\ &\qquad C_u + C_c + C_L \quad \text{.........(11)} \end{aligned}$$

Similar equation can be deduced to represent total manufacturing cost for the same amount of production in case of Synthetic wire and can be represented as

$$\begin{aligned} C_{T(P)} &= C_p.\ WK\sqrt{P}\ n_\rho\ (1 + f_1 + f'_2 + f'_3) + \\ &\qquad C'_u + C_c' + C_L \quad \text{.............(12)} \end{aligned}$$

If the base cost for plastic wire is N times that of bronze the equation (12) can be written as

$$C_{T(P)} = C_B . N.WK\sqrt{P}\, n_p (1+f_1+f'_2+f'_3)+ C'_u + C'_c + C_L \quad \text{(13)}$$

The annual utility cost for entire process depends upon the amount of consumption of steam, eleccricity, fuel and process water.[32]

Typical values for production of kraft paper can be given as[26] electricity 0.37 kwhr/kg., 4.2 kg. steam/kg., 3 kg. of fuel/kg., 0.21 m^3/kg. for water.

At the wire only steam and electricity costs are considered and others are neglected. It indicates that utility consumption at wire is directly proportional to process operation rate[26]. In absence of any mathematical expression expression annual consumption rate is expressed as a function of annual production rate[26] and can be written as

$$C_u = C_s K_1 P^{n}{}_1 + C_e K_2 P^{n}{}_2 \quad (14)$$

$$C'_u = C_s K_1' P^{n}{}_1 + C_e K_2 P^{n}{}_2 \quad (15)$$

Periodical cleaning costs[24] needs the idea of consumption of chemicals, its costs, frequency and duration of cleaning. Therefore, it appears that the equation will be complicated because of the semi continuous mode of operation. It will be felt prudent to use as functional dependence of production and can be represented as

$$C_c = C_c K_3 P^{n}{}_3 \quad (16)$$

$$C'_c = C_c K'_3 P^{n}{}_3 \quad (17)$$

Substituting the equations (14), (15), (16), (17) & (13) one gets.

$$C_T(m) = C_B.W K\sqrt{P}\; n_m (1+f_1+f_2+f_3) + C_S K_1 P^{n}{}_1 + C_e K_2 P^{n}{}_2 + C_c K_3 P^{n}{}_3 + C_L \quad (18)$$

$$C_{T(P)} = C_B . N.W K\sqrt{P}\; n_p (1+f_1+f_2'+f_3') + C_S K'_1 P^{n}{}_1 + C_e K_2' P^{n} + C_c K_3' P^{n}{}_3 + C_L \quad (19)$$

Marginal increase in manufacturing cost is obtained by (19) from (18), which gives.

$$C_{T(m)} \sim C_{T(p)} = C_B\, WK\sqrt{P}\; [(n_m - Nn_p) + (n_m f_1 - Nn_p t_1) + (n_m f_2 - Nn_p\, f'_2) + (n_m f_3 - Nn_p f'_3)] + C_s P^{n}{}_1 (K_1 - K'_1) + C_e P^{n}{}_2 (K_2 - K_2') + C_c P^{n}{}_3 (K_3 - K_3') \quad (20)$$

$$= C_B WK\sqrt{P}\, [\triangle n + \triangle f_1 + \triangle f_2 + \triangle f_3] + \triangle C_s + \triangle C_e + \triangle C_c \quad (21)$$

A close look at the above equation will show that $\triangle n$, $\triangle f_1$, $\triangle f_2$, $\triangle f_3$ are always positive while $\triangle C_s$, $\triangle C_e$ are negative and $\triangle C_c$ is insignificant. The magnitude of the factors $\triangle C_s$ and $\triangle C_e$ are far lesss controllingthan the magnitude of positive factors $\triangle n$, $\triangle f_1$, $\triangle f_2$ and $\triangle f_3$. The magnitude of increase in manufacture costs when using a metal wire in preference to a synthetic wire can be assessed only when actual cost figures are available.

PROFITABILITY ANALYSIS

The most commonly used methods [24,32] for profitability evaluation are :Return on investment, cost and profit chart, discounted cost flow based on full life performance, Net present worth, payout time etc. Each of these methods has its advantages and disadvantages. For new venture the profitability analysis can be effectively made using the concept of new earnings on the invested money. To obtain reliable estimates of investment returns, it is necessary to make accurate predictions of profits and the required investment. To determine the net earnings estimates must be made of direct production, fixed charges, plant overhead costs and general expenses. From the analysis of a capital allocation problem[32], it can be concluded that if the money should not be risked in a project for which the rate of return is less than the current earning rate of the firm a simplified economic design criteria can be established $\frac{E}{I} > i$ which further leads to the marginal investment design criteria :

$$\frac{dE}{dI} = i \quad (22)$$

In the present case profitability analysis is made on a small component of an overall operation and the return on investment is based on the fixed capital investment instead of total investment. Net earnings is related to the gross earnings according to the following relation.[32]

$$E = P\,x = P(1-Y) \quad (23)$$

Where Y is the function on income-tax. Average income tax for chemical company is 52% of gross earnings. For pulp and paper it is roughly 50.5%. This value becomes uncertain in Indian conditions and lies between 55-60%. It is quite reasonable at this present stage to assume this value to be 55% for calculation purposes.

SAMPLE CALCULATION

Service Life :	Bronze :	1-10 days (6 days average)
	Fabric :	60 days :
Unit Base cost of wire :	Bronze :	Rs. 350/m^2
	Fabric :	Rs. 1050/m^2 (3 times higher)
Salvage value :	Bronze :	1/15 to 1/20 of the initial cost.
	Fabric ;	Nil
Income Tax :	0.55 of the Gross earnings.	
Working days: in ayear:	360	
Scheduled or planned : maintenance and repair shut down.	5-10 days/year (say 7 days)	
Non-planned shut down: in Case of power failure	$1\frac{1}{2}$ hr/day.	

Production : Length of the wire = 34 metres
Width of the wire = 4.2 metres
Speed of the machines = 200-250mts/min
C. S M. = 60-120
Production rate = 60 tonnes (approx.)

A. **Reduction of fixed capital inxestment :**

i) No. of Bronze wire required per year = 60
Base cost of each wire = Rs. $34 \times 4.2 \times 350$ = Rs. -9980 = Rs. 50,000/-
Total material costs/year = Rs. 30,00,000/-
No. of fabrics required per year = 6
Base cost of each fabric wire = Rs. 149040/- = Rs. 150000/-
Total material costs/year = Rs. 900000/-
Reduction in raw material cost = Rs. 100000/-

ii) **Salvage Value**
Salvage value/year for the bronze wire = $1/15 \times 3000000$ = Rs 2,00,000/-
Actual reduction in raw material costs = Rs. 1900000/-

B. **Operational Charges :**

i) Change over time : (Installation. replace ment and idle time). with runout or cantiliver system bronze wire needs 4 6 hrs. as total change over time. For manual system 7-8 hrs. are needed with 12-15 persons including one hour idle time. The change over time for plastic wire is normally 3 hrs. For metal wire the total time spent for wire changes/year = 60x5 = 300 hrs.

For plastic wire the time spent/wear for installation and replacement = 6×3 = 18 hrs. The down time saved for wire changes = (300—18) hrs. = 282 hrs.

Additional time required for normal maintenance in case of Synthetic wires is nomally 4-5 days which includes the time spent for installation as well as replacement. Therefore the net downtime saved for wire changes = 200 hours. The costs involved are operating labour and production loss : Normally 3 extra labourers are required for wire changes.

Labour cost saved Rs. $200 \times 3 \times 20/8$ = Rs. 1500 = Rs. 0.015×10^5

Productin saved : $200 \times \frac{60}{24}$ = 500 tonnes

Kraft paper selling price = Rs 7000/- tonne.
Total earnings from sales = Rs. 500×7000 = Rs. 3500000 = 35×10^5.

ii) Scheduled and non scheduled steps are same in both the cases Therefore no earnings are involved due to this down-time. In planned shut down time normally maintenance, repair, cleaning are carried out.

iii) **Revenue loss due to utility.**

Consumption of steam, electricity, water is higher in case of fabric per unit of production than that for metallic wire. In absence of data regarding consumption of these chemicals, the revenue loss for utility could not be calculated. However, it is obvious that this extra expenditure is negligibly small compared to any other cost item.

iv) Cleaning costs are also comparable in the two cases.

v) Labour costs are also equal (10-12) persons/shift). Therefore it will not add anything to the new earnings.

C. **Other revenue due to operation**

i) Gain in production due to increase in machine speed. Bradshaw reported[2] that due to change over from metal to fabric and installation of a new dewatering equipment machine speed will be increased and quality control rejects will be reduced which will lead to approx. 5% increase in production. This increase may be due to the increase of dryness of wet web at couch roll.

Assuming 340 days are actual no. of days/year (7-10 days for planned shuts and 1 hr./day at the maximum in case of power failure), for production, the total amount of production

$= 20400$ tonnes

Paper production through fabric wire

$= 21420$ tonnes

Increase in production $= 1020$ tonnes

Total revenue/year $=$ Rs. 7140000

From Sales.

D. **Total Net Earnings/Year**

Total average revenue from Sales due to operational advantage and increase in machine speed. $=$ Rs. 3500000 + Rs. 7140000

$= 10640000 = 106.40 \times 10^5$

The average ratio of production cost to sale price in 1981 in India (34) is $= 0.8223$.

Based on the increase in raw material prices, this figure is taken as 0.85 for the present case.

Accordingly gross earnings from sales

$= 106.40 \times 10^5 (1-0.85)$

$=$ Rs. 15.96×10^5

Savings due to laboure and materials (wire changes)

$= 19 \times 10^5 + 0.015 \times 10^5$

$=$ Rs. 19.015×10^5

Total savings before taxes

$=$ Rs $19.015 \times 10^5 +$ Rs. 15.96×10^5

in the new venture

$=$ Rs. 34.975×10^5

Taxes to be paid on gross profits at the rate of 55.0%

$=$ Rs. $15.96 \times 10^5 \times 0.55$

$=$ Rs. 8.778×10^5

Net profit from sales $=$ Rs. $15.96 \times 10^5 \times 0.45$

Rs. 7.182×10^5

Net savings after taxes in the new venture.

$=$ Rs. $7.182 \times 10^5 +$ Rs. 19.015×10^5

$=$ Rs. 26.197×10^5

Extra Capital Cost involved for fabric installation

i)	Hydro foil (forming board) equipment	= Rs. 500000
ii)	High pressure shower equipment with oscillating jets.	= Rs. 50000
iii)	Polypack such in boxes covers (3 Nos)	= Rs. 19000
		Rs. 568000

These are exclusively needed for modern high speed machines. However Sarangi[26] reported that table roll replacement by hydrofoil is not essential for slow and high speed machines.

The payout time for additional equipment before taxes n_b is based on fixed investment I_f

$$n_b = \frac{I_f}{P} = \frac{568{,}000}{34.975 \times 10^5} \times 12 \times 30 = 58.46 \text{ days}$$

$$= 59 \text{ days}$$

Payout time based on net earnings is

$$n_a = \frac{I_f}{E} = \frac{568{,}000}{27.581 \times 10^5} \times 12 \times 30$$

$$= 78 \text{ days}$$

$$= 2.6 \text{ months} = 3 \text{ months}$$

These values compare very well with those reported by Bradshaw Purely based on only investments on the wire and the production the production per unit investment can be used as a basis for comparison.

Total investment $=$ Rs. 30×10^5

Production $= 20400$ tonnes

$$\text{Production/Rs. (Tonnes)} = \frac{20400}{30 \times 10^5} = 580 \times 10^{-5}$$

For Plastic Wire

Total investment : Rs. $9 \times 10^5 +$ Rs 5.68×10^5

$= 14.68 \times 10^5$

Production $= 21420 + 500 = 21920$ tonnes

$$\text{Tonnes/Rs.} = \frac{21920}{14.68 \times 10^5} = 1493.19 \times 10^{-5}$$

This clearly shows the advantage of using synthetic wire in prefernce to the conventional metallic wire.

CONCLUSION

The above analysis gives us a method of comparing the performance of two different types of wires. The accuracy of the mehod will depend on the correctness of cost figures. The payout time and unit production investment costs can be used as good criteria in making a proper selection of wire systems be it metallic or synthetic at the wet end of the machine. There is need for the user mills to provide actual cost figures for drawing definite conclusions.

REFERENCES

1. Aries, R. S. and Newton R. D. -Chemical Engineering Cost Estimation - Mc-Graw Hill Book Co., 1955, pp-39-41, 76,162,166.

2. Bradshaw W.H. - IPPTA Vol.- XVI No 3, Sept., 1979 pp-139.

3. Bird, R.B, Stewart W.E. & Lipht-foot, E.N. Transport Phenomena, A Wiley International Edition, 1960,pp- 200.

4. DasGupta, S.P.-Report on Energy Conservation in plup and paper Industry-held at Japan 1982.

5. Dayden, C E - Outlines of Chemical Technology, East West Press Ltd, 1967,pp-478.

6. Garg, N,K. and Bhargava, S.L. - IPPTA Vol. XVI, No. 1 March 1979,pp-23-

7. Gune,, N.V. IPPTA Vol. No. XVI No. 1, March 1979 pp- 7-

8, Goyal, M.K and Banerjee, C. IPPTA Vol.- XVIII No. 2, June 1981, pp-42.

9. Goyal, M.K. and Kumar, S. IPPTA, 19 (2) June, 1982 pp 48

10. Haylock, J P.,- Paper -its making, merchanting and usage- Longman, 1974, pp-75.

11. Helle, T. Dr Ing. - paper Tech and Indusry 21 (4) 123, 1980.

12. Hose. A.G. Britt, W.K. (Editor) - Handbook of pulp and paper Tech -Second Edition-Van NOS trand, Reinhold Company, 1974, pp-503-507.

13. Ionides, G.N. and Donglas, E C -TAPPI, Vol-60 (1) 1977.

14. I S. Codes 2825- 1969 pp-14.

15- Joshi. M.V - Process Equipment Design-Mac Millan India Ltd., Second Edition,1981, pp-18.

16 K_1K_1 Ewich. Z & Pandey, R S.D.-Theory and Design of Paper Machine, Vol-1, Tarabook Agency, 1983, pp-112, 131, 134-35, 163-164, 167.

17. Linderof, J- Svensk Paper Stiding 81(10), 333, 1978, IPPTA (XVII,2) June, 1980.

18, Leonard, J.D.- Chemical Engineering, 58(9) 151-1951.

19. Lyall, J D.-TAPPI-1974 pp-207, 37 (5)

20. Macdonald, M.-IPPTA Vol-XVI, No-1, March, pp-1.

21. Man Mohan Singh and Negi, D.D.S-IPPTA, Vol-XVI (1), March, 1979, pp-19.

22. Macdonald, M. 1 bid, pp-15

23. Macdonald, G,R.-Pulp and paper Manufacture McGraw Hill Book Company, 1970, Vol III, pp-289-295.

24. Peter, S.M. and Timmerhaus, D.K.-Plant Design and Economics for Chemical Engineers Third Edition, Mc-Graw Hill KogaKhusa Ltd. 1980 pp-468.

25. Rao Mohana G.-IPPTA Vol-XVI, No. 3 Sept. 1979

26. Rudd, D.F. and Watson, C.C,-Strategy of Process Engineering. Wiley International Edition, 1968 pp-133.

27. Sarangi. S. and Sangar, K.D -IPPTA, 19 (2) June 1982,pp-46.

28. Sarangi. S. June,1981. pp-45.

29, Tyler Chaplin-Chemical Engineering Economics- Mc-Graw Hill Book Company, 1926, pp-162

30. Uppal, M.M.-A Text book of Engineering Chemistry, 6th Edition. Khanna Publishers, 1966, pp-285, 485, 489.

31. V. Podder- Technology in Paper Industry-Pitambar Publishing Co., First Edition, 1983, pp-520.

32. Vilbrandt, C F. & Dryden, C.E.-Chemical Engineering Plant Design Fourth Edition, Mc-Graw Hill Book Co., 1959. pp-85, 190, 228 240, 251-254-

33. Private Communicatian with factory Personnels in India

34. Subhas Chandra. 354 Special Course on stock preparation and paper making May. 17-29 1982 Sl No. 25 held at I P.T. Saharanpur.

NOMENCLATURE

A	: Surface area or Cross Scctional area. m^2.
A_1	: Constant in ERGUN Equation .... (1)
a	: Aspect factor in Permeability equation .... (4).
a_1	: Material index defined as the cost in Rs. of repair material part KWhr.
B_1	: Constant in equation (1)
b_1	: Labour index defined as the man hours of repair labour/Kwhr used.
C	: Cost Factors.
C_T	: Total cost, p for fabrics, m for metallic, Rs.
C_B	: Base cost of metallic wires, Rs/m^2
C_C	: Annual cleaning cost (annual) Rs.

C_F : Fixed charges. Rs.

C_{IR} : Annual cost due to installation and replacement. Rs.

C_L : Annual cost of direct labour and supervision. Rs.

C_{r-m} : Annual cost due to maintenance and repair. Rs.

C_S : Cost of steam/kg. Rs.

C_e : Cost of power/Kwhr. Rs/Kwhr.

C_c : Cost involved/cleaning. Rs.

C's : Respective costs for fabric installation. Rs.

D : Diameter of fibre, mm

P_E : Net earnings. Rs.

f_1, f_2, f_3 : Factor for fixed charges, maintenance and repair.

G_o : Superficial man velocity, Kg/m^2hr.

g_e : Newton's connection factor.

h : Manometric height in water permeability, cm.

I_f : Fixed investment. Rs.

I : Total investment Rs.

L : Rate of return Rs./year/Rs allocated.

K : Dimensional Constant in equation (10).

$K_1, K_2 K_3$: Proportionality factors in equations 14 to 17) etc.

L : Thickness of mat in the wire. m

L_a : Actual length of flow path. m

l : Length of the wire. m

n : No. of wires required/year, m-for metal, ρ for synthehetic.

n_1, n_2, n_3 : Power of annual productivity.

N : Cost time of metallic.

ρ : Production rate, kg/hr/trim.

P : Production rate, Tonnes/year.

$\bar{p}$: Gross earnings. Rs.

S_r : Speific surface area of fibre.

V,V' : Volumetric rate of water drainage,m^3/hr.

W ; Width of wire. m

X : Electricity used/year, KW/hr.

Y : Income Tax in fraction of Gross Earnings.

y : Cost per man hour with over head.

Creak Symbol

ϱ = Density of liquid.

μ = Viscosity of liquid.

$\triangle$ = Difference

ϵ = Porosity or void fraction.