THE APPLICATION OF PINCH TECHNOLOGY HEAT EXCHANGER NETWORK ANALYSIS AT A CRUDE OIL REFINERY

by

E. V. Crisostomo* and R.M. Wood**

ABSTRACT

This paper applies the principles of pinch technology to data obtained from a crude oil refinery. The existing design is highly integrated and additional heat exchange surface had been added following the increase in oil prices in the last decade. However, the targeting procedures identified possibilities for energy savings and a retrofit saving about 10% of the existing energy consumption with about a two-year payback is proposed.

INTRODUCTION

An earlier paper [1] outlined the principles of pinch technology. This paper discusses the results obtained by applying these principles to a major processing unit.

The plant studied comprises a crude oil distillation unit, which is thermally integrated with a catalytic reformer and a hydrotreater for the kerosene and lighter fractions from the crude unit. The distillation sections of the reformer and hydrotreater are also part of the process flowscheme considered. The unit started operation in 1970.

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* Petron Corporation, Bataan Refinery, Limay, Bataan, Philippines.

** School of Chemical Engineering and Industrial Chemistry, University of New South Wales, Australia

Since then, as a result of the first oil shock of 1974, additional heat exchange surface had been added as an energy conservation measure.

Enthalpy-temperature data were based on a plant survey. Inevitably this survey contained some inconsistencies and adjustments were made to smoothen the data and minimize errors. The data so obtained are given in Table 1.

ENERGY AND AREA TARGETING

Energy Targets

The computer program HENTARG (which is based on the problem table procedure of Linnhoff and Flower [2]) was used to predict energy targets for the plant. Stream data from Table 1 were used and the results for various values of ΔTmin are presented in Table 2. The location of the pinch point was 444°F (hot streams) and (444°F - ΔTmin) for the cold streams. Composite curves may also be used to determine the energy targets. Such curves are given in Fig. 1 for ΔTmin = 30°F. This figure shows that the composite curves are almost parallel for most of the temperature range in this investigation. Such parallel composite curves mean that the design for maximum energy recovery will have little flexibility, that matching of streams will be heavily constrained and hence the network will be complicated.

Process Modification

There is a pump around or circulating reflux stream on the main fractionator of the crude oil distillation unit. This stream (19 Table 2) leaves the column at 500° and is returned to the column at 373° so crossing the pinch temperature for hot streams. Thus, approximately half the enthalpy in this stream is available above the pinch and half below. Since this stream leaves the column at its boiling point, doubling its flowrate and keeping the enthalpy duty constant can upgrade the enthalpy duty below the pinch to above it. The result of the change is to reduce the energy target as shown in Table 2. These results are also plotted in Figure 2. Reducing energy targets by manipulation of pump around flowrate has been done before [3] and this is an example of reducing utility targets by the use of the plus/minus principle of Linnhoff and Vredeveld [4].

Area Targets

Assuming strict counter current heat transfer as determined by the composite curves, the network area target may be calculated from the equations [5, 6] outlined previously [1].

Table 1. Process Stream Data

Stream No.	Temperatures (°F)	C_p	ΔH MMBTU/h
1	97		
	266	.372	62.9
	389	.391	48.1
	431	.440	18.5
	660	.520	119.1
			248.6
2	115		
	223	.128	13.8
	379	.167	26.0
	493	.277	31.6
	567	.241	17.8
			89.2
3	180		
	257	.254	19.6
	325	.253	17.2
	498	.191	33.0
	900	.209	84.0
			153.8
4	424		
	458	.721	24.5
			24.5
5	424		
	443	.242	4.6
			4.6
6	260		
	345	.232	19.7
			19.7
7	380		
	443	.313	19.7
			19.7
8	86		
	215	.09	11.6
			11.6
9	892		
	740	.268	40.7
	375	.135	49.3
	110	.136	36.0
			126.0
10	611		
	450	.196	31.6
			31.6
11	632		
	531	.243	24.5
	468	.176	11.1
	320	.172	25.5
			61.1
12	518		
	460	.1276	7.4
	107	.0533	18.8
	460		
	306	.0039	0.6
			26.8
13	444		
	410	1.088	37.0
	370	.508	20.3
			57.3
14	370		
	194	.273	48.0
	105	.253	22.5
			70.5
15	450		
	322	.204	26.1
	246	.145	11.0
	86	.076	12.2
			49.3
16	381		
	205	.0278	4.9
	93	.0107	1.2
			6.1
17	441		
	145	.0389	11.5
			11.5
18	443		
	239	.0721	14.7
	86	.0654	10.0
			24.7
19	500		
	373	.124	15.7
			15.7

N.B. $\Delta H - C_p \Delta T$

Table 2. Energy Targets and Pinch Location for Various Values for ΔT_{min}.

ΔT_{min}(°F)	Q_h MMBTU/h	Q_c	Pinch (°F)
30	136.0	45.0	444/414
50	160.4	69.4	444/394
70	181.7	90.7	444/374
90	196.7	105.6	444/354
110	212.2	123.2	444/334
Pump Around Flowrate Doubled			
30	129.0	37.9	444/414
50	153.4	62.3	444/394
70	175.0	83.9	449/379
90	191.9	100.8	470/380
110	209.6	118.5	490/380

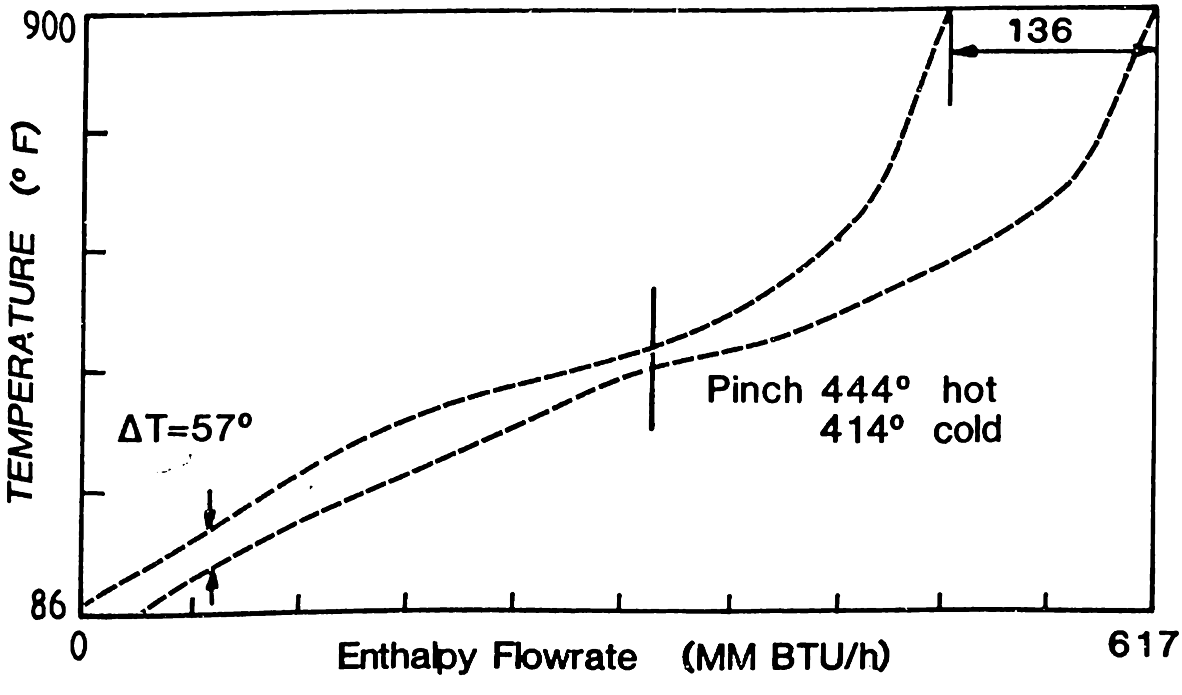

Figure 1. Composite Curves for $\Delta T_{min} = 30\ ^{0}F$

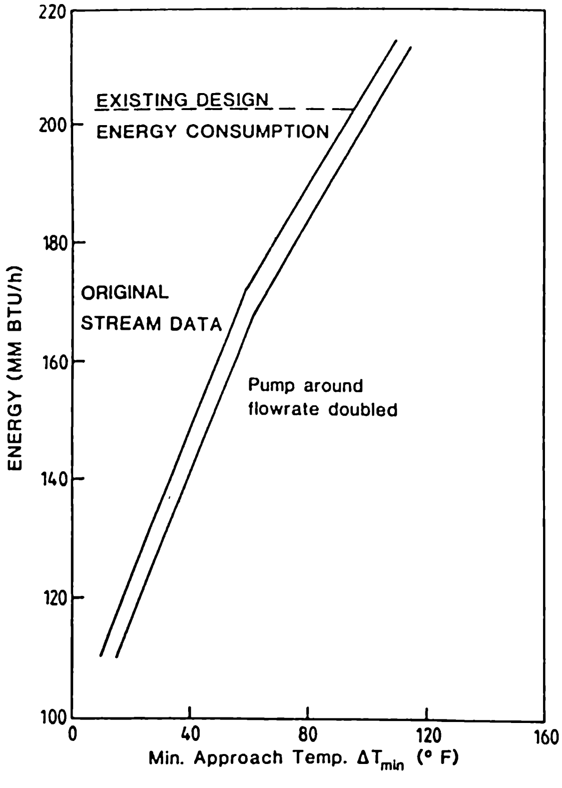

Figure 2.
Target Energy Requirements as a Function of ΔT_{min}

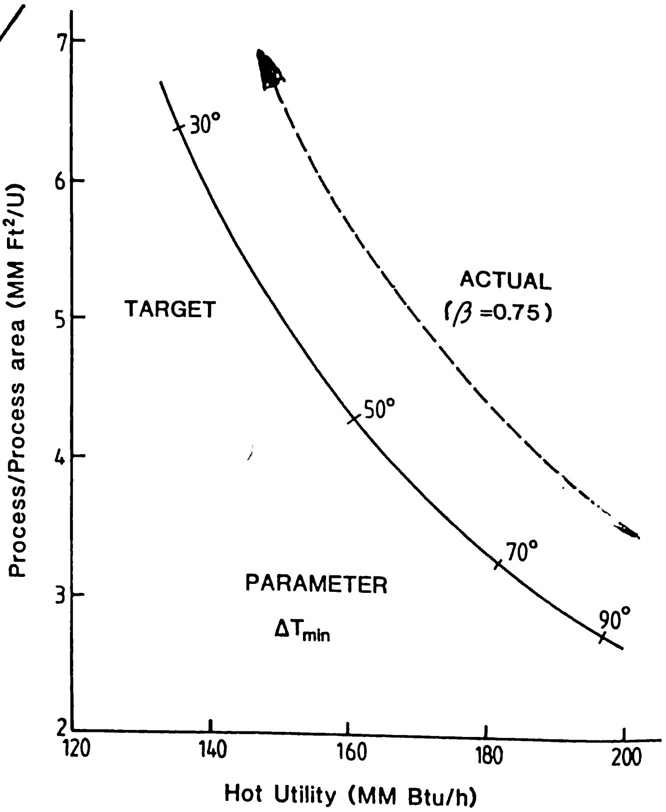

Figure 3.
Area/Energy Plot - Target and Actual

An energy saving retrofit will reduce the need for exchangers supplying heat to the network from hot utilities (in this case fuel fired furnaces). Likewise, with improved heat recovery there will also be a reduction in the duties of the exchangers rejecting heat to cold utilities. Although for a new design there will be cost savings resulting from smaller furnaces and air/water coolers, for a retrofit there is usually no economic benefit as this equipment already exists. Thus the data for area requirements plotted on Figure 3 is for the target area for exchange between hot process streams and cold process streams. (The areas for utility exchangers have been excluded). The process/process area (MM ft^2/U) target is plotted against the hot utility target with the parameter on the curve being T_{min}. For U equal to say 50 BTU/h $ft^{2o}F$, the area target for $\Delta T_{min} = 70^oF$ is approximately 65,000 ft^2.

Targets for Retrofits

In practice the area target is not achieved. This is partly due to heat exchange in the network deviating from the 'vertical' heat transfer from the hot to the cold composite curve. Also shell and tube exchangers require more area than that for counter current heat exchangers, due to the log mean temperature difference correction factor. Thus, the actual installed area may be compared with the target area for the actual hot utility requirement (in this case 203 MM BTU/h). Such a comparison will give the value for the network area efficiency ß

$$ß = \frac{\text{Target Area}}{\text{Actual Area}}$$

In a retrofit, additional process/process heat transfer surface is installed to save energy. Thus the path for the retrofit will be similar to the dotted line shown on Figure 3. If is assumed that the value for ß is constant (here it is assumed that ß = 0.75) along this path, the additional area requirements may be estimated as a function of energy savings as shown below:

HOT UTILITY MM BTU/h	ENERGY Saving %	AREA MM ft^2/U	AREA Increase %
200	--	3.6	--
180	10	4.3	19
160	20	5.8	61
140	30	7.9	119

This clearly shows that area requirements increase much more rapidly than energy savings. If the installed costs of similar heat exchangers are known, then the area cost may be estimated. Thus plotting energy savings against area costs, the retrofit which achieves a required economic objective (e.g. a two year pay back) can be determined [7]. In this case it was decided to identify a retrofit which achieves energy savings of 10%.

Retrofit Design

Retrofit designs are difficult because the aim of the retrofit is to seek energy savings which are compatible with the existing design. Starting with a maximum energy recovery (MER) design achieved by the pinch design method (PDM) provides an initial design which can be quite complex for multistream problems (there are 19 streams considered here). Furthermore as MER designs are often so different from existing designs [3], it is virtually impossible to adapt these designs for retrofits in a systematic, energy efficient manner. Identifying cross-pinch exchangers [7] (i.e. exchangers in which a hot stream above the pinch exchanges heat (sometimes partially) with a cold stream below the pinch) seems a more promising approach. For $\Delta T_{min} = 50^{o}F$ there are about 40 MM BTU/h exchanged across the pinch of which about 45% occurs in heat exchange from the reformer effluent. Thus, pursuing this approach would result in a considerable increase in heat transfer area for cooling the reformer effluent. This may also increase the power costs for the reformer recycle gas compressor due to increased pressure drop. Such a design could, however, be a viable retrofit project. The retrofit eventually identified required modifications to some of the crude preheat exchangers, but the reformer and hydrotreater streams were left almost unchanged.

Pseudo-Pinch Design Method

For some years, it has been known [8] that networks having a fixed energy consumption determined byΔT_{Nmin} (N for Network) are cheaper if the exchanger design is determined by a smaller approach temperature ΔT_{Emin} (E for Exchanger). However, in order to use such a dual approach temperature design procedure, it has been necessary to use the computer program HEXTRAN.

The concept of the pseudo-pinch [9] also uses dual approach temperatures and allows for more flexibility in design than the pinch design method. Moreover, by splitting the problem into two parts above and below the pseudo-pinch, design is simplified enormously (especially for problems with a large number of streams such as this one) compared to the previously published [8] dual approach procedure.

With two approach temperatures there are two values for the energy consumption, viz EC Δ(T_{Nmin}) and EC(ΔT_{Emin}). If the network energy consumption is EC(ΔT_{Nmin}) but has exchangers with minimum approach temperature ΔT_{Emin}, then according to the pinch concept, an energy flowrate

$$\alpha = EC(\Delta T_{Nmin}) - EC(\Delta T_{Emin})$$

crosses the pinch. However α may be used to determine alternative temperatures at the pinch point - which is now defined as a pseudo-pinch point. The choice of the pseudo-pinch point temperatures may be used to prevent streams from crossing this point which leads to simpler designs. For retrofits it is possible to use this flexibility to try to maintain most of the existing design, so that few modifications need be made to the network.

Modified Design Proposal

Using the procedure outlined above the design shown in Figure 4 was developed. This achieves an energy saving of 10% and requires additional area for the following crude preheat exchangers.

	Additional Area ft^2
E4	2500
E7	1200
E15	2500
E13	4200

The additional area was estimated by calculating the required values for $UA(=Q/F(LMTD))$ both for the modified design shown in Fig. 4 and that from the plant survey, so as to find the % increase required. Then assuming the exchangers at the time of the survey were in reasonable condition, the additional area was estimated by multiplying the actual installed area from the exchanger data sheets by the percentage increase required. In addition there is a new match E36 which is estimated to have an area requirement of 2000 ft^2. This total increase in surface area of 12,400 ft^2 is similar to that predicted by the targeting procedure.

Pipework changes are required to change the order of exchangers E18 and E19 on the reduced crude line and to relocate E15 in the crude preheat train. Calculations have assumed that the pump around flowrate can be doubled. This may be possible as the duty for this service at the time of the survey seems fairly small. However, both the capacity of the pump and the pump around section of the fractionator would need to be checked.

Although the proposed changes are substantial, only a small proportion of the nineteen streams and existing thirty-five exchangers are affected. However, there would be other alternative possibilities which may be preferable when space constraints and piping costs etc. are considered.

Estimated Economics of Proposal

On the basis that the installed cost for an exchanger of size 2000 ft^2 is Ps $2.8.10^6$ and making allowance for extra costs associated with the pump around system, the capital costs are estimated to be Ps 18.10^6. The annual energy savings of 20 MM BTU/h are estimated to be worth Ps 9.10^6, thus a payback period of two years is estimated.

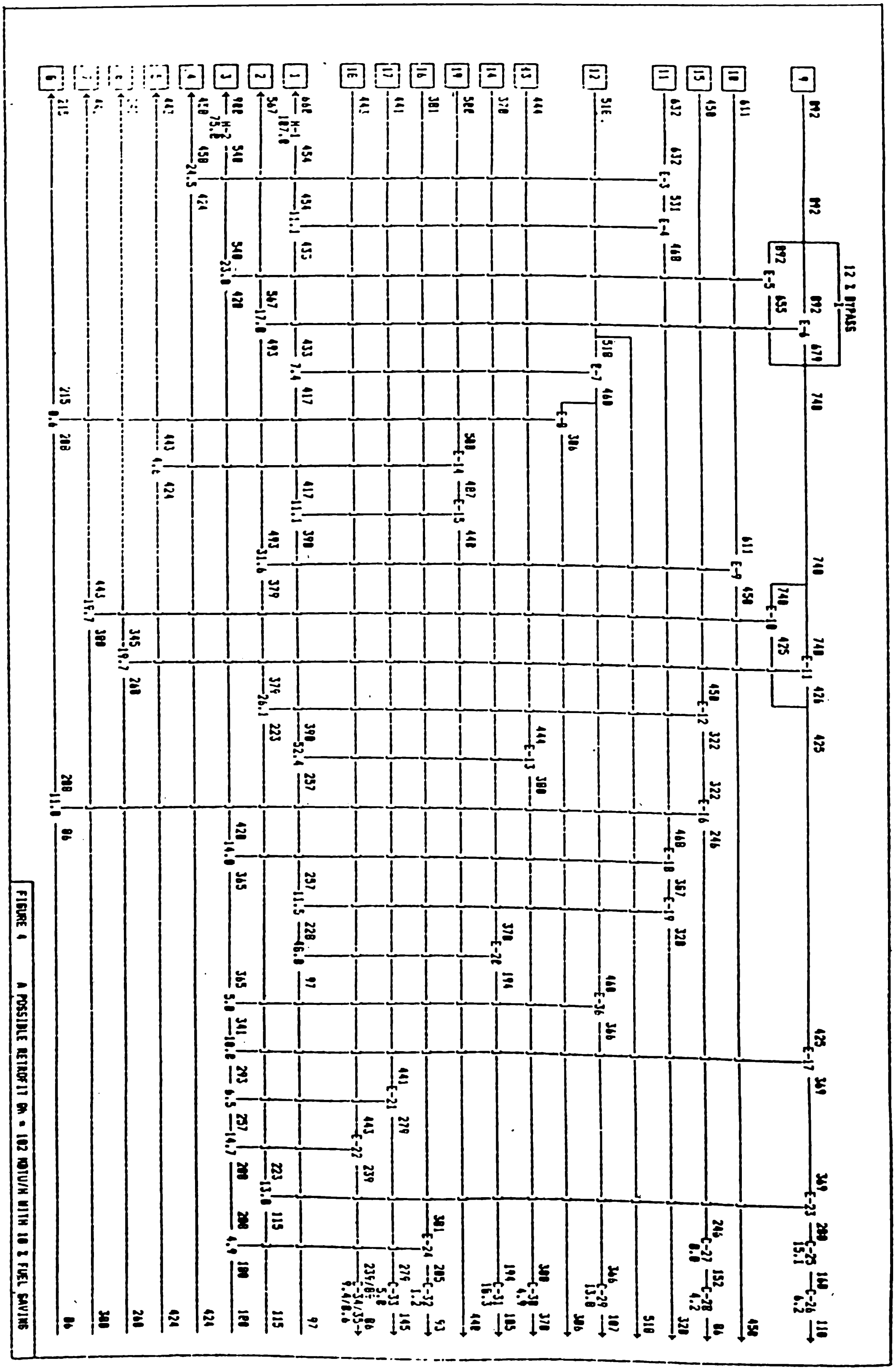

Figure 4. Proposed Retrofit Design

CONCLUSIONS

Pinch technology targeting procedures have been applied to stream data from a refinery crude oil distillation unit and integrated reformer and hydrotreater. This demonstrated some scope for energy savings although for major savings of the order of 25-30% very large additional area requirements would be required. Thus, energy savings in the vicinity of 10-15% seemed to be more viable economically.

The energy targets were reduced by about 7 MM BTU/h following a process change. This increased the flowrate of the pump around stream while maintaining the total duty (15.7 MM /BTU/h) for this service constant.

A retrofit design for energy savings of 10% (20 MMBTU/h) required increased surface area for four existing duties, one new duty and some pipework changes. Obtaining this design was facilitated by the use of the pseudo-pinch design procedure. It is estimated that the payback period for this design is about two years.

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