Process Integration Through Pinch Analysis : A Concept

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ABSTRACT

Process-integration techniques based on pinch technology represent a new and powerful way to optimize process designs, yielding results superior to those achievable using conventional methods. These new techniques permit the design engineer to track the energy flows in a manufacturing process more clearly and to modify the process to reduce energy consumption. Pinch technology also enables the design of an optimum interface between the process and the utility systems. Pinch analysis has been widely accepted in mills in developed countries resulting in significant energy saving. Present articled highlights an overview of Pinch technology for process integration and its application in pulp and paper industry.

INTRODUCTION

Pinch technology is a process integration technique and a powerful way to optimize the process design, yielding results superior than achievable by using conventional optimization of processes in isolation, tends to optimize the system (a collection of interrelated processes and unit operations) as a whole. Application of pinch technology in pulp and paper industry has provided innovative ways to reduce the energy consumption in pulp & paper manufacturing processes. Reduced energy consumption is one of the beneficial aspect of the pinch technology. Other benefits include correct integration of steam turbines, co-optimization of energy and capital cost, identification of the most appropriate process changes and increased plant flexibility. This approach provides overall process designs that are intrinsically environmentally friendly.

The Concept of Pinch Analysis

Pinch analysis is a new thermodynamic concept where a proper analysis of Process Heat Exchange is required. Appropriate Thermodynamic analysis also leads to identification of preferred options in terms of many other design objectives. for example, minimization of capital cost and operational cost.

In Chemical Process, the engineering design problems are dealt in two ways.

- Unit Operation level or
- Total system design level

In Pinch Analysis the system design problems are considered for indentification of Energy saving opportunities and modification of existing plant or for designing of a new energy efficient plant. The approach vests on concepts that are convenient and simple and make it possible to deal with problems hither to considered complex. The technique emphasizes on simple sums rather than complex mathematics.

Process Heat Exchange Analysis

The hot and cold steams in a process are identified and represented on a Temperature - Enthalpy graph. The analysis work is started from the individual streams and by simple summing of heat contents over temperature ranges, composite curves of all hot streams and cold streams in a process are constructed. The results of hot and cold streams of two composite curves are plotted in a single curve and overlap between the composite curves represents the maximum amount of heat recovery possible with in the process. (Fig. 1) The hot "overshoot" of the hot composite curve represents the minimum amount of external cooling required. Similarly the "overshoot" of the cold composite curve represents the minimum amount of external heating. Both curves approach closely at one point, which is known as "Pinch" (Fig. 2). Pinch is a point below which the system represents itself as a heat source i.e. heat goes out to the cold utilities but no heat goes in. Above Pinch the system is a heat sink. Heat goes in from the hot utility, no heat goes out. The system is therefore separated at the Pinch in total hot and cold requirements of the proceses and indicates the amount of excess heating or cooling

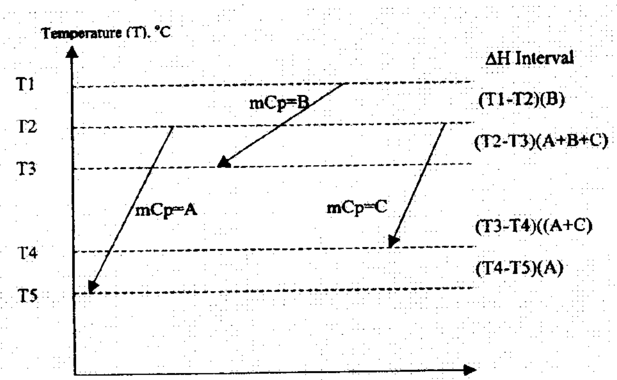

Fig. (a) Heat Content (H), KW

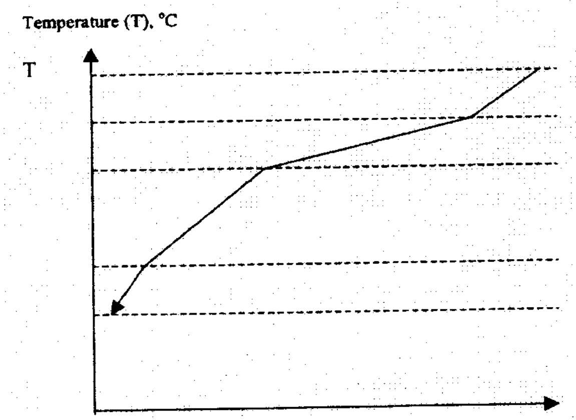

Fig. (b) Heat Content (H), KW

Fig. 1 (a and b) Construction of "Composite Curves"

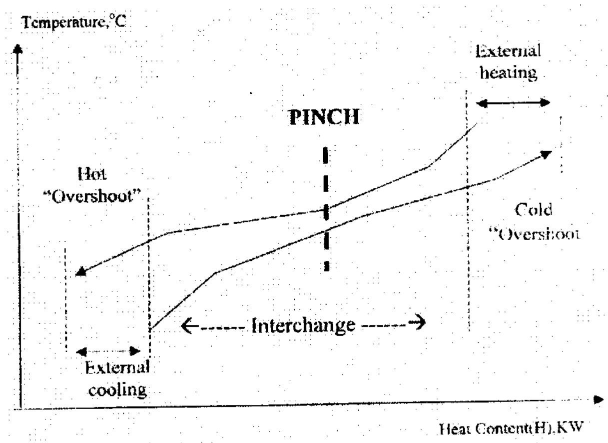

Fig. 2 Composite curves for prediction of energy targets

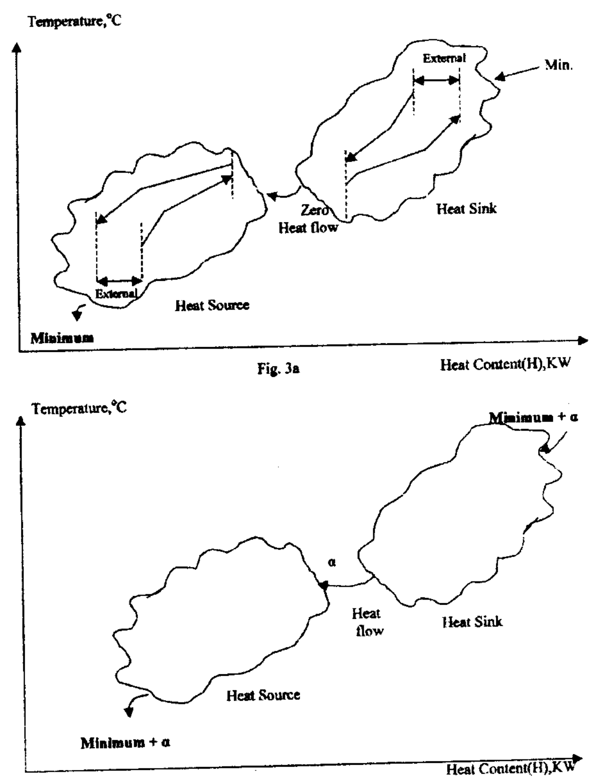

Fig. (3b)

Fig. 3 (a and b) Thermal characterization of a process for heat exchange

being done within the system. In a system where only required heating and cooling are maintained, the heat flows across the Pinch is zero. This system is identified as a system where utility targets are achieved very close to optimal conditions (Fig. 3a) where external heating is done in excess over the minimum possible requirement of the processes. The heat balance shows a heat flow across the Pinch and therefore an excess external cooling is required (Fig. 3b).

Energy Targets

The technique provides way to set energy targets for optimizing the heat recovery systems. The T-H diagrams (Fig.4) are made for hot and cold utilities which represent thermal characteristic of process streams. For example, for a stream requiring heating (cold steam), the temperature is raised from "Supply temperature" (T_S) to a "Target temperature" (T_T). The total heat added (Q) will be equal to the Stream enthalpy change (ΔH).

$$Q = \int_{T_S}^{T_T} C_p \, dT = (T_T - T_S) = \Delta H, \text{ where}$$

C_p - Heat capacity flow rate (KW/K).

--mass flow (Kg/sec) x specific heat (KJ/Kg K) and

dT -- differential temperature change

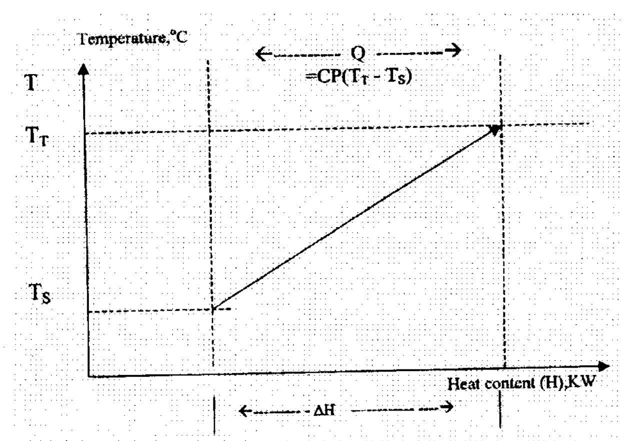

Fig. 4 Representation of Process Streams in the Temperature - Enthalpy diagram

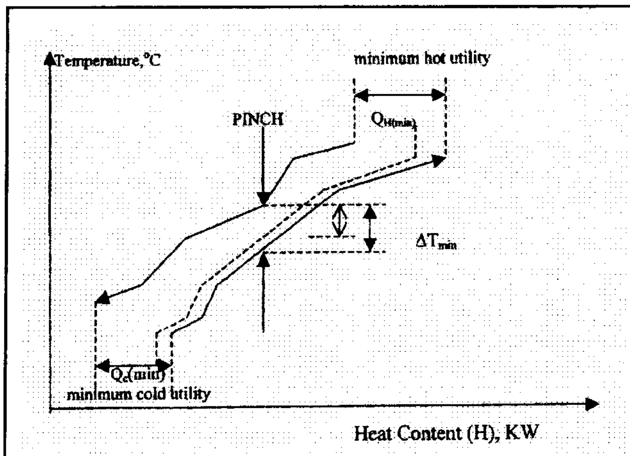

Fig. 5 Energy targets and "the pinch" with Composite Curves

Composite Curves

Heat exchange between many hot and cold streams can be analysed similarly. A single composite of all hot and a single composite of all cold steams can be reproduced in the T/H diagram (Fig. 5), and handled in just the same way as the two-stream problem. Fig. 5 shows a typical pair of composite curves. Shifting of the curves leads to behaviours similar to that shown by the two stream problem. Now though, the "kinked" nature of the composites means that ΔT_{min} can occur anywhere in the interchange region and not just at one end for a given value of ΔT_{min} the utilities quantities predicted are the minima required to solve the heat recovery problem. Note that although there are many streams in the problem, in general ΔT_{min} occurs at only one point, termed the "pinch". This means that it is possible to design a network which uses the minimum utility requirements, where only the heat exchangers at the pinch need to operate at ΔT values down to ΔT_{min}.

Application of Pinch Concept in Pulp and Paper Industry

Pinch analysis has been found useful in pulp and paper industry for setting energy targets and optimizing the heat recovery systems. Using this methodology in a bleached Kraft mill, various successful cost effective proces integration and design approaches have been adopted to maximize the heat recovery.

In a typical case, all process heating and cooling duties are reviewed, hot effluents being included as potential sources of additional heat. Stream data is then extracted as hot and cold steams according to analysis procedure to derive composite and grant composite curves, shown in Fig. 3 for a typical pulp mill. The curve shows opportunity for reducing plant energy consumption by modifying the processes. For example, small modification by withdrawing vapour for intermediate evaporator effect and condensing to provide process heating above the pinch results in reduced hot utility targets by 24% lower than the unmodified plant. In this case the evaporators energy consumption actually increased, while overall plant consumption went down. This illustrates problems in optimizing the unit operations in isolation and benefits of process optimization and integration. Similarly mill personnel can find out many other process modification alternatives and find out effect of process integration on a whole system. Pinch technology provides a methodology to confidently select the most appropriate projects for a given set of circumstances.

- Pinch analysis can also be used to optimize the steam extraction levels from the turbines. In some mills, scope to increase power cogeneratin by reducing the MP steam pressure by approx. 4 bars has been reported.
- Pinch principles can be used for cogeneration schemes consideration by appropriately integrating the pass out steam for heating to the processes by selecting the pass out pressures.
- The composite curves can also be used to determine the boilers minimum fuel requirements.
- Mills can design a network based on the flow sheet and propose the modifications easily by using composite curves.
- The mills can also easily evaluate the energy demand and benefits in retrofits as well as new design. For a given pay back criterion, it

enables the appropriate level of investment to be determined and the corresponding energy savings to be identified before the design is begun.

Pinch technology can help mills to design integrated plants for a wide range of operating conditions, such as seasonal variations, changes in raw material or product specifications etc. It can help to achieve good flexibility in the design at a lower cost than can be achieved using traiditional design methods.

Process integration by Pinch analysis is good for identifying fundamental insight into heat transfer and mass transfer problems and also help the industry to set target for its reduced energy and water consumption. Other benefits include correct integration of steam turbines, co-optimisation of energy and capital cost by supertargetting, identification of most appropriate process changes and increased plant flexibility. Appplication of pinch technology in Indian paper industry is yet to be explored and CPPRI is looking for the options to apply this technology for setting up new energy and water consumption targets in the industry.

CONCLUSION

CPPRI has initiated studies on process integration using Pinch analysis techniques. The studies will be conducted in some selected mills and based on the findings appropriate measures/ modification in existing mill process will be taken up. CPPRI is very optimistic in this endeavour and feels that the studies will result in considerable energy savings in Indian Pulp and Paper Industry.

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