Black Liquor Evaporation : The key to Power And Chemical Recovery

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ABSTRACT

The black liquor from the pulping process is an aqueous solution of complex organic aud inorgaeic materials. Its organic content has a gross heating value of approximately 5500 Kcal/kg at 20°C. If, however, the black liquor is fed to the recovery furnace at a low concentration the result is poor steam generation since the evaporation of water in the black liquor consumes a large share of the heating value.

Evaporation technology of conventional LTV or STV has got limitations. It has become a hard task to achieve concentration above 50—52% even with forced circulation concentrators. To meet the firing requirements this is further concentrated in direct contact evaporators.

The incentive of running higher solids in Evaporators was there but the technology was not available. There was a big break through in mid 60's when Rosenblad Corporation of Princeton, New Jersey, U S A developed the falling film free flow (F F F F) evaporators which is being described hereafter.

PASCO-ROSCO EVAPORATION SYSTEM.

INTRODUCTION.

The Rosenblad Free Flow Evaporator described in this brochure delivered its first commercial installation in the mid 60's and has been successful in all services where it has been applied. These services include black liquor evaporators and concentrators for sulphate, all acid and neutral sulfite pulping liquors and distillery effluents etc. These evaporators incorporate stainless steel heating surface. Every application of free flow evaporator has proven successful especially in dealing with a very high level of scaling liquor.

STRUCTURE OF PASCO-ROSCO EVAPORATOR.

Heating surface of Pasco-Rosco Evaporator is so composed that two dimpled plates are put together. The circumference of two plates is seal-welded, and the dimple parts of the plates are spotwelded. It is a hollow heating surface.

A required number of heating surfaces are arranged in the Evaporator in a parallel or fan-shape order. On top of the heating surfaces stainless steel perforated distributor tray is provided.

Heating steam is introduced from bottom of the heating surfaces. Condensate is removed at the bottam whereas non-condensibles are removed at the top. The liquor, which is distributed to heating surfaces uniformly by distributor flows downward on the outside of heating surfaces in a falling film configuration where a portion is removed and the balance is recycled to the top. The vapour is released immediately upon generation and moves horizontally into vapor release area. Mist entrained with vapour is separated from vapour by mist eliminator mounted on the top of Evaporator. Please refer to Fig 1.

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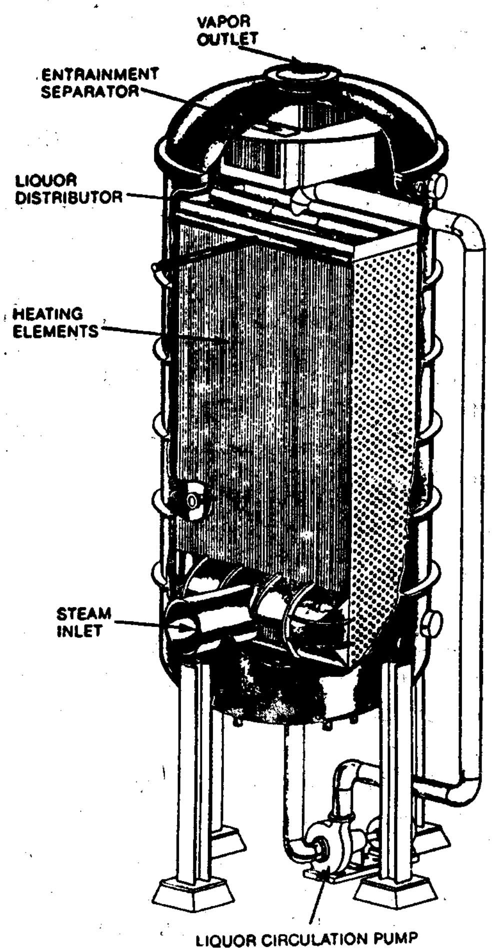


Fig. 1.
PASCO-ROSCO FREE FLOW EVAPORATOR

FEATURES OF PASCO-ROSCO EVAPORATOR.

It now appears that the modern odour-free kraft mill have evaporator where full end concentration can be raised and that the direct contact evaporator has been eliminated.

Any modern evaporator flow diagram will, therefore, incorporate a concentrator to bring the liquor to full end concentration.

1. POWER FOR RECIRCULATION.

Power requirement for circulation in the PASCO-ROSCO Evaporator is much less compared with that of the tubular type forced circulation evaporator. (Refer Table 1 below)

TABLE 1

	Pasco-Rosco	Forced Circulation
Heating Surface (MM)	1,200 X 7,300	31 8 ⌀ X7300
Circulation (M^3/Hr M^2)	0 7	9
Pump Head (M)	10.5	15
Pump Power (KW/M^2)	0.06	0.6

In the case of forced circulation evaporator, it is so designed that the liquor velocity inside tube is 2.5 to 3 m/s. This aims at an improvement in heat transfer coefficient and preventing scale deposit. As a result, the forced circulation evaporation consumes much power for circulation purposes.

On the other hand, in the case of PASCO-ROSCO Evaporator, power consumption is considerably less because it only requires power to pump liquor to the distributor of the Evaporator. The circulation liquor flows down by gravity.

2. SIMPLIFIED CLEANING.

Scale formed on the surfaces must be removed to maintain heat transfer coefficient. Cleaning of the heating surface can be economically significant.

The liquor hold - up of the PASCO - ROSCO Evaporator is relatively small so that a displacement wash with cleaning water can be done in a short time at minimum expenses and more frequent cleaning is economical. Dilute black liquor can be used as the cleaning media and speciality cleaning chemicals are not normally required in case of kraft black liquor evaporators.

In the first effect of the Evaporator the heating surface area is divided equally into 3 sections. In this mode, one section is reserved as a spare surface, and concentration operations are performed in the two other sections.

When scale adheres to and is deposited on the heating surface of the concentrating section, the section is washed with diiute black liquor, and in turn, the spare section performs the concentration operation.

Each of the three sections perform cyclically, full-end-concentration, middle concentration and washing at any given interval of time.

As a result the exchange sufaces are maintained clean for peak efficiency and interruption of production for cleaning is not there.

3. PLUGGING.

Scale formation in tubular heating surface is deposited in successive layers. The scale deposits are dense and normally cannot be cleaned by dilute black liquor displacement washes as is possible with PASCO-ROSCO Evaporator.

4. VISIBLE HEATING SURFACE.

The liquor to be evaporated flows in a downward direction on the heating surface while steam is condensed inside the heating surface. It is possible to observe the heating surface during evaporation from the large sight glasses.

5. TURN-DOWN RATIO.

With the very low temperature difference required to sustain the evaporation and the constant liquor circulation flowing on the falling film heating surface this evaporator is very stable at all evaporation rates. It can generally be operated in any range from 20 to 100 percent.

6. GREATEST AMOUNT OF CLEAN CONDENSATE.

Contaminated vapours enter the bottom of heating surfaces and flow upward while condensate flows downwards This counter current flow gives a stripping action of methanol and non-condensibles. The PASCO-ROSCO Evaporator will split condensate in one large stream (95% of total) which is odour free and contains less than 33% of the B. O D. and methanol. The small stream (5% of the total) contains most of the pollutants and can be passed through a steam stripper if so desired.

7. LOWEST AMOUNT OF B.O D. AND -ETHMANOL IN CLEAN CONDENSATE.

By selective condensate splitting in more than three or more effects it is possible to reduce the B.O.D. (and methanol) of the clean condensate, thereby reducing B.O.D. in mill sewers in cases where clean condensate is for pulp washing.

DESCRIPTION OF EVAPORATOR OPERATION.

The heating surface of the evaporator is comprised of a multitute of self-supporting surfaces, normally 4 ft. wide, 24 ft high and about 1 inch thick. The heating surfacas are shop assembled into packages containing 20 to 30 surfaces with a spacing between heating surfaces with a spacing between heating surfaces of about 1 inch.

The liquid to be evaporated is pumped from the bottom of the evaporator to the distributor tray where the liquor is distributed over the top edge of the vertical heating surface. A film of liquid flows downwards the heating surface. Due to that the friction between the liquid and the heating surface is greater than the friction between the liquid and the sorrounding vapour. There will be a difference in velocity between the outer and inner layer. This is popularly called turbulence. This turbulence appears as a wave motion on the heating surface which even at high viscosity liquids gives a high heat transfer coefficient. The Reynold No. for turbulent flow for falling film is around 400., compared with 2300 for a tubular type heating surface.

The evaporation takes place when steam or vapour condenses on the inside of the heating surface. The evaporation from the liquid could be defined as a "multiflash" in a micro scale. Liquor is heated close to the heating surfaces, and is cooled by 'flashing' when cxposed to the surrounding vapour. The actual change in temperature during the evaporation is only tenths of degrees, which in practice means that the liquor always has the same temperature.

As the liquor film flows downward on each heating surface, a small portion is boiled off and vapours released move horizontally into the main body of the evaporator. The released vapours then flow upwards and through an entrainment separator before exiting the evaporator body.

Steam or evaporated vapour is introduced inside of each heating surface through a header located at the bottom. Steam then proceeds upwards inside of each heating surface and condenses. The condensate flows downwards in a countercurrent flow to the upflowing steam and is removed from the inside of the surfaces. Non-condensibles are removed from the inside of the heating surfaces through the top vent.

The heat transfer coefficient characteristics for a plate type falling film evaporator is that it will decrease with increasing heat load and vice versa, which opens up almost unlimited possibilities for multiple effect applications. Free Flow Failing Film design, the latest landmark in Evaporator technology, is being used in.

1. Multiple effect evaporators.
2. Evaporative Condensers.
3. Waste Heat Evaporators.
4. Vapour Compression Evaporators.

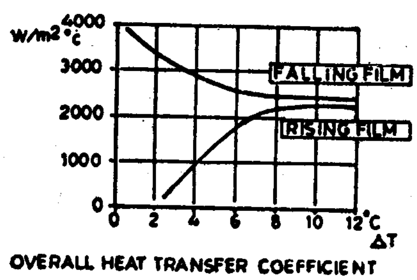


Fig. 2

1. MULTIPLE EFFECT EVAPORATOR.

This type of evaporator uses the steam generated in one effect as the heating media in the following effect. This permits evaporation rates that are much higher than the steam usage up the first effect. The reasons for selecting the evaporator for multiple effect application are as follows :

— Because it requires low temperature diff.rence i. e. driving force it is possible to operated a train of 8 to 10 effects. This allows evaporation rates of 8 to 10 kgs of water per kg of fresh low pressure steam.

— The positive circulation permits 100% turn down and fully stable part-load operation.

— The ease of cleaning fouled heating surface permits a continuous on-line self cleaning operation while evaporating fouling liquor to high solids. This allows product solid concentrating of over 68% without off-line cleaning.

— Over 95% of the evaporated condensate is clean and odour free. Existing LTV evaporator trains have successfully been retrofitted with one more effect, either with a new No. 1 effect as Concentrator or a New No. 6 or 7 in existing evaporator trains. This is made possible due to the low temperature differential required.

Depending on the appiication this can either give capacity increase with improved steam economy or just improved steam economy.

2. EVAPORATIVE CONDENSER.

The Evaporative Condenser combines an indirect condenser and cooling tower into one Unit. The Evaporative Condenser is used to condense or cool fluids from any source; namely - vapours from evaporators, turbine exhaust steam or cool refrigerant. Steam is condensed inside dimpled plate surfaces which are 24 ft. high by 4ft. wide by 1.3 inch thiek. The dimple plate surfaces allow air to flow upwards between them. Water is circulated from a sump to the top of the surfaces and flows down the sides of the dimpled surfaces as a thin falling film. Therefore as the falling fiim of water is heated by the condensing steam inside the surfaces, the water is also cooled by the upflowing air so that a steady state heat transfer condition occurs. Please refer figure 3.

Advantages of the evaporative condenser cooling tower combination are :

— HIGH POWER GENERATION.

The water film flowing down the surfaces is always at a high temperature so that the driving force between the air and water is at a maximum. This allows for a 10 to 15°F lower steam condensing temperature and therefore a higher electrical energy output from the turbine-generator.

— LESS SPACE REQUIRED.

Because of the high driving force between the water film and the cooling air, the velocity of the cooling air is in 24 to 30 fps range as compared to 6 to 9 fps air velocity for cooling towers.

Hence a smaller cross section will result in lower capital cost and will need a smaller floor area.

— LOWER PUMPING POWER :

As only a thin film of water is circulated over the dimpled surface the pumping power is a small fraction of that required for an indirect condenser/ cooling tower combination.

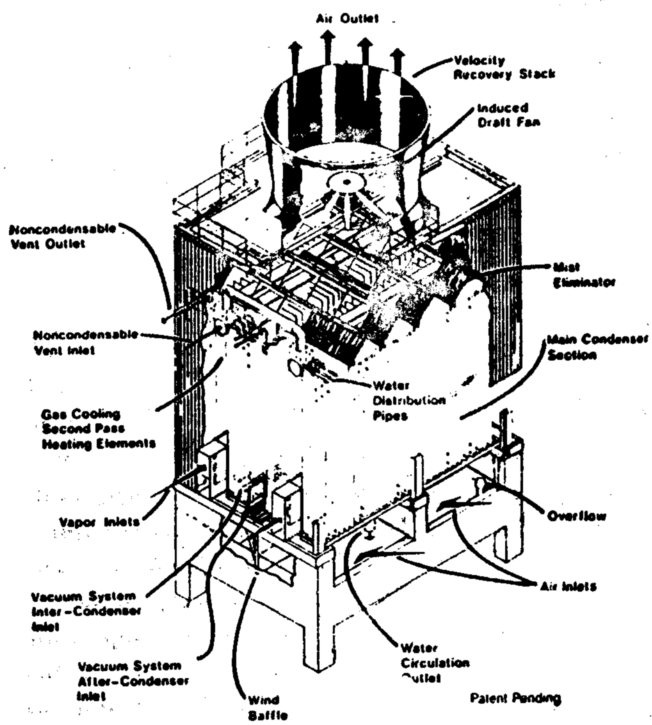


Fig. 3
EVAPORATIVE CONDENSER

3. WASTE HEATE EVAPORATOR : INTRODCTION.

Black liquor discharged from the digester contains a substantial heat potential. Effective recovery of this heat energy contributes to energy saving for the entire mill.

EXHAUST HEAT RECOVERY FOR THE BATCH DIGESTER.

Pulp in the batch digester is discharged to a blow tank with the cooking liquor upon completion of the cooking process. The temperature drops from the cooking temperature to about 100°c by adiabatic flashing The quantity of heat released in this process is approximately 550×10^3 Kcal/BKP ADT.

Considerable blow heat is generated in a relatively short time and the quantity of heat released fluctuates considerably reaching a maximum heated volume of 1.8 times the average at the peak of operations.

1. PRESENT RECOVERY METHODS

Blow steam is condensed by direct contact with recirculating water in the jet condenser, and the heated recirculating water is used for heating fresh water, The fresh hot water thus produced can be used for pulp washing hot water for bleaching process :

When,

— blow heat $Q = 550 \times 10^3$ Kcal/BKP ADT

— required temperature of hot water $tw2 = 70°C$

— temperature of fresh water $twl = 20°C$

hot water production quantity will be :

— hot water production quantity $w = Q/(tw2 - twl)$

$= 550/(70 - 20)$

$= 11$ t/BKP ADT

2. PASCO-ROSCO BLOW HEAT EVAPORATOR

The PASCO-ROSCO blow heat evaporator is used to concentrate dilute black liquor and produce hot water at the same time, utlizing blow steam as a heat source for the evaporator. In planning recovery with a double effect evaporator, hot water is obtained by preheating cold water using the second effect evaporated steam which is heated to 70°C by a part of the firtst effect evaporator. The remaining part of the first effect evaporated steam can of course become the heat source of the second effect evaporator.

Dilute black liquor is supplied nnd drawn out to and from each blow heat evaporator in parallal sequence in order to prevent a drastic drop in the supply liquor temperature for the existing evaporator. The result is in balance as shown in Fig. 4.

The table 2 gives the figures when compared with existing evaporators.

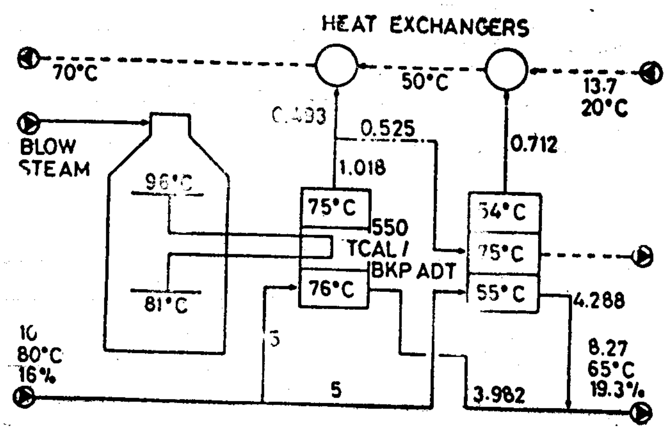


Fig. 4
BLOW HEAT EVAPORATOR IN BATCH DIGESTER

TABLE 2

BLOW HEAT RECOVERY — BATCH DIGESTER
UNIT : TON/BKP ADT

		EXISTING CONDITION	BLOW HEAT EVAP.
Dilute Black Liquor		10 (16% TDS)	
Conc Black Liquor		2.5 (64% TDS)	
Total Evaporation		7.5	
Evaporation	Blow heat Evap,	0	1 73
	Existing Evap.	7.5	5 77
Steam consumption of Existing Evap.		1.875	1.443
Production of Hot Water		11	13.7
Ratio of Steam Consumption		100%	77%

The total quantity of the evaporation for this blow heat evaporator is 1.73 t/BKP ADT, and hot water of 70°C is 13.7 t/BKP ADT.

Assuming that

— total dissolved solid : S = 1.6 TDS/BKP ADT
— full end concentration : X P = 64% TDS
— Dilute black liquor concentration : X i = 16% TDS
— Quantity of total evaporation : ET
black liquor : F

The total quantity of evaporation will be :

$$E_T = \frac{Xp-Xi}{Xp} X F = \frac{64-16}{64} X 10 = 7.5 \text{ t/BKP ADT}$$

$$F = \frac{S}{Xi} X 100 = \frac{1.6 X100}{16} = 10 \text{ t/BKP ADT}$$

As clearly seen from the above equations, the quantity of evaporation at the rate of 1.73 t by means of the blow heat evaporator is equivalent to 23% of the total evaporation.

As a result, steam consumption of the existing evaporator can be reduced to 77%.

The quantity of hot water will also be increased by 24 5% to the present level.

3. COMPARISON OF OPERATING COSTS

The following describes the basic operational cost for a pulp mill having a pulp production of 300 BKP ADT/D with a batch digester.

1. PRESENT RECOVERY METHODS

When the present evaporator is of five effects, and the steam economy is 4 :

— The total evaporation
E=Pulp production X ET=300 X 7.5=2,250 t/D

— Present steam consumption
S=E/steam econony=2,250/4=562.5 t/D

— Present hot water production quantity
W=Pulp production X Unit hot water production
= 300 X 11
= 3,300 t/D

2. WHERE A BLOW HEAT EVAPORATOR IS UTILIZED :

Where a double effect blow heat evaporator is utilized, this configuration will be :

— Evaporation of blow heat evaporator
EB=Pulp production X Unit evaporation
= 300 X 1.73
= 519 t/D

— Evaporation of existing evaporator
Ee = E — EB = 2,250 — 519 = 1,731 t/D

— Steam consumption of existing evaporator
Se = Ee/steam economy = 1,731/4 = 432.75 t/D

— Hot water production

W= Pulp production X Unit hot water production

W= 300 X 13.7 = 4,110 t/D

When the unit price of steam is Rs. 150/t, the steam cost that can be saved will be :

(S — Se) X 150 = (562 5 — 432.75) X 150 = Rs. 19,462.50/D

When the digester operates 330 days annually, this will equal :

Rs. 19, 462.50/D X 330 days = Rs. 64,22,625/- per year.

While the difference in hot water production is :

4,110 — 3,300 = 810 t/D

B O D DISTRIBUTION IN EVAPORATOR CONDENSATES

B O D distribution in evaporator condensate when Pre-Evaporator is used alongwith Multiple Effect Evaporator and Concentrator is shown in Fig 5 below Condensate sampling in Multiple effect

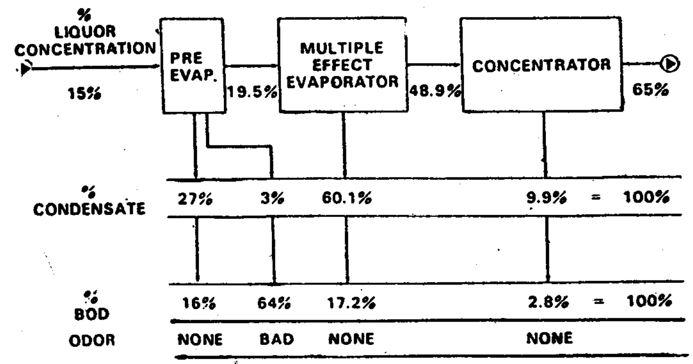
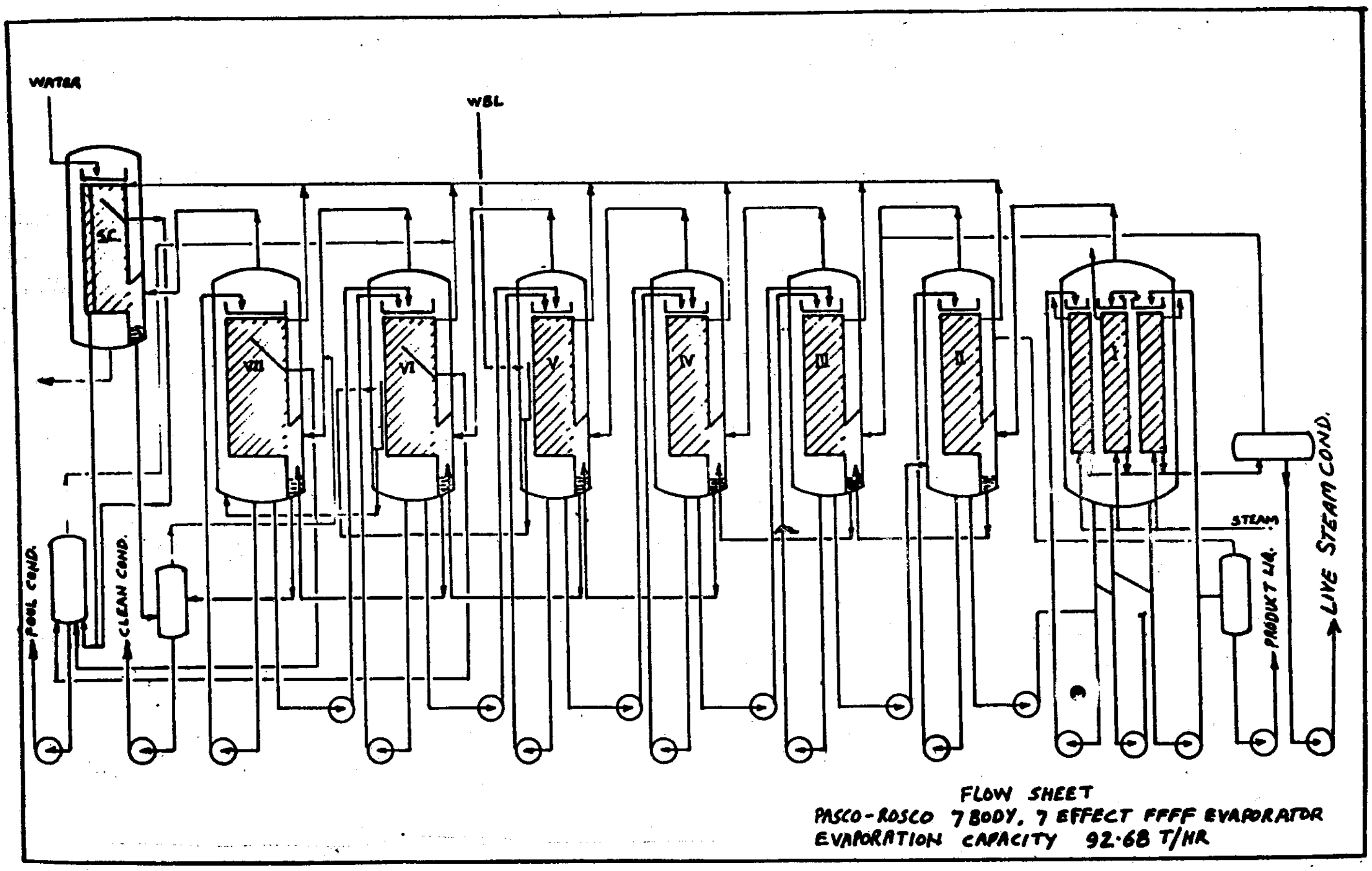


Fig. 5.

evaporators has established that approximately 80% of the total condensate B O D came off with the first 30% evaporation. Since Blow Heat evaporation performs over 30% of the total evaporation, all of the condensate from the existing sets of evaporators would be cleaned up and only about 15% of the condensates from the pre-evaporator would require treatment like steam stripping.



Thus adding up blow heat pre-evaporation system with existing multiple effect evaporator would result in :

1. Reducing the load on existing multiple effect evaporator or in other terms increasing the total evaporation capacity.
2. All the condensate from existing evaporators would be clean.
3. There will be improvement in overall steam economy whereas hot water for process would still be available.

4. VAPOUR COMPRESSION EVAPORATORS :

(i) Mechanical Vapour Recompression Evaporator (hereafter referred to VRC)

Thi- is one of the simplest evaporator techniques, since the boiled off vapour is just passed through a compressor and is then used as the condensing medium at a slightly higher pressure and temperature. The power input to the compressor can be very low especially when converted to Kcal and compared to heat input of a multiple effect evaporator, but this is mechanical power as compared to low pressure steam ordinarily used for the evaporators, and consequently much more costly per Kcal. Therefore the vapour Recompression cycle is much more economical in terms of total energy if it is to be unpassed on the basis of economics. Operational cost comparison between VRC and a 6 effects cycle is shown in Table 3.

TABLE 3—OPERATING COST
EVAPORATION=100T/H

	Utility Cost*	VRC	6 Effect
Steam	Rs. 150/T	0	20.8 T/HR
Cooling Water	Rs. 2/T	0	800T/HR
Power For	Rs. 0.90/ KWH	2300 KWH/ HR	0
Evaporation Operating Cost		Rs. 2070/HR	Rs 4720/ HR

*Cost will very from mill to mill.

(ii) Multiple Effect Evaporator with Thermal Compressor.

This is similar except that a thermocompressor is used in place of a mechanical compressor. This can be used to advantage when high pressure steam is available for the evaporator but cannot be used to increase total temperature differential because of process considerations.