Heat Integration of Multiple Effect Evaporator by Pinch Analysis

B. P. Thapliyal, R. M. Mathur, A.K.Goel, and A. G. Kulkarni

Black Liquor Evaporation is one of the energy intensive unit operations in pulp mill. The steam economy of different types of evaporators used in Indian mills ranges from 2.5 to 5.0 depending upon the type & configuration of multiple effect evaporators (MEE). Steam consumption is often higher on account of fouling tendency of liquor on the heat transfer surface and poor heat integration, which are the main reasons for high energy demand in black liquor evaporation.

Heat integration by using pinch analysis is a very effective tool for optimization of the heat exchange from processes. Pinch analysis, based on simple thermodynamic principles and systematic process integration & optimization approach, helps to achieve financial saving by maximizing the process-to-process heat recovery and minimizing the utility loads. It is emerging as one of the effective energy conservation tool and has been extensively used in Chemical and Petrochemical sector.

In Pulp & Paper industry, pinch analysis can be very effectively used for heat integration of digester house, multiple effect evaporators, paper machines and power network optimization. A large number of mills in developed countries are using this approach to minimize their energy demands. In India, this concept is new and gaining acceptance.

This Paper presents two case studies conducted by CPPRI to understand the heat duty analysis of evaporators and to explore the possibilities of heat integration in multiple effect evaporators used in Indian mills by using pinch analysis as an energy conservation tool.

INTRODUCTION

Pulp and Paper manufacture is highly energy intensive, in spite of the fact that significant improvements in energy efficiency have been made due to introduction of advanced technology and controls system. Energy cost in Indian paper mills accounts from 25-30 % of total manufacturing costs, and therefore energy efficiency improvements offer the largest opportunities for reducing the cost of production .Among the Kraft pulp mill operation, black liquor evaporation is one of the highest steam consumers. In an evaporator system by improving steam economy and attaining higher solids content, recovery boiler performance can also be significantly improved. It is a well known fact that in the recovery boiler at 95 % reduction efficiency, with every 1% increase of water in black liquor, there is a 0.5 % decrease in recovery boiler efficiency. It is therefore economical to remove maximum quantity of water from the liquor in the evaporator bodies in order to maximize the efficiency of the recovery boiler. The best way to accomplish this is by applying process control system, evaporator optimization and all possible heat integration within the evaporator train.

Heat Integration addresses various methodologies aimed at heat exchanger network designing for improving the heat recovery in an existing evaporator train by looking at it as a whole and optimizing the interrelationship of its constituent parts, rather than improving each unit by itself. Thermal pinch analysis mainly developed for analysis and optimization of heat exchanger network, defines the minimum driving force allowed in the exchanger units, which is represented as minimum temperature difference in composite curves, commonly referred to as the pinch. The prime objective of pinch analysis is to achieve financial gains by better process heat integration by maximizing process-to-process heat recovery and reducing the external utility loads. It is emerging as one of the effective energy conservation tool and has been extensively used in Refinery, Chemical and Petrochemical sector.

Looking into the potential of this technique, Central Pulp and Paper Research Institute, Saharanpur initiated studies on application of heat integration and optimization in Indian pulp & paper mills by adopting pinch analysis. The paper highlights the studies conducted at two selected mills for minimizing the specific energy demand through heat integration of multiple effect evaporators by using

Central Pulp & Paper Research Institute, P.O.Box-174, Saharanpur

pinch analysis.

Methodology:

The objective of the study conducted at selected mills was to find out the heat duty analysis of evaporator bodies in multiple effect evaporators (M.E.E.) and to identify the potential of energy conservation by process integration using pinch analysis technique. In first mill, pinch analysis was conducted on hot & cold stream from pulp mill section and evaporator section to establish the energy saving potential. In another mill, data from evaporator streams only was used to carry out the targeting of evaporator section. Heat Integration study of the MEE's involved several steps, which were;

- Plant data Collection from both the mills
- Heat and Material Balance of pulp mill & evaporator bodies
- Data Extraction from heat & material balance
- Targeting by generating Composite Curves (CC) and Grand Composite Curve (GCC), to establish minimum hot and cold utility requirement for the processes.
- Comparison of targeted hot & cold utility requirements with the actual consumption to find out the saving potential. At this stage possibility of process modification to reduce the utility target value was also explored.

Case Studies:

Studies were conducted in following two mills.

Mill – 1:

The mill has 6 batch digesters for cooking the wood chips. After digestion the pulp is washed and resultant black liquor is stored for evaporation in the MEEs. In this mill, heat integration study was conducted in hot and cold stream extracted from pulp mill and evaporator section. MEE consists of six effects (five long tube vertical evaporators and 3 falling film evaporators). Fig. 1 illustrates a simplified process flow diagram of evaporator section.

The mill uses hardwood & bamboo weak black liquor containing about 13 % solids. The black liquor flow sequence is 5-6-4-3-PH2-2-PH1-4FC-4FB-4FA.the bodies in finished stage (4FA-4FB-4FC) are falling film evaporator. The black liquor, which after flashing contains about 52 % solids, is sent to the cascade evaporator where the black liquor comes in direct contact with hot flue gas from recovery boiler. The feed rate is about 80250 kg/hr and the evaporation rate is about 60187 kg/hr. Live steam of 3.0 kg/cm^2 is injected into the chest of 4FA, 4FB & 4FC. The vapour from the 1st effect is then used in the next effect and this process is continued until the 6th effect. The vapours from the 6th effect are condensed in a surface condenser by the cooling water. The condensate available from 1st effect is flashed in two pressure levels (Vapour from the 1st flash vessel goes to the 2nd effect while the flash vapour from the 2nd flash vessel goes to 6th effect. Condensate from the 2 nd effect is flashed and the vapour is fed into the 3rd effect. Similarly condensates from 3rd, 4th, 5th effects are flashed and introduced into the 4th, 5th and 6th effects respectively. Liquid product from falling film evaporators is also flashed and than the flash vapor is taken in 4th effect.

Mill –2:

MEE in this mill has six effects of five long tube vertical evaporators and one forced circulation evaporators (Fig.2).

The hardwood and bagasse mixed weak black liquor containing about 14.5 % solids is fed in following mixed backward flow sequence, 5-6-PH5-PH4-3-PH2-2-PH1-1-FC. Final liquor (effect 4 bypassed) after flashing contains about 50% solids and is sent to the cascade evaporator for further concentration. The feed rate is about 85780 kg/hr and the evaporation rate is about 60680 kg/hr. Live steam of 3.5 kg/cm^2 is injected into the chest of FC and 1st effect. The vapour from the 1st effect is then used in the next effect and this process is continued until the 6th effect. The vapours from the 6th effect are condensed in a surface condenser by the cooling water. The condensate available from FC and 1st effect taken to various flash tanks (FT) from where it is flashed in to five levels. (Vapour from the FT1 goes to the 2nd effect, the flash vapour of FT 2 goes to 3rd effect, the flash vapour of FT 3 goes to 4th effect, the flash vapour of FT 4 goes to 5th effect and the flash vapour of FT 5 goes to 6th effect.)

Pinch Analysis Studies in the Mills:

For the purpose of analysis of pulp mill & evaporators, the processes are broken down into its fundamental units (called streams), defined as a part of

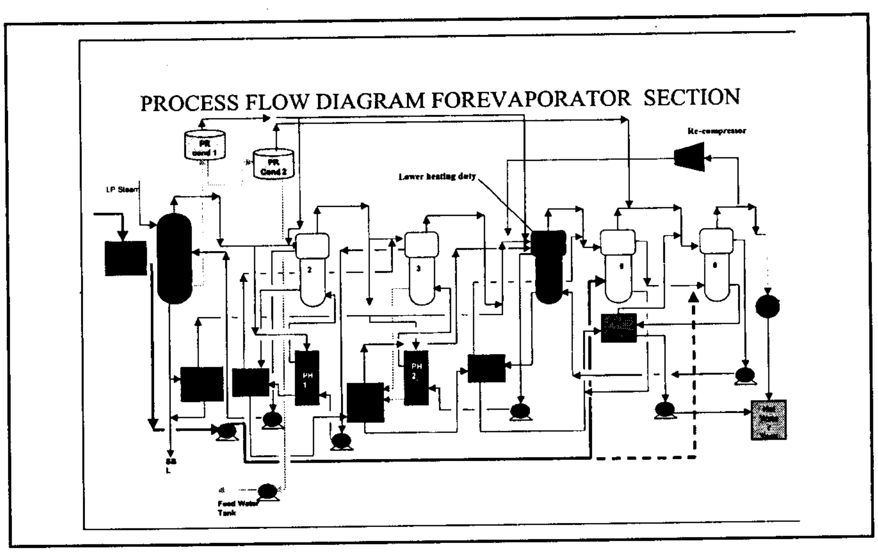

Fig.1 : Process Flow Diagram of Evaporator Section in Mill-1

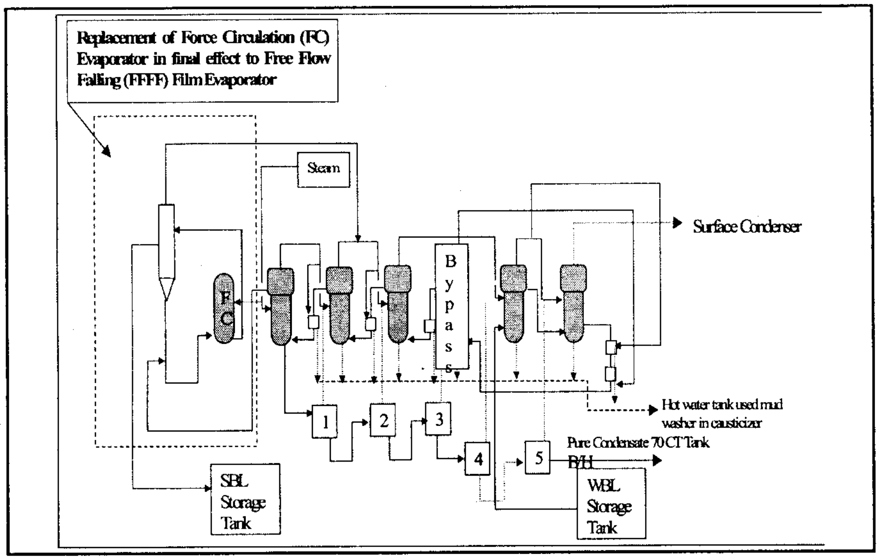

Fig 2: Process Flow Diagram of Evaporator Section in Mill -2

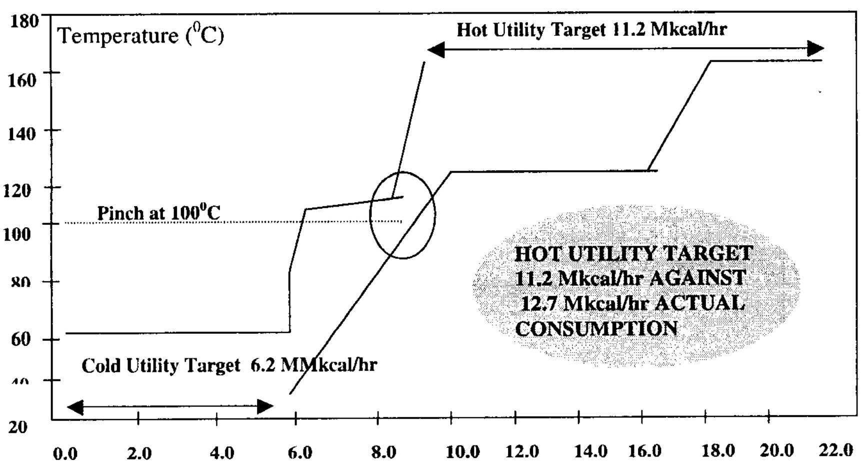

Fig. 3 Composite Curve for Pulp Mill & Evaporator Streams in Mill-1.

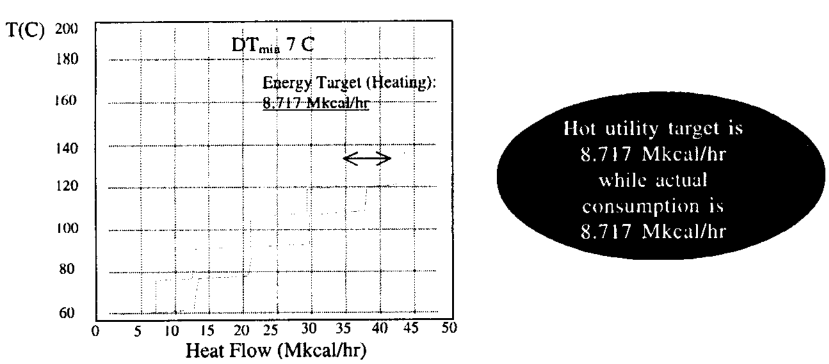

Fig. 4 Composite Curve (Temperature VS Heat Flow) for Evaporator Streams in Mill -2

the process in which heat is added to or removed from a process material of constant mass flow. From the stream data set, the composite curves were generated by plotting temperature against the heat load. The composite heating and cooling curves are shown in Fig 3 & 4 for pulp mill & MEE in mill-1 and for MEE only in mill-2.

Pulp mill & Evaporator Heat Integration in Mill - 1

Based on the stream data for mill – 1, range targeting was carried out to establish the optimum DTmin. Optimum DTmin of 7°C was identified, Composite curve and Grand composite curve were generated based on DTmin of 7°C and are shown in Fig. 3 & 5 respectively. Composite curve reveals that the evaporator section is already well integrated.

Analysis of Grand Composite Curve reveals that vaporization duty in Effect 4 is comparatively less than the other effects. If it was possible to increase vaporization in Effect 4 by modifying the process, energy savings could be achieved. Process modifications were suggested to be carried out in two ways- either by reducing the pressure in Effect 4 or by introducing more vapors in Effect 4. More vapors could be introduced by two ways, either by recompressing low-pressure vapor or by flashing high-pressure condensate. All these options were tried and saving potential for these options is listed below.

i) Reducing pressure of Effect 4 by increasing vapor line size from Effect 4 to Effect 5 produces negligible saving in steam consumption.

ii) Recompressing vapor from Effect 6 and introducing it into Effect 4 will not result in energy savings, since it will consume lot of power.

iii) Flashing condensate from Pre-Condensate Tank-1 to the vapors of Effect 4 by using another flash drum will produces steam savings of 85 kg/hr.

Another process modification was also tried by changing the feed location from

Effect 5 to Effect 6. This process modification could save 300 kg/hr of steam with payback period less than one year. Since, this modification may lead to excessive entrainment of liquor in Effect 6 therefore, a catchall type of vessel may be required to reduce entrainment analysis of all these modifications suggested a moderate energy saving in the Evaporator Section.

Evaporator Heat Integration in Mill – 2

Targeting for evaporator section in mill - 2 was carried out for hot & cold streams from various evaporator bodies only, without integrating it with pulp mill streams. Based on the stream data range targeting was carried out to establish the optimum ΔT_{min} for process-to-process heat recovery. The optimum ΔT_{min} of 7 °C was considered in this case. CC and GCC were generated based on ΔT_{min} of 7 °C and are shown in Fig 4 and 6 respectively. Though the evaporator is very well integrated, following recommendations were suggested.

1. Recompressing vapor from effect-6 and introducing it into effect-1,
2. Flashing secondary condensate and introducing it to effect -1,
3. Replacing the Forced Circulation Evaporator by Falling film Evaporator,

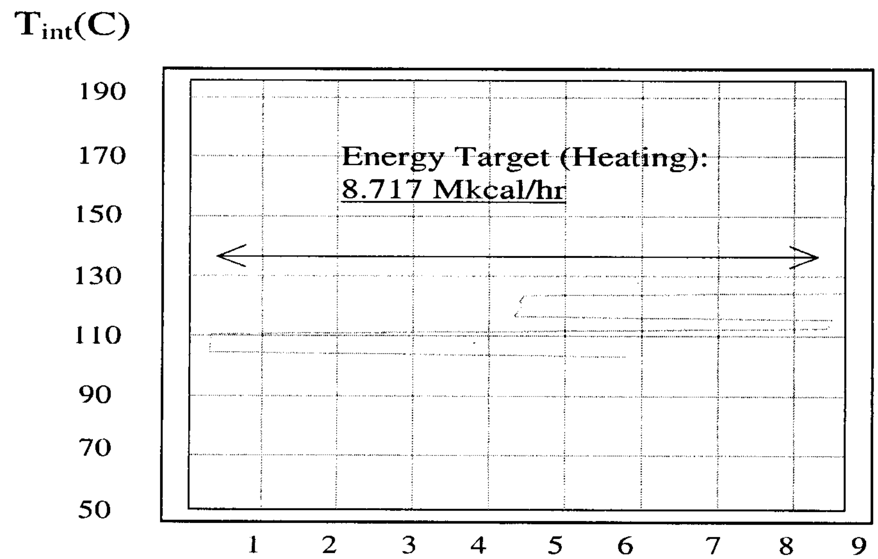

Fig. 6 Grand Composite Curve for Evaporator Streams in Mill-2

Fig 7 & Fig 8 show the CC & GCV after introduction of falling film evaporator in the finisher stage. The hot utility targets after introducing falling film evaporator comes down to 7.01 Mkcal/hr from actual consumption of 8.71 Mkcal/hr.

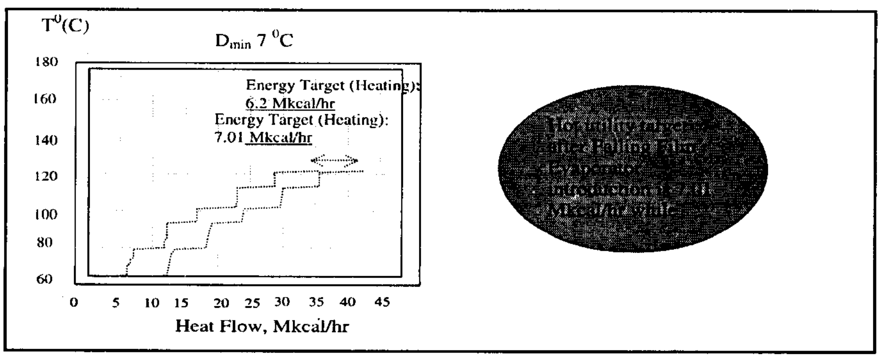

Fig. 7 Composite Curve after Introduction of Falling Film Evaporators in Finisher Stage in Mill-2.

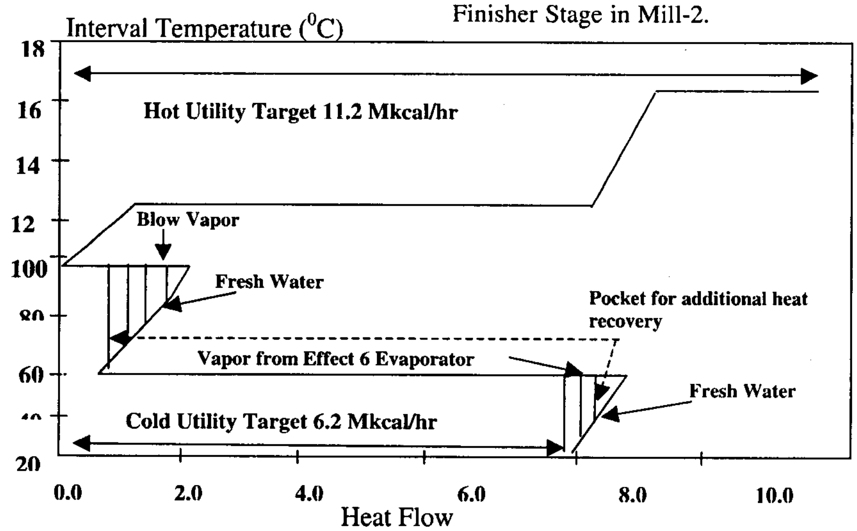

Fig. 5 Grand Composite Curve for Pulp Mill & Evaporator Streams in Mill-1

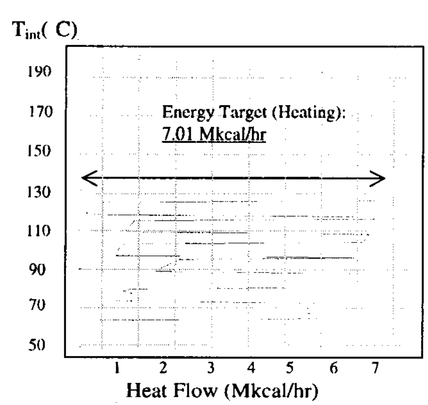

Fig. 8 Grand Composite Curve after Introduction of Falling Film Evaporators in Finisher Stage in Mill-2.

Table-1 Benefits of Energy Saving Schemes.

S.No	Energy Saving Schemes	Benefits		Pay Back Period
		Energy Savings, Mkcal/hr	Steam Saving, t/hr (Savings Rs/annum)	
Mill-1 1.	Introduction of Flashed Vapors from live steam condensate in Effect 4	0.04	0.08 (3.0 lakhs/yr)	Within 3 years
2.	Introduction of feed to Effect 6	0.15	0.3 (11.5 lakh/yr)	Less than 1 year
Mill-2 1.	Recompressing Vapor from 6 Effect and introducing it into Effect 1	0.02	0.04 (1.5 lakh/yr)	More than 3 yrs
2.	Flashing Secondary Condensate and introducing it into Effect 1	0.10	0.2 (7.0 lakhs/yr)	Within 1 year
3.	Replacing the Forced Circulation Evaporator by Falling Film Evaporator	1.0	2.0 (70 lakhs/yr)	Within 3 years

The energy saving schemes and their benefits in both the mills are shown in Table-1.

Conclusions:

Pinch analysis studies conducted in two mills have shown that in spite of the operation of MEEs in a very well integrated manner, there is scope for improvement leading to reduction in energy conservation. During the studies due to lack of proper instrumentation in the mills, most of the measurements were made by using non-contact type measuring instruments, which may result in significant error (upto + 10%) in calculated data. Therefore, if the mills have option to collect online data and if subsequently heat integration analysis is made by using pinch technique, the chances of errors in calculated data may be reduced. this may result in better analysis of heat integration results.

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