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A 'Pinch' technology analysis of energy integration in the Huntly Power Station

by

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SUMMARY

A technique of energy analysis called pinch technology was applied to the Huntly power station. Its purposes were to investigate the potential for improvement in operating efficiency and the Linnhoff March Limited's 2.5% energy saving claims.

As the plant's power output varies depending on the consumer demand, different data with three different power outputs (i.e. 250 MW, 200 MW and 150 MW) were analysed separately.

This thesis shows that the pinch technology has been successfully applied to the Huntly power station . As the result, several possible areas for efficiency improvement have been indentified. Unfortunately, the savings for the areas of efficiency improvement identified by the technique have proven insufficient justification for the extra complexity in the design.

The overall conclusion is that the plant is already operating at the near optimum levels for the type of equipment used.

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NOMENCLATURE

This section lists the symbols used in the thesis and gives a description of what they represent. Units for each symbol are also shown.

Symbol	Description	Units
A	Heat transfer area	m^2
CP	Heat capacity flowrate	W/°C
CP_c	Cold stream heat capacity flowrate	W/°C
CP_h	Hot stream heat capacity flowrate	W/°C
F	Flowrate	kg/s
H	Flow enthalpy or Heat content	W
δH	Change in flow enthalpy	W
h	enthalpy	J/kg
L	Number of loops in a network	-
N	Number of process streams plus utilities, or process stream branches	-
P	Pressure	Bar
S	Entropy	J/kgK
s	Number of separate components in a network	-
T	Temperature	°C
δT	Temperature difference	°C
δT_{LM}	Log mean temperature difference	°C
δT_{min}	Minimum temperature difference	°C
U	Overall heat transfer coefficient	$W/m^2\,°C$
u	Number of heat exchange units	-
u_{min}	Minimum number of units	-
α	Heat flow across the pinch	W
$\varnothing$	Heat flow	W

Any extra symbols used will be defined where appropriate.

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SECTION 1

INTRODUCTION

Most processing industries use combinations of heat exchangers for heating and/or cooling process streams. A large amount of the energy used by the processing industries is used just for process heat. In the industrial nations of Western Europe approximately one third of the national energy use is for process heat (Smith, 1981).

The design of most industrial processes is based on a long period of development with many evolutions and improvements leading to a current flowsheet. It is often assumed that these flowsheets are more or less optimal, with no significant "faults" left in them. This is of course not true. An analysis carried out by the New Zealand Dairy Research Institute (NZDRI) showed that theoretical minimum energy consumptions are 25 -30% lower than the actual energy consumption of the most efficient of New Zealand's dairy processing plants (Lovell-Smith and Baldwin,1988). For instance, the average energy use per tonne of casein powder produced in New Zealand is 16.9 GJ/tonne but the optimal energy usage is only 9.9 GJ/tonne.

Recently, Linnhoff March Limited claimed that 2.5% energy saving in Huntly Power Station is possible but unproven. In terms of money this means about NZ$ 80 million of total saving over the station operating life (≈ 30 years).

1.1 PROCESS INTEGRATION

Process integration includes minimising costs, while still producing the product to the correct specification, by obtaining the optimal process design. When designing a process the engineer faces two tasks. First there is the conventional engineering task of designing the individual pieces of equipment. Second there is the task of designing the overall process. This involves decisions of where and how to integrate the various pieces of equipment or whether to integrate at all. Until recently this has been conducted on an ad hoc basis, primarily through the use of engineering experience and perhaps the observation of specific patterns in specific processes.

Pinch Technology, however, allows process integration to be conducted in a scientific and systematic manner. As a result the use of the technology has become quite widespread (B. Linnhoff, 1983, B. Linnhoff & D.R. Vredeveld, 1984 and B. Linnhoff & A.R. Eastwood, 1987).

Over the last six years process integration using Pinch Technology has been proved to provide significant improvements in the design of process plants. It has been demonstrated that the integration results in plants that are cheaper to build and also more economical and easier to operate (B. linnhoff & A.R. Eastwood, 1987).

This shows an optimal process not only results in energy cost savings but capital equipment saving too. This is due to the fact that most processes are not designed to be as efficient as possible and thus require extra utilities. Linnhoff et al, (1982) and B. Linnhoff & E. Hindmarsh, (1983) stated that about 20%-30% energy savings, coupled with capital savings, can be realized in state-of-the-art flowsheets by improved Heat Exchanger Design. In ICI, the pinch concept was reported to have saved on average of 30% on energy cost, coupled with capital cost savings in new plant designs (B. Linnhoff, 1983 and B. Linnhoff & J.A. Turner, 1981). Payback times in retrofit applications were reported to be typically of the order of 12 months (B. Linnhoff & D.R. Vredeveld, 1984).

1.2 THE OBJECTIVES OF THE PROJECT

The main objective of this project is identify the potential efficiency improvements at Huntly power station using Pinch Technology as one of the major tools. The other objective is to investigate the Linnhoff March Limited's 2.5% energy saving claims.

SECTION 2

LITERATURE REVIEW

Many techniques have been developed for energy integration but essentially all consist of finding a feasible sequence of heat exchangers in which pairs of streams are matched so as to achieve an optimal network.

The heat exchanger network synthesis (HENS) problem was first stated formally by Masso and Rudd (1969). They proposed a systematic method for arriving at the minimum cost heat exchanger network while meeting process specification. They suggested a set of heuristics that could be used to match the streams, so that the network is optimal as judged from an overall cost viewpoint. Difficulty arises from the extremely large number of possible stream combinations. Even for small problems, all possible networks cannot normally be enumerated, due to the inordinate demand for computer memory and execution time. Techniques like branch and bound (Lee et al.,1970) and tree searching (Pho and Lapidus, 1973) have helped to reduce the number of combinatorial possibilities to be enumerated, but the largest problem solved so far in the literature by means of such techniques involved no more than ten streams (Pho and Lapidus,1973). In addition, optimality could not be strictly guaranteed with these techniques, and cyclic network structures (that is, structures in which two streams are matched against each other more than once) could not be obtained unless the combinatorial problem was allowed to increase in size quite significantly (Rathore and Powers, 1975).

An alternative synthesis method, presented by Ponton and Donaldson (1974), is mainly based on the heuristic of always matching the hot stream of highest supply temperature with the cold stream of the highest target temperature. This method can yield cyclic network structures without additional computational effort, and it has been applied to example design problems of realistic size taken from the previous work of Masso & Rudd (1969), Lee et al. (1970) and Pho & Lapidus (1973).

Unfortunately, the method is somewhat unreliable in the sense that it may produce results which are quite far from optimum so that it tends to generate demand for additional heuristics in unexpected situations. They also showed that for five hot streams and five cold streams that there were $1.6*10^{25}$ possible stream matches. This poses severe computational problems.

Rathore and Powers (1975) pointed out that costs for steam and cooling water will normally be more important than the costs for plant to the extent that several quite dissimilar network topologies will all feature near optimal costs insofar as they feature near maximum energy recovery. Based on this observation, they recommended a procedure to identify the upper bound on energy recovery for a given problem, and to carry out a tree search in order to rapidly identify some, but not all, networks with maximum or near maximum energy recovery. These networks, they argued, will feature similar and near optimal costs. They can then be compared on grounds of safety, control, starting-up procedures, etc.

There are, however, two basic disadvantages in the approach. Firstly, the computational effort required per final candidate structure identified may not be significantly reduced. Secondly, some suitable candidates might not be found because they narrowly fail to meet design constraints (such as δT_{min}) or the problem specifications (such as a target temperature for a stream).

A realistic synthesis technique should not only be capable of identifying optimal networks for a strictly defined problem but should also allow the user to recognise chances, where they exist, of slightly relaxing problem constraints to gain some advantage.

Nishida et al. (1977) presented an algorithmic evolutionary synthesis method which appears to be suitable for the solution of realistically sized problems. It employs three basic criteria:

(1) maximise energy recovery.
(2) minimise total heat transfer area.
(3) minimise the total cost of the network.

The total heat transfer area is minimised by a minimum area algorithm, while the total cost is minimised using evolutionary rules. Maximum energy recovery is sought by a theorem and corollaries using a heat content diagram adopted from previous work (Nishida et al., 1971). Hohmann(1971) presented a method for synthesis of minimum area networks which also includes a technique for assessing the feasibility of a system of streams assuming a suitable approach temperature and given utility supplies. Hohmann and Lockhart (1976) described developments which are aimed at assessing the feasibility of a network of exchangers by examination of the minimum approach temperature found in the network. Both techniques indirectly provide correct estimates of resource requirements by confirming the feasibility of a network for assumed utility supplies.

Linnhoff and Flower (1978a) developed the temperature interval or TI method. The method allows the users to identify the upper bound on energy recovery for a given heat exchanger network synthesis problem. This method is based on enthalpy balances. It also allows the users to systematically generate a variety of networks which perform at this upper bound. The networks are produced by the TI method with very small computational effort. This has been made possible by interpreting the problem on thermodynamic rather than on combinatorial ground.

However the tendency of the TI method to introduce more units than strictly necessary is a disadvantage. To overcome this Linnhoff and Flower (1978b) developed the evolutionary development or ED method. The method enables the users to obtain rapid insight into beneficial, or detrimental, effects of potential synthesis steps in the design of heat exchanger networks. Thus, the formulation of strategies aimed at achieving given design goals is greatly helped. This eliminates, by and large, the need to accumulate many different solutions to a given problem before checking whether any display a desired combination of features in aspects such as cost, operability, safety, etc. Instead, the desired features can be methodically introduced in a sequence of evolutionary steps, starting from any feasible structure. Preferably, but not necessarily, the structure from which one starts should exhibit maximum energy recovery. Such structures can always be found by means of the TI method.

Combination of TI and ED methods provides a powerful means to design networks quickly and confidently when thermal integration is somewhat difficult: the TI method will produce the essential matches and the ED method will help to tidy up the remainder of the design to achieve the minimum, or near minimum number of units. However, in cases where thermal integration is easy, or where the remainder of the network is comparatively large, the TI method will leave many options open and pass on rather more possible designs to the ED method than user might wish to handle. Therefore, in order to be able to handle such a case an alternative design method was developed by Linnhoff and Flower (1980).

The method is called TC method (for "thermodynamic-combinatorial"). It is based on combinatorial principles different from tree searching methods. It uses thermodynamic and topological arguments to reduce the size of the combinatorial problem. This method permits listing of all solutions for a particular problem subject to the following conditions:

(1) the networks use a prescribed degree of energy recovery.
(2) the networks use the minimum number of units.
(3) the networks do not use stream splitting.

An apparent disadvantage of the method is the fact that where solutions of the kind specified above do not exist, the method will yield no answer. This situation would be encountered in problems where full heat recovery is difficult to achieve, i.e., where more than the minimum number of units have to be used and/or streams have to be split for a satisfactory solution.

The main problem in finding a minimum cost network while meeting process specifications was the non-linearity and non-convexity of the cost objective function which is based on the heat exchange surface area.

Hohmann (1971) and Linnhoff and Flower (1978) susgested that the difficulties associated with optimising the nonlinear and nonconvex cost function could be avoided by breaking up the objective function into two specific performance targets:

(1) First determine the minimum utility requirements, that is, maximum energy recovery
(2) then determine the heat exchangers subject to maximum energy recovery.

This led to the definition of the pinch point and to the development of the so-called Pinch Design Method (Linnhoff, 1982 , Linnhoff & Hindmarsh, 1983), and demonstrated that one could predict the minimum utility and minimum heat exchanger unit requirements prior to actually developing the network and then synthesize the network in order to meet these targets. This method is discussed in full detail in the following section.

Cerda et al. (1983) and Cerda and Westerberg (1983) formulated the pinch design problem as a network flow problem and used the transportation model and standard optimisation algorithms to determine the minimum utilities and minimum number of heat exchangers. They developed a linear programing transportation model for the minimum utilities problem and solved it using the northwest algorithm. To determine the minimum number of heat exchangers subject to maximum energy recovery, they developed a mixed linear programing (MILP) approach based on the transportation model and then used several relaxations to reduce it to a transportation problem. This approach requires an initial feasible solution. Cerda et al.(1983) describe a row-column reordering algorithm to determine an initial feasible solution.

In the transportation model, heat flows from the hot streams/utilities that act as sources directly to the cold streams/utilities that act as destinations. Papoulias and Grossman (1983) approached the problem using the transshipment model. In this model, heat flows from the hot streams/utilities to the cold streams/utilities via intermediate nodes or "warehouses". The temperature intervals obtained by applying the rules of Cerda et al. serve as intermediate nodes. Papoulias and Grossman solved the resulting MILP for the minimum units and did not apply the relaxations of Cerda and Westerberg (1983). The minimum utilities transshipment model involves fewer variables than the corresponding transportation problem.

Generally, the transshipment model was used for determination of the minimum utilities and the transportation model was used for determination of the minimum number of units. The disadvantages of both the transshipment and the transportation models are:

(1) they need a feasible starting point.
(2) they cannot handle forbidden and restricted matches.

From all the methods available in dealing with process integration, the pinch design method is chosen for this project. This is because it already has a proven record of industrial application which covers a wide range of industries using both continuous and batch operations. It has been demonstrated that the integration using this method results in plants, that are cheaper to build and also more economical and easier to operate.

In this project, the pinch method was applied to a thermal power station. The main reason for choosing the station is because so far the method has been mainly applied in Chemical plants. Its application to power stations is not widely recognised yet. The other reason is because Linnhoff March Limited (owned by the founder of Pinch Technology) had claimed that it is possible, but unproven, to reduce the energy use in the thermal power station by 2.5% if the method is applied. In terms of money, this means about NZ$ 80 million of total saving over the station operating life (≈ 30 years).