PINCH ANALYSIS :
For the Efficient Use of Energy, Water & Hydrogen

OIL REFINING INDUSTRY
Energy Recovery at a Fluid Catalytic Cracking (FCC) Unit

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Cat. No.: M154-60/2-2004E-PDF
ISBN: 978-1-100-19816-3

This Pinch Analysis Application Example has been initially developed by Rossiter & Associates.

Table of Contents

Pinch Analysis Application Example

PINCH ANALYSIS APPLICATION EXAMPLE

Oil Refining industry

Energy Recovery at a Fluid Catalytic Cracking (FCC) Unit

This example is a description of the steps required to carry out a Pinch study of a refinery Fluid Catalytic Cracking (FCC) Unit. The simplified data used to illustrate the procedure is based on an existing FCC Unit. The objective of this presentation is to illustrate in concrete terms the different steps in a Pinch analysis of an industrial process in retrofit situation. It is one of the step-by-step examples that support the technical guide entitled *Pinch Analysis for the Efficient Use of Energy, Water and Hydrogen* produced by Natural Resources Canada. The Pinch concepts used in this example are presented in more details in this guide.

Pinch techniques were initially developed to address energy efficiency issues in new plant design situations. The techniques need to be modified for retrofit studies like the one described here. The key distinction is that in retrofit situations the analysis must take into account equipment that is already installed, whereas in a new design situation the designer has the flexibility to add or delete equipment at will. This difference makes the retrofit problem inherently more difficult.

Although different approaches are possible, in this example we will be following perhaps the simplest one for Pinch studies in retrofit situation, which can be summarized in the following steps:

❶ Obtain data relevant to Pinch study

❷ Generate targets for each relevant utility

❸ Identify major inefficiencies in the heat exchanger network

❹ Define options for reducing or eliminating the largest inefficiencies

❺ Evaluate competing options

❻ Select the best option or combination of options

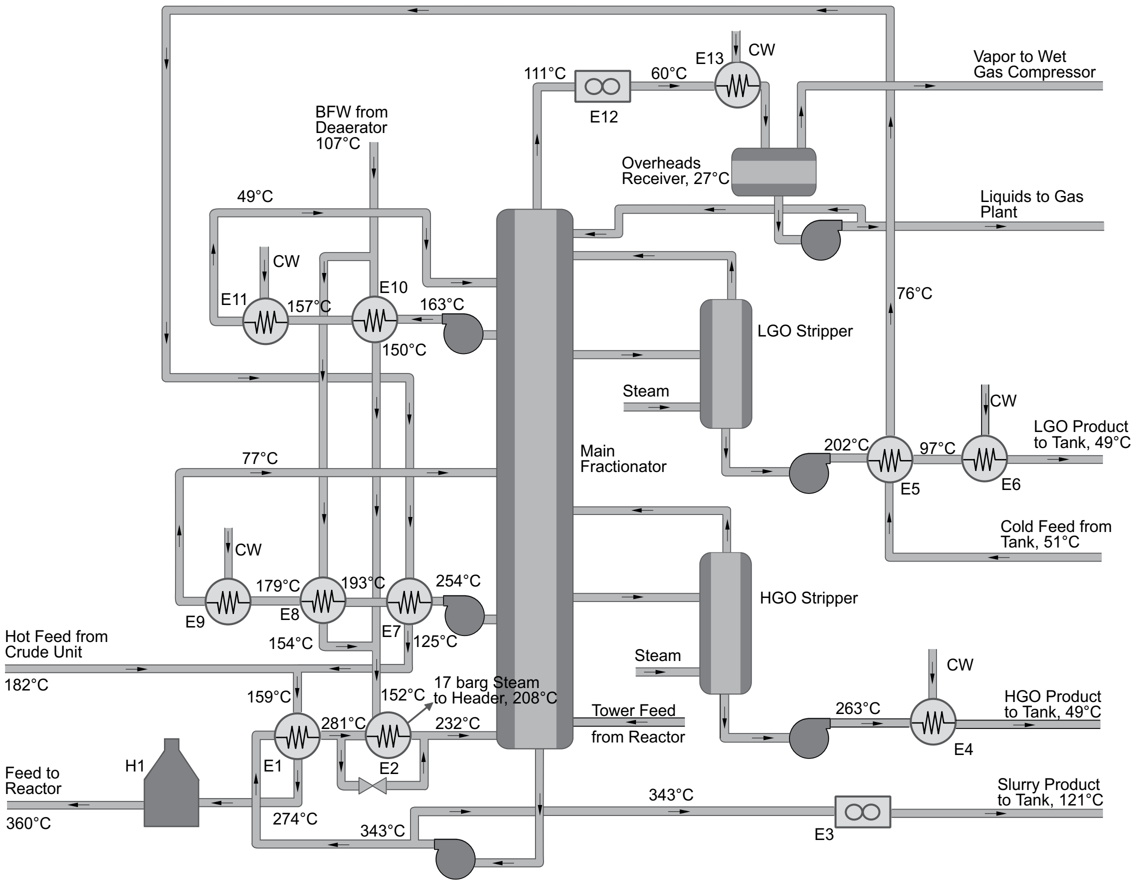
The objective in the Pinch study is to make changes that reduce the net cost of utilities for the process. All costs mentioned in this text are given in Canadian dollars (CAN$).

Process Description

The process under examination is based on the feed reactor and fractionation section together with the associated preheat train, pumparounds, product streams and heat recovery network of an existing 35,000 BPD[1] FCC Unit. The feed reactor includes two feed streams, one coming hot from a crude unit, and the other coming cold from tankage.

The process is illustrated as a simplified process flow diagram (PFD) in Figure 1 where main process streams and actual design heaters and coolers are represented as well as the existing heat recovery network, including the 17 barg steam generator.

Figure 1 Simplified Process Flow Diagram of the FCC Unit



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[1] BPD: barrel per day

Step 1: Obtain Data Relevant to the Pinch Study

Operating Data

Data needed for the Pinch study includes heat loads and temperatures for all of the utilities and process streams. In most cases this is obtained from a combination of test data, measured plant data and simulation, often supported by original design data. These data can be divided into two categories: process data and utility data.

Additional information needed to quantify potential savings include:

- ❒ Furnace efficiency: 85%, and
- ❒ On-stream factor: 96% or 8,400 hours/year.

Economic Data

The other type of data required is economic data. In the early stages of a study, the most important economic data relates to the cost of energy. Later capital costs become important; this is discussed under **STEP 5**.

Energy prices generally depend on which utility is being considered, and in the present example we need to consider furnace heating and 17 barg steam generation. Many companies have standardized utility prices that they use for project evaluations, and in the present example the company provided its standard prices:

- ❒ Fuel: 5.00 CAN$/GJ,
- ❒ 17 barg steam generation: 5.20 CAN$/GJ.

However, utility pricing – especially steam pricing – is a complex issue, and in many Pinch studies steam system models are used to develop an appropriate price structure.

The ambient cooling utilities – air and water – are comparatively inexpensive, and were ignored in this example.

Once the data required for the analysis has been collected, we need to put it in the proper format for the Pinch study. This is often referred as the data extraction phase. The main rules for data extraction are presented in the *Pinch Analysis for the Efficient Use of Energy, Water and Hydrogen* guide of Natural Resources Canada.

Data Extraction: Process Data

Heat loads and temperatures for all the streams in the process are required for the study. This information is shown on the PFD (Figure 1). However, rather than simply accepting the data "as is", we must first check if there are any aspects of the existing design that might bias the Pinch results. This commonly occurs when the process includes the mixing of two streams at different temperatures.

Whenever two streams mix physically they necessarily also transfer heat from one stream to the other, as the hotter stream heats the colder one and is itself cooled down to the mix temperature. A mixer may therefore be considered as a "hidden heat exchanger". If this mixing occurs across a Pinch it will alter the targets, and we may miss an opportunity to improve the process. Our data extraction must take this fact into account.

Modifying the data in this way does not necessarily mean that we will want to separate the hot and cold feeds in our final design, although this possibility must be explored later, during the heat exchanger network design stage. All that we have done thus far is to provide a better representation of the temperature profile of the heat sink in the FCC Unit, and this should result in a more aggressive target for energy savings.

Stream Mixing Specifics

In the existing design, the hot feed stream (at 182°C) mixes with the cold feed stream (at 125°C) ahead of the Mixed Feed Preheater (E1). This preheater heats the mixed feed from the mix temperature of 159°C to 274°C. However, we can conceptually keep the two feed streams separate, and split E1 into E1A, which heats the hot feed from 182°C to 274°C, and E1B, which heats the cold feed from 125°C to 274°C. The combined duty of E1A and E1B is equal to that of E1 and the heat source (bottom pumparound between 343°C and 281°C) is unchanged. However, by separating the two feed streams we have defined a new temperature profile for the heat sink, and this includes a part of the duty that is colder than any part of the current mixed feed heat sink in E1. This reduced temperature heat sink creates an opportunity for improving heat integration (see **STEP 3**).

The final data set used for the study is shown in Table 1.

	Heat Exchanger	Duty (MW)	Hot Side			Cold Side		
			Stream Name	Ts (°C)	Tt (°C)	Stream Name	Ts (°C)	Tt (°C)
E1A	Mixed Feed Preheater A	11.46	Bottom Pumparound	343	281	Hot Feed	182	274
E1B	Mixed Feed Preheater B	11.28	Bottom Pumparound	343	281	Tank Feed	125	274
H1	Feed Heater	20.34	Fired Heater	427	427	Mixed Feed	274	360
E2	17 barg Steam Generator	16.88	Bottom Pumparound	281	232	17 barg Steam Generator	152	208
E3	Slurry Product Cooler	1.82	Slurry Product	343	121	Air	43	43
E4	Heavy Cycle Oil Cooler	1.23	Heavy Cycle Oil	263	49	Cooling Water	27	27
E5	Tank Feed Preheater 1	2.05	Light Cycle Oil	202	97	Tank Feed	51	76
E6	Light Cycle Oil Cooler	1.23	Light Cycle Oil	97	49	Cooling Water	27	27
E7	Tank Feed Preheater 2	4.04	Mid Pumparound	254	193	Tank Feed	76	125
E8	Boiler Feed Water Preheater 1	0.8	Mid Pumparound	193	179	Boiler Feed Water	107	154
E9	Mid Pumparound Cooler	5.77	Mid Pumparound	179	77	Cooling Water	27	27
E10	Boiler Feed Water Preheater 2	0.75	Top Pumparound	163	157	Boiler Feed Water	107	150
E11	Mid Pumparound Cooler	14.04	Top Pumparound	157	49	Cooling Water	27	27
E12	Tower Overhead Cooler 1	18.17	Tower Overhead	111	60	Air	43	43
E13	Tower Overhead Cooler 2	5.25	Tower Overhead	60	37	Cooling Water	27	27

□ **Process Data** ▨ **Utility Data**

Table 1: Summary of extended data from the existing Heat Exchanger Network

Data Extraction: Utility Data

A furnace provides utility heating in the FCC Unit. In practice, and unless we plan to investigate possible changes in furnace design, we represent fired heaters for the Pinch analysis as a heat sources at a single temperature that is hot enough to satisfy any anticipated heat load in the FCC Unit. The air-cooling and water-cooling likewise can each be represented as heat sinks at a single temperature.

Representing the 17 barg steam generation is more specific. Boiler feed water (BFW) is supplied at 107°C, and the steam is generated at 208°C. However, the heat for generating the steam serves partly as sensible heat (441 kJ/kg between 107°C and 208°C), and the rest as latent heat (1912 kJ/kg at a constant temperature of 208°C).

Steam Generation Specifics

If we represent 17 barg steam generation as a heat sink at a constant temperature, we would have to choose that temperature as 208°C. This implies that all of the heat (including the sensible heat) must be supplied at or above the saturation temperature. Many steam generation systems are in fact designed this way (for example, with cold boiler feed water being fed directly to a saturated steam drum). Nearly 19% of the heat is sensible boiler feed water (BFW) preheat that can be provided below the saturation temperature. Recognizing this fact allows us to use lower-temperature heat sources to perform the preheat function, thereby increasing the scope for steam generation. This fact is already exploited in the FCC design in the two BFW preheaters, E8 and E10.

Note: The BFW leaving E8 is at 154°C and the BFW leaving E10 is at 150°C, giving a mix temperature of 152°C. This is therefore another example of non-isothermal mixing, although the temperature differences and the amount of heat involved are small, and can be neglected in this example.

To determine minimum energy consumption rigorously we need to represent the steam generation as a “segmented utility”. The colder segment (107°C to 208°C) represents BFW preheat, and the hotter segment (at a constant 208°C) represents the latent heat.

The utility data for the Pinch study are summarized in Table 2. The annual costs shown here are based on the basic cost and efficiency data above mentioned. The credit for saving furnace duty is about 13% greater than the credit for using the

Utility	Temperature		Δh (kJ/kg)	Cost (CAN$/MW-year)
	Ts (°C)	Tt (°C)		
Furnace	427	427	n/a	178,000
17 barg Steam Generation	107 208	208 208	441 1,912	-157,000*
Ambient Air	43	43	n/a	n/a
Cooling Water	27	27	n/a	n/a

*** A negative cost means that steam generation reduces energy costs**

Table 2: Utility Data Summary

same amount of heat for increased steam generation. However, economics ultimately dictates how the savings should be allocated (see **Step 6**).

Step 2: Generate Targets for Each Relevant Utility

Set ΔT_{min} value

In order to generate targets for minimum energy targets we must first set the ΔT_{min} value for the problem. ΔT_{min}, or minimum temperature approach, is the smallest temperature difference that we allow between hot and cold streams in any heat exchanger, assuming counter-current flow.

This parameter reflects the trade-off between capital investment (which increases as the ΔT_{min} value gets smaller) and energy cost (which goes down as the ΔT_{min} value gets smaller). It is generally a good practice to analyse this trade-off quantitatively by using Pinch area targeting and capital cost targeting tools as presented in the *Pinch Analysis for the Efficient Use of Energy, Water and Hydrogen* guide and in a similar example produced by Natural Resources Canada for a Pulp and Paper process entitled *Energy Recovery and Effluent Cooling at a TMP Plant*. For the purpose of this example, typical ranges of ΔT_{min} values that have been found to represent the trade-off for each class of process have been used. Table 3 shows typical numbers that are appropriate for many refinery units such as FCC Units, cokers, crude units, hydrotreaters and reformers.

Type of heat transfer	Experience ΔT_{min} values	Selected ΔT_{min} values
Process streams against process streams	30 - 40°C	30°C
Process streams against steam	10 -20°C	10°C
Process streams against cooling water	10 - 20°C	10°C
Process streams against cooling air	15 - 25°C	15°C

Table 3: Experience and selected ΔT_{min} values

In this study we take a ΔT_{min} value of 30°C, which is fairly aggressive for FCCs. This is applied to all process-to-process heat exchanger matches. Rather different trade-offs apply for heat transfer between process streams and utilities, so we typically define separate ΔT_{min} values for each utility.

In the case of the furnace, as discussed in **STEP 1**, we chose an arbitrary utility temperature (high enough to satisfy any heating duty in the FCC), and the ΔT_{min} value is similarly arbitrary.

For the 17 barg steam (including BFW preheating), however, we aim for a very close temperature approach (ΔT_{min} = 10°C). This reflects the fact that incremental duty in these services is generally cheaper to install than it would be for process-to-process services. Furthermore, for operability reasons designers prefer to provide ample steam generating capacity.

The ΔT_{min} chosen for air-cooling (15°C) is close to the minimum temperature approach in the existing air coolers. A tighter approach (10°C) is assumed for water-cooling, as this is the coldest utility available and must be able to satisfy the lowest temperature cooling services.

Determine Targets

Having set the ΔT_{min} values, we can now proceed with targeting using data from Table 1. The results are shown in the form of Composite Curves (Figure 2), the Grand Composite Curve (Figure 3) and a summary table (Table 4).

The Composite Curves determine minimum hot and cold utility requirements and comparing this target with the actual utility consumption gives the scope for saving. The Grand Composite Curve provides targets for individual utilities and illustrates the effect of representing 17 barg steam as a segmented utility. The BFW appears as a diagonal line that touches the process Grand Composite Curve at a utility Pinch point. Part of the heat input to the BFW is below this Pinch point. If we had represented the steam with a single temperature corresponding to the saturation conditions we would have failed to identify the opportunity to recover any heat below the Pinch point, and this would have resulted in a smaller 17 barg steam target.

The heat integration opportunities in the FCC Unit are best understood from the summary information in Table 4. The first two columns show the existing heat loads for each utility and the corresponding target loads. In the case of 17 barg steam generation these numbers include both the BFW and steam generation duties. The third column shows the scope for reducing each utility (existing load – target load). In the case of the 17 barg steam generation we gain credit for exporting the steam. From Table 4 we can draw the following broad conclusions:

There is scope to reduce the furnace duty by 9.2 MW, or 45%. This is worth $1,641 K/year.

The 17 barg steam generation is on target; there is no scope to increase 17 barg steam generation.

We can shift about 12 MW from cooling water to air-cooling. In practice the financial incentive for doing this is in the present case negligible, so we will not pursue this further.

Note: However, in new design situations there are often capital cost savings associated with maximizing air-cooling. Also, in some retrofit situations the cooling water system is a bottleneck. In these cases the cooling water/air-cooling trade-off should be explored further.

Figure 2 Composite Curves for FCC Unit (ΔT_{min} value of 30°C)

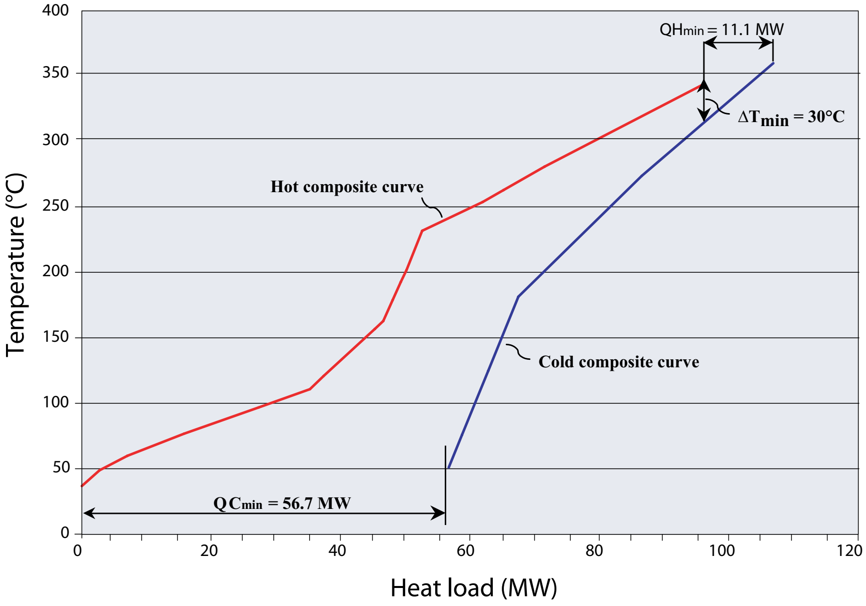
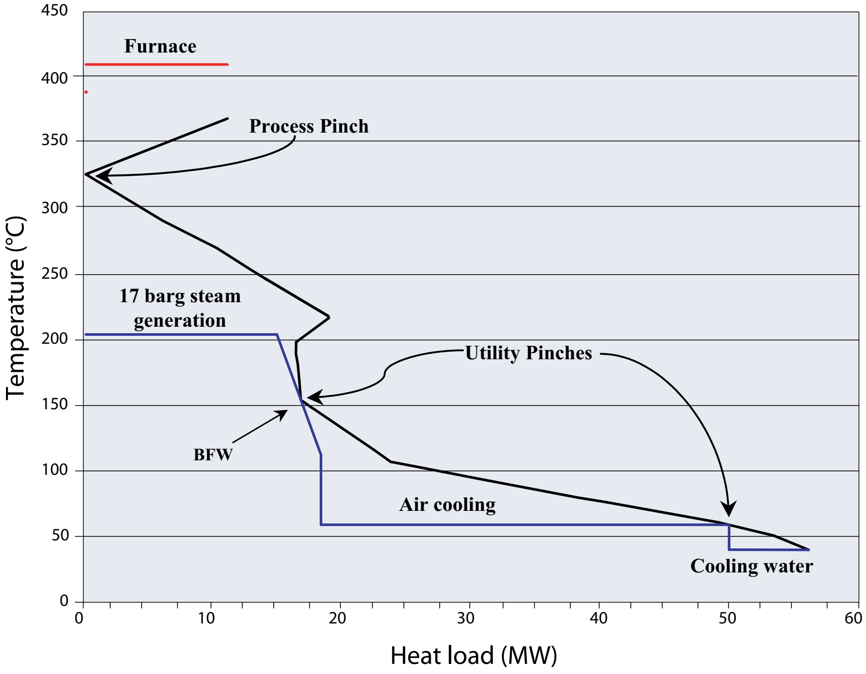


Figure 3 Grand Composite Curve for FCC Unit



	Existing (MW)	Target (MW)	Scope (MW)	Saving (k$/year)
Total hot demand	20.3	11.1	9.2	
Total cold demand	65.9	56.7	9.2	
Hot Utilities				
Fired Heater	20.3	11.1	9.2	1,641
Cold Utilities				
17 Bar Steam Generation	18.4	18.4	0.0	0
Air	20.0	32.0	-12.0	0
Cooling Water	27.5	6.3	21.3	0
Total				**1,641**

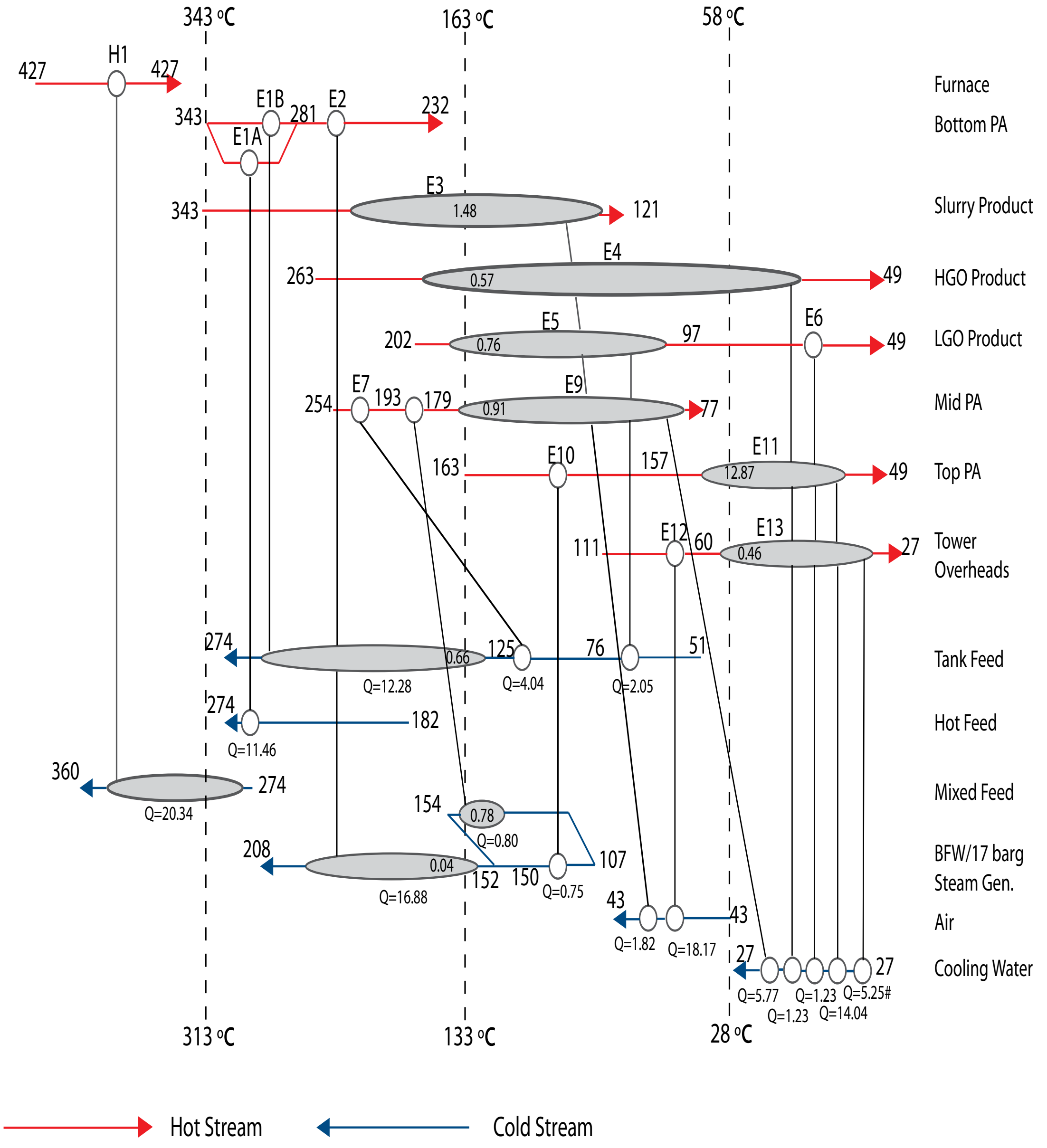
Table 4: Targets for Energy, Utilities and Existing Situation (Process ΔT_{min} = 30°C, Steam and Cooling Water ΔT_{min} = 10°C, Air Cooling ΔT_{min} = 15°C)

Step 3: Identify Major Inefficiencies in the Heat Exchanger Network

This step turns to design considerations. Most commercial Pinch software has tools to identify major inefficiencies and determine where heat is crossing each of the pinches in a heat exchanger network (HEN) and violate Pinch rules (see *Pinch Analysis for the Efficient Use of Energy, Water and Hydrogen* guide). The results may be presented as a cross-Pinch summary table (Table 5) and/or as a grid diagram (Figure 4). Both provide substantially the same information, but in different formats.

The grid diagram shows the supply and target temperatures (in °C) of all process streams and utilities, as well as the intermediate temperatures between heat exchangers. It also shows the hot and cold process stream temperatures corresponding to each of the Pinches, and identifies the heat exchangers in which all or part of the heat crosses a Pinch. Such situations are sources of inefficiencies that lower heat recovery opportunities. Where all of the heat in a heat exchanger crosses a Pinch, the two ends of the dumbbell representing the heat exchanger are on opposite sides of the Pinch, and are connected by a diagonal line. Where part of a stream within a heat exchanger is above a Pinch and part is below that Pinch, the corresponding end of the dumbbell is elongated across the Pinch. The amount of heat crossing the Pinch (in MW) is shown within the elongated end of the dumbbell. The overall heat load for each heat exchanger (in MW) is shown under the cold end of its dumbbell.

Figure 4 Grid Diagram of the existing Heat Exchanger Network



Heat Exchanger		Hot Stream	Cold Stream	Pinch		
				Process	Utility	
					17 barg steam	Air
				328°C	**148°C**	**43°C**
E1A	**Mixed Feed Preheater A**	Bottom Pumparound	Hot Feed			
E1B	**Mixed Feed Preheater B**	Bottom Pumparound	Tank Feed		0.66	
H1	**Feed Heater**	Fired Heater	Mixed Feed	9.2		
E2	**17 barg Steam Generator**	Bottom Pumparound	17 barg Steam Generator		0.04	
E3	**Slurry Product Cooler**	Slurry Product	Air		1.5	
E4	**Heavy Cycle Oil Cooler**	Heavy Cycle Oil	Cooling Water		0.57	1.2
E5	**Tank Feed Preheater 1**	Light Cycle Oil	Tank Feed		0.76	
E6	**Light Cycle Oil Cooler**	Light Cycle Oil	Cooling Feed			1.0
E7	**Tank Feed Preheater 2**	Mid Pumparound	Tank Feed		4.0	
E8	**Boiler Feed Water Preheater 1**	Mid Pumparound	Boiler Feed Water		0.78	
E9	**Mid Pumparound Cooler**	Mid Pumparound	Cooling Water		0.91	5.8
E10	**Boiler Feed Water Preheater 2**	Top Pumparound	Boiler Feed Water			
E11	**Top Pumparound Cooler**	Top Pumparound	Cooling Water			12.9
E12	**Tower Overhead Cooler 1**	Tower Overhead	Air			
E13	**Tower Overhead Cooler 2**	Tower Overhead	Cooling Water			0.46
Total (MW)				**9.2**	**9.2**	**21.3**

Table 5: Cross-Pinch Summary

Our primary concern at this stage is to identify the main inefficiencies at each of the Pinches:

❶ At the process Pinch (328°C interval temperature, which corresponds to a hot process stream temperature of 343°C usually at the top of the diagram and a cold process stream temperature of 313°C at the bottom of the diagram) there is only one cross-Pinch duty: H1, the fired heater (9.2 MW). This tells us that the mixed feed stream needs to be heated further before going to H1. More specifically, as the Pinch temperature is 328°C, the mixed feed stream should ideally be heated to $328 - \Delta T_{min}/2 = 313$°C. The only process heat sources available in the temperature range needed to do the heating are the bottom pumparound (BPA) and the slurry product.

❷ The Utility Pinch at 148°C interval temperature (hot process stream temperature of 163°C, cold process stream temperature of 133°C) corresponds to the point where the BFW line touches the grand composite curve in Figure 3. The total cross-Pinch duty is 9.2 MW, and the largest single inefficiency is in E7, the mid pumparound (MPA)/tank feed service (4.0 MW). The MPA is supplied at a fairly high temperature (254°C), and we need to get the tank feed hotter before we make this match. The next largest inefficiency is in E3, the slurry product cooler (1.5 MW), and then E9, the mid pumaround cooler (0.9 MW).

Ideally we would like to recover this "cross-Pinch" heat in the hydrocarbon feed, and thus save furnace firing.

There are also five smaller cross-Pinch duties including E1B, the "conceptual" bottom pumparound/cold feed heat exchanger that we added during data extraction. The existence of the cross-Pinch duty in E1B confirms that there is a lost opportunity inherent in the existing design, because the two feed streams are mixed ahead of the mixed feed heat exchanger E1. If we had extracted the data with the mix in place this inefficiency would not have been apparent in the Pinch analysis, and the target for 17 barg steam generation would have been lower.

Two of the heat exchangers involved in 17 barg steam generation (E2 and E8) also exhibit some cross-Pinch characteristics, but the small magnitude of the heat loads involved means that they are of no consequence in the overall study.

❸ The two largest duties crossing the air-cooling Pinch at 43°C interval temperature (hot process stream temperature of 58°C, cold process stream temperature of 28°C) are E11, the top pumparound (TPA) cooler (12.9 MW), and E9, the MPA cooler (5.8 MW). These inefficiencies show where the greatest opportunities exist to shift cooling water loads to air-cooling. However, as we have already noted, there is no incentive to make this load shift. As it happens these heat exchangers (E11, E9) are also the largest sources of heat that can be used to provide additional heat to the hydrocarbon feeds, especially the colder tank feed. This is of much greater importance (see **Step 4**).

Step 4: Define Options for Reducing or Eliminating the Largest Inefficiencies

During the targeting phase (**Step 2**) we established the magnitude of the potential opportunity for energy savings. In network analysis (**Step 3**) we identified the specific inefficiencies in the existing HEN. We now turn our attention to correcting the inefficiencies in order to approach the target energy usage in practice.

It is rarely practical or economic to eliminate every inefficiency in a HEN. Attempting to do so usually leads to unreasonably complex designs. The approach to take, therefore, is to focus on the largest inefficiencies that we identified in **Step 3**. This means, first and foremost, we must increase the mixed feed temperature ahead of furnace H1, to reduce the H1 cross-Pinch duty. We must also tighten the temperature approach in E7, the MPA/tank feed service, and thus reduce its cross-Pinch duty at the 17 barg steam generation Pinch. We will then seek to correct the next largest inefficiency at this Pinch – E3, the slurry product cooler - and, if the economics are favorable, we will also look at some of the heat exchangers with smaller inefficiencies. At the same time we must try to maximize the reuse of existing equipment, which tends to reduce the cost of the changes we make.

In order to reduce energy use we must recover heat that is currently being rejected to ambient cooling. From the grid diagram (Figure 4) or the process data summary (Table 1) it is clear that the most promising sources of heat are the TPA Cooler (E11, 14.0 MW) and the MPA Cooler (E9, 5.8 MW). The Tower Overheads is also a potential source of heat (E12 plus E13, 23.4 MW), but this is at a rather lower temperature. Moreover, plant layout does not favor its recovery.

The network analysis showed us that we need to provide additional preheating for the cold tank feed before we mix it with the hot feed. This sounds simple, but there are many possible options and combinations of options that could achieve this objective. Pinch analysis indicates what sorts of changes we need to consider in HEN designs, but in general the solutions are not unique. This is especially true in retrofit situations, where the existing plant layout often has a major impact on the economics of each option. Issues to consider include:

- What sequence of heat exchanger matches should we use on the feed (e.g. should we place a new TPA vs. tank feed match at the cold end of the preheat train, or should we use a new MPA vs. tank feed match in this location?)
- Should we add a new shell to the existing MPA/tank feed match (E7)?
- After adequately preheating the tank feed, is it advantageous to add a new MPA vs. mixed feed heat exchanger?
- Is there any low-cost way to recover the heat in the slurry product?
- How many new heat exchangers should we add?

The answers to these questions are not directly apparent from the Pinch targeting results. In general, at this point there is no alternative to a technical and economic comparison of the options that have been identified and the use of commercial Pinch software is very useful. In the original project upon which this document is based about a dozen different scenarios were evaluated.

Step 5: Evaluate Competing Options

In any heat exchanger network each change we make in any given heat exchanger is likely to have knock-on effects on other heat exchangers. Some of the commercially available Pinch software packages incorporate tools for estimating these effects. Either way, we require some type of model to quantify the utility savings attributable to each option and combination of options we wish to evaluate. These utility savings are converted to monetary savings using the utility costs data in Table 3.

We also need to estimate the cost of implementing each option. Most often this involves estimating the size and cost of heat exchangers. We can generally obtain estimates of the heat transfer coefficients for new shells from the data sheets of the existing heat exchangers, and with this information we can estimate the area of any new shells using the models discussed in the preceding paragraph. Rough cost estimates can then be obtained from simple “rule of thumb” correlations – e.g.,

Installed Cost (CAN$)= 2000 x Area (m2)

The cost of piping and any other equipment required for the identified options can be estimated in similar ways. Ideally any correlations of this type should be agreed with cost estimators at the site for which the study is being performed, as site-specific factors often come into play. However, in the absence of this input it is generally possible to generate sufficiently accurate cost correlations using published data.

When we have the cost and savings numbers for an option we can calculate the simple payback (cost/annual savings), or compute other measures of value such as ROI or NPV. Any of these measures can be used to quantify the attractiveness of each option. The way this is done generally depends on the preferences of the sponsor of the study. For example, the sponsor may wish to invest in all options that achieve a payback of less than a certain number of years. In other cases there may be a maximum total investment budget available, and the sponsor's goal is to obtain the highest return with that money.

Step 6: Select the Best Option or Combination of Options

The final design that resulted from the evaluation described in **Steps 4** and **5** is shown in Figure 5, and the corresponding grid diagram is given in Figure 6. The changes incorporated in the process are as follows:

❶ Add a new service E14, which matches TPA against the cold tank feed ahead of the existing service E5 (light cycle oil/cold tank feed).

❷ Add a shell to E7, the existing MPA/cold tank feed service.

❸ Re-pipe the slurry product draw to a point downstream of steam generator E2.

Overall these changes save 2.29 MW in heat absorbed in furnace H1 and increase total heat to steam generation by 4.26 MW. The combined savings are 6.55 MW, worth CAN$ 1,077,000/year.

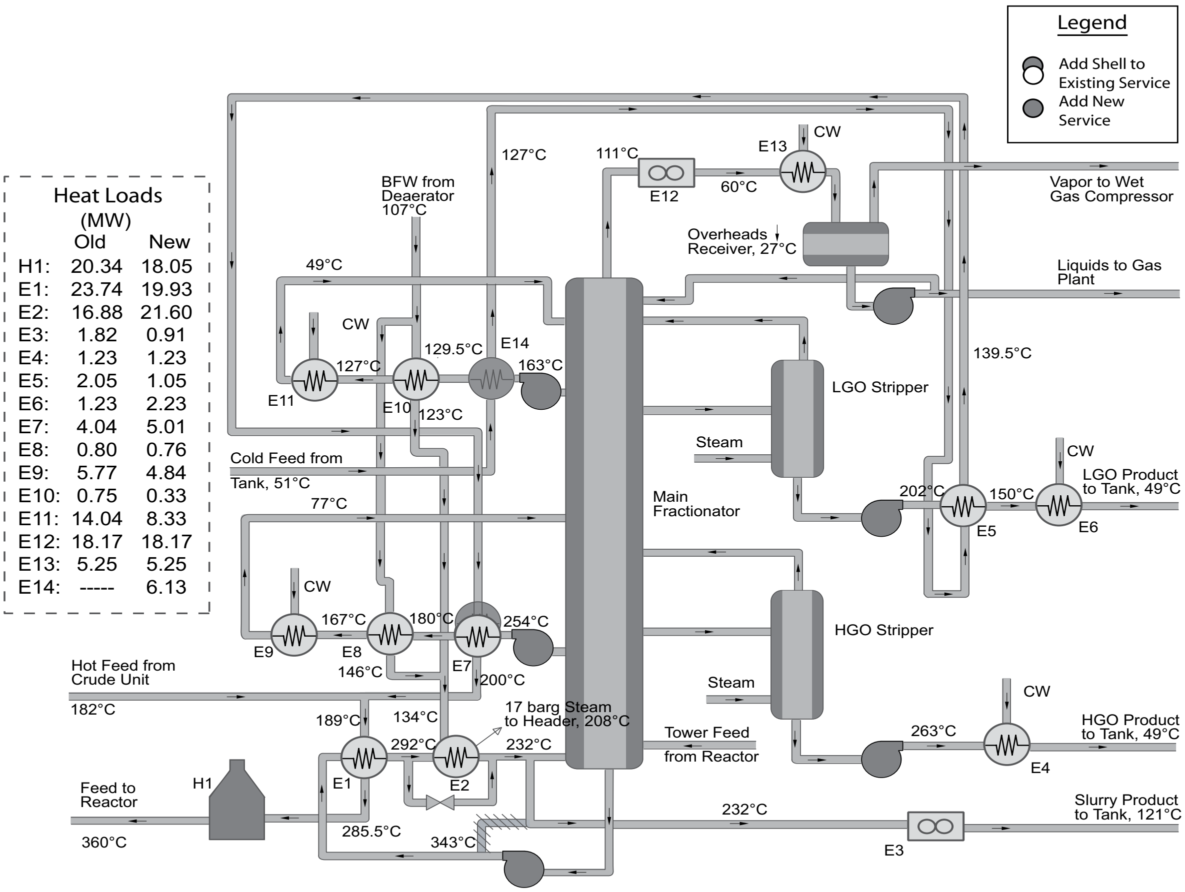
The changes can be divided into two separate groups or projects:

Project 1: This consists of change ❶ and change ❷. Together these changes deliver more heat to the cold tank feed by recovering heat from the TPA and MPA that would otherwise go to coolers E11 and E9. As a result of the higher tank feed temperature, the mixed feed going to E1 (the bottom PA/mixed feed exchanger) is hotter than in the existing design. This causes the duty in E1 to go down, while the steam generation rate in E2 goes up. E2 is an oversized exchanger; we control the return temperature of the pumparound to the tower by adjusting a bypass around E2.

The combined savings for Project 1 amount to 2.29 MW of furnace savings and 3.35 MW of steam generation. This is worth CAN$ 934,000/year. The cost of the project, including the new shells and piping, is CAN$ 1,800,000, giving a simple payback of 1.9 years.

Project 2: This is a stand-alone project, consisting only of change ❸. In the existing design the slurry product goes via air cooler E3 to tankage. However, this stream is identical in composition to the bottom pumparound (BPA), and is in fact drawn from the same pump. In this project, the take off point for the slurry product is moved: Instead of being taken from the pump discharge at 343°C, it is now taken from a point after the steam generator E1, at 232°C. This recovers 0.91 MW of heat that would otherwise be lost in the air cooler E3. Almost all of this heat appears in incremental steam generation in E2, worth CAN$ 143,000/year. Only piping changes are needed, at a cost of CAN$ 120,000, giving a simple payback of less than one year.

Figure 5 FCC Unit with proposed changes



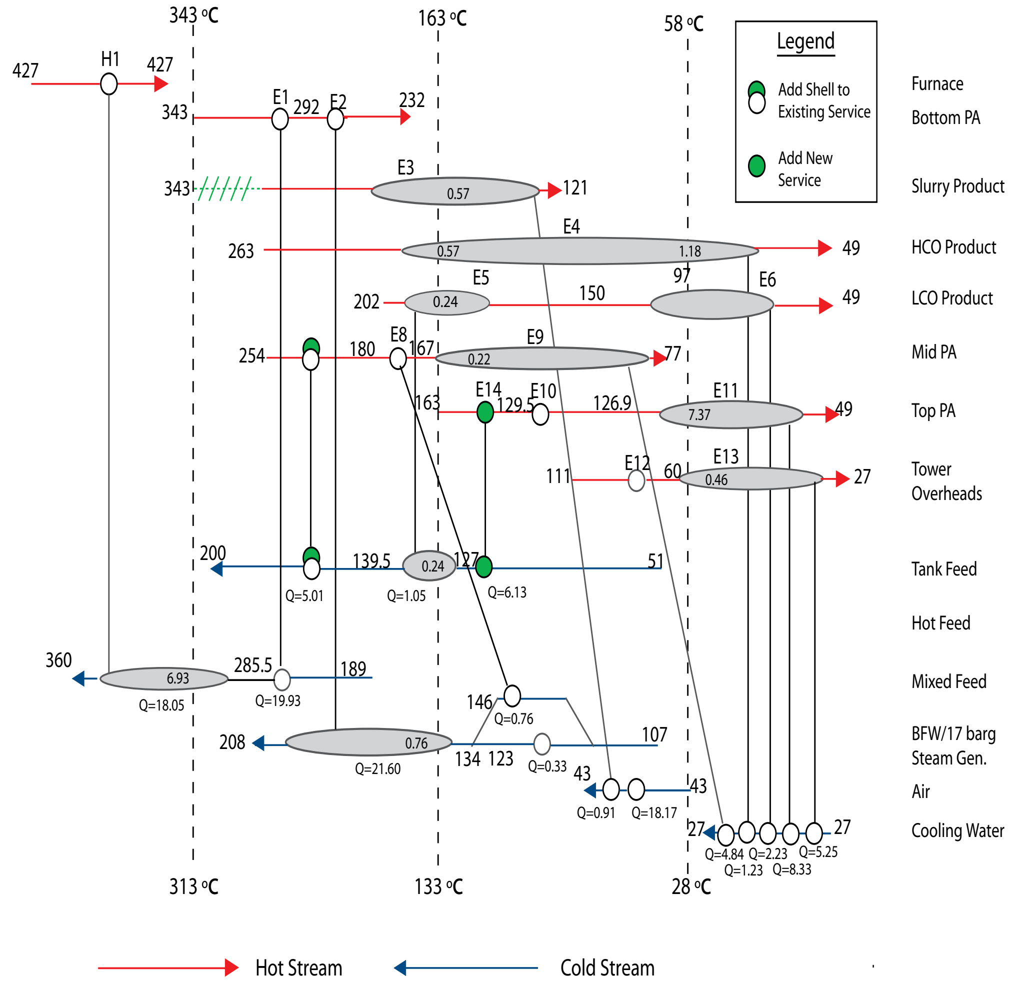
Heat Loads (MW)

	Old	New
H1:	20.34	18.05
E1:	23.74	19.93
E2:	16.88	21.60
E3:	1.82	0.91
E4:	1.23	1.23
E5:	2.05	1.05
E6:	1.23	2.23
E7:	4.04	5.01
E8:	0.80	0.76
E9:	5.77	4.84
E10:	0.75	0.33
E11:	14.04	8.33
E12:	18.17	18.17
E13:	5.25	5.25
E14:	-----	6.13

These results compare with a target utility reduction of 9.22 MW in furnace heat absorbed and no change in steam generation, with a net monetary target savings of CAN$ 1,641,000/year (see Table 4). The natural question to ask is: Why does the selected design achieve only about 71% of the target energy savings and 66% of the target monetary savings?

A comparison of the grid diagrams in Figure 4 and Figure 6 provides a simple answer. The largest single duty across the 17 barg steam generating Pinch in Figure 4 is E7, the MPA/cold tank feed exchanger (4.04 MW). This entire cross-Pinch duty has been eliminated in Figure 6. There are no duties greater than 0.76 MW crossing this Pinch in the modified design, and it is not economic to implement changes for such comparatively small increments. Furthermore the changes incorporated in Figure 6 have reduced temperature approaches in the network, making it more difficult and expensive to achieve further savings.

Grid diagram for FCC Unit with Proposed changes **Figure 6**



It is also noteworthy that there is still a duty of 6.93 MW crossing the process Pinch in H1. The only way to correct this is by increasing the duty of E1 (bottom pumparound/mixed feed exchanger) at the expense of steam generation in E2. The incentive for doing this is CAN$ 21,000/MW-year (see Table 3) – i.e., CAN$ 146,000/year for 6.93 MW. However, we would need to add shells to E1 to achieve this, and the cost of new shells in this service far exceeds the value of the upgrade.

CONCLUSIONS

Pinch Analysis is a very powerful technique to identify minimum energy consumption targets for heating and cooling and to identify projects that will allow significant energy consumption. This example highlights an important fact about Pinch analysis. Properly calculated Pinch targets are always thermodynamically achievable, and we try to select ΔT_{min} values that will ensure the targets are economically realistic. However, achieving savings requires not just targets, but actual projects. In most cases, practical process constraints limit the economically attainable project savings to a value that is somewhat less than the target savings. This does not invalidate Pinch targets – it simply illustrates that they are best treated as guidelines, not absolutes.

The CanmetENERGY research centre in Varennes is one of three research and innovation centres of Natural Resources Canada (NRCan). CanmetENERGY in Varennes designs and implements technological solutions, and disseminates knowledge in order to produce and use energy in ways that are more efficient and sustainable, to reduce greenhouse gas (GHG) and other air emissions, and to improve innovation capabilities of targeted sectors of the Canadian economy.

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