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Operability and Flexibility of Pinch Applications on Heat Exchanger Network in Chemical Industry – A Review

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Abstract

Energy conservation has recently become one of the most important considerations in industries, especially in petrochemical industries. This is due to the limited availability of fuel which affects the price of energy sources, as well as the tightening of the regulations concerning environmental and social issues related to pollutant emissions produced by industries. The successful energy-saving efforts made by industries impact on not only lowering production costs but also indirectly preserving natural resources as well as reducing the pollution of CO₂ which is one of the gases contributing to global warming. Pinch analysis has been widely known for process integration, especially in heat integration, in order to gain energy efficiency and cost efficiency in many industries for decade. The analysis allows selection of efficient heat exchanger network with minimum hot and cold energy requirement. By using pinch analysis, the number of heat exchanger units required could also be minimized which leads to the optimum cost of operational and investment. Pinch analysis is also allowing for the investigation of any pinch problems, such as pinch threshold problems, cross pinch problems, and problems related to incorrect placement of utilities which impacted to the wastefulness of energy consumption. Despite many success studies of highly potential saving of heat integration through pinch analysis, the real implementation of efficient and effective heat exchanger network (HEN) based on pinch analysis is still facing difficulties, for example in term of flexibility and controllability of operation. This paper provides preliminary information in increasing energy efficiency or energy savings when utilizing pinch technology considering operability and flexibility of its operation for retrofitting units for chemical industrial plants.

Key Words: Pinch Analysis,
Pinch Threshold Problem,
Process Integration

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1. INTRODUCTION

Huge amounts of energy consumptions have become a problem to any kind of industries for decades. Energy is consumed to convert raw materials into value added products in manufacturing processes. The higher the energy consumed, the higher the cost must be paid in a production process. Fuel price continues to increase, however fuel sources stock continues to decrease. To overcome the ever-increasing price and the limitation of fuel, industries have been endeavoring to find alternative solutions to reduce the utilization of energy in their processes to lower manufacturing cost. One of the solutions is heat integration using pinch analysis which has been proven credible in many industries [6].

Despite its fame for energy integration in oil and gas industry, recent literatures of pinch analysis application in chemical industries, covering either design study and/or its real application, are hardly found especially in an Indonesia context. Yet, the implementation of pinch technology in an actual plant site is rarely done due to, for example, the limitation of plant licenses or warranty operations. Moreover, a current study of pinch analysis

largely focusses more on the trade-off between cost capital and utility cost, overlooking operability and flexibility of operations such as a temperature disturbance of heat exchanger networks (HEN) [23] or fouling factor [39]. Therefore, this study is aimed at the application of pinch analysis as early data analysis for problem solving of heat recovery at a vinyl chloride monomer (VCM) plant of one of Petrochemical companies in Indonesia. The paper will serve as a preliminary literature review of the pinch technology applications in chemical industries, especially VCM industries, considering operability and flexibility of the operation.

2. PINCH ANALYSIS

Pinch analysis is a method invented in late 1977 by Bodo Linnhoff in a response to world energy crises in early 1970s. Although some researchers mentioned that the earliest study of pinch analysis was done by Ed Hohmann in 1971 on his PhD paper, the technique had not gained popularity in energy saving research until Linnhoff and Flower introduced Pinch technology in 1977 on which it is known in a process integration [46].

Table 1. Previous research of energy saving utilizing pinch point.

Industries	Method	Energy Saving	Reference
<i>Oil refinery (CDU)</i>	Pinch	45%, payback < 4 years	[47]
<i>Oil refinery (CDU)</i>	Pinch	72 MW & 64 MW (hot & cold utility)	[29]
<i>Oil refinery (CDU)</i>	Pinch	24%	[18] [19]
<i>Oil refinery (CDU)</i>	Process Integration, HTRI	Reduction 46.200 T CO ₂ , saving 386 M RUR	[57]
<i>Oil refinery (CDU)</i>	Pinch of modern design, Hysys	31,3%, CO ₂ 45,1%	[6]
<i>Oil refinery (CDU)</i>	Pinch, Aspen Energy V8.8	45–75%	[35]
<i>Oil refinery (Liquid Catalytic Cracking)</i>	Pinch	74% (8,955 MW)	[4]
<i>VCM plant (Reactor)</i>	MINLP	16 KW hot utility	[33]
<i>Palm Oil</i>	Pinch	66% steam, 48% cool water	[41]
<i>Aniline & Aromatic hydrocarbon plants</i>	Pinch (boundary unit & site)	27,32% & 53,3% (Aniline & Aromatic Hydrocarbon Plants)	[16]
<i>Olefine Plant</i>	Pinch of old plant design	51 MW hot utility & 144,2 MW cold utility	[8]
<i>Steels</i>	Pinch, total site	0,9x10 ⁶ GJ/Year	[45]
<i>PVC & Biorefinery</i>	Pinch, total site	Potential of total site pinch	[22]
<i>VCM (India)</i>	Pinch, Aspen Energy V8.0	15,38% hot; 47,52% cold utility	[10]
<i>VCM (Turki)</i>	Pinch	32,58% ~ 38,98% hot utility 15,25% ~ 18,26% cold utility	[3]

At the very beginning, it was widely known to be used for a heat recovery method, especially in oil and gas industries. Over decades, it then found its application in various industries such as chemicals [3] [10] [33], pharmacy, foods such as milk [58], and steels [45]. Potential energy and cost savings were also reported on various papers as several examples of previous pinch analysis studies as shown in Table 1. Nowadays, pinch analysis is not only used for the purpose of energy efficiency but also can be applied for water efficiency, CO₂ emission reduction [42], mass integration and other applications such as appraisal of economic investment for sustainable project [5], assessment of regional water resources [27], air emission reduction strategic of regional transportation [56], financial pinch analysis for selection of energy conservation [48], greenhouse gases mitigation in managing municipal solid waste [28], etc.

2.1 Basic Concept of Pinch

The concept of Pinch analysis is simple yet powerful in estimating energy saving on the design of HEN. Pinch analysis is developed based on the principle of the 1st and 2nd thermodynamic law. The 1st law of thermodynamic states that heat released by hot streams will be equal to heat absorbed by cold streams, while according to 2nd law, it is not possible for any process to have heat transfer from cold streams to hot streams.

The idea of energy saving utilizing pinch analysis is to maximize the process of heat exchanges and avoid any excess of utility's consumption [40]. Pinch analysis describes the baseline of energy target of any processes by plotting the available energy (enthalpy) and the aggregates of hot and cold streams which is later known as hot composite and cold composite curves (Figure 1). Those curves describe the entire process which are the heat availability and the utility requirements. The middle region, where the curves are overlapping, indicates the maximum of potential heat recovery which can be obtained from the process streams. Meanwhile, the closest point between the overlapping of hot and cold composites is referred as Pinch. This pinch temperature is the smallest temperature driving force for a heat exchange which will limit the heat recovery [40]. Figure 1 shows the relation between hot and cold composites with utility requirements. The overshoot lines (blue and orange shade) represent the minimum utilities requirements both for cold and hot utilities. The requirement for external energy (utilities) increases in line with the increasing portion of ΔT_{\min} chosen.

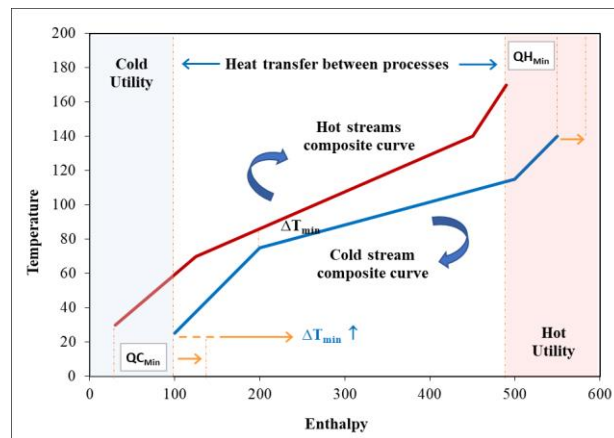


Figure 1. Relation of hot & cold composite with utility requirements.

The Pinch divides the curved area into two thermodynamic regions [37], namely, the area below the pinch (heat source) and the area above the pinch (heat sink). This will lead to the requirement that only hot utilities (for example steam) will only be present above the pinch area, whereas only cold utilities will only be allowed for the area below the pinch (Figure 2).

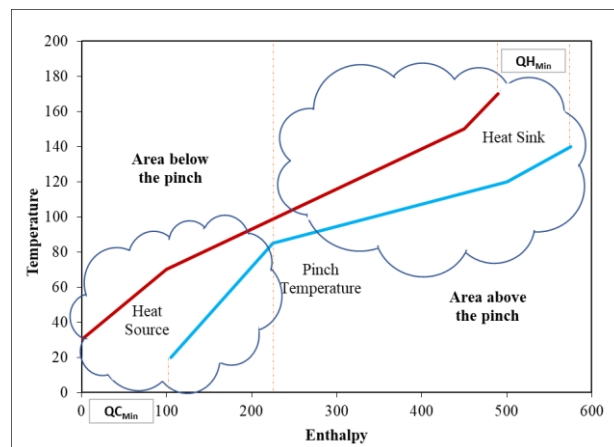


Figure 2. Pinch thermodynamically regions

There are three “golden rules” which have become a consensus in the application of Pinch:

- 1.) Heat transferred across the pinch is prohibited.
- 2.) Incorrect placement of utilities is not recommended; below the pinch only cold utilities are needed, while above the pinch only hot utilities are needed.
- 3.) Heat transfer which is smaller than the determined ΔT_{\min} is not allowed.

2.2 Typical ΔT_{\min} for Various Industries

Generally, similar processes may have similar composite curve. Typical experience of ΔT_{\min} , as seen on Table 2, 3 and 4 show the typical ΔT_{\min} for various industries, utilities matches and retrofitting targeting in various refinery process. They may practically be useful for retrofit project targeting as preliminary assumption [38] or can be used with caution for practical target.

Table 2. Application experienced of ΔT_{\min} in industries

Sector of Industries	ΔT_{\min}
Oil Refinery	20~40°C
Petrochemical	10~20°C
Chemical	10~20°C
Process with low temperature	3~5°C

Source: [38]

In oil refining industry, practical target of ΔT_{\min} is between 20~40°C with relatively low of heat transfer coefficient, and in many applications composite curves are parallel and there high potentially for heat exchanger fouling. While in Petrochemical and Chemical industries, ΔT_{\min} is between 10~20°C due to generally reboiling and condensing duties provide a better heat transfer coefficient and low fouling is expected. While for process with low temperature ΔT_{\min} is between 3~5°C, with caution that power generation for refrigerant system is very expensive, the lower temperature, ΔT_{\min} decreases, requires large area of heat transfer.

Table 3. Typical of ΔT_{\min} (utilities & process match)

Match	ΔT_{\min}
Steam vs process stream	10~20°C
Refrigeration vs process stream	3~5°C
Flue gas vs process stream	40°C
Flue gas vs steam generation	25~40°C
Flue gas vs air heater	50°C
Cooling water vs process stream	15~20°C

Source: [13]

Matches between steam and process stream, expected ΔT_{\min} is between 10~20°C, due to good heat transfer coefficient for steam condensing and evaporation. Utilization of refrigeration will be costly due to ΔT_{\min} is low. Flue gas with process stream is expected to have ΔT_{\min} around 40°C due to the low heat transfer coefficient for flue gas, so does with flue gas and air heater, it will depend also on the acid dew point temperature. While cooling water versus process stream ΔT_{\min} is between 15~20°C depend on condition such as whether cooling water is competing with refrigerant or summer operation.

The typical of targeting for retrofitting in various refinery processes as can be seen on Table 4. In Crude

Distillation Unit (CDU), the composite curves are tightly parallel, with the expected ΔT_{\min} is between 30~40°C, while in Vacuum Distillation Unit (VDU), composite curves are relatively wider compared to CDU composite curves but lower heat transfer coefficient with ΔT_{\min} is expected fall between 20~30°C. As for Naphtha reformer expected ΔT_{\min} is between 30~40°C with heat exchanger network dominated by feed-effluent exchanger, limitation of pressure drops and parallel temperature driving force. Fluid Catalytic Cracking (FCC) practical ΔT_{\min} that can be used is between 30~40°C, similar caution with CDU and VDU.

Table 4. The typical of ΔT_{\min} in retrofit processes

Sector of Industries	ΔT_{\min}
Crude Distillation Unit	30~40°C
VDU	20~30°C
Naphtha reformer	30~40°C
FCC	30~40°C
Gas oil hydrotreater	30~40°C
Residue hydrotreater	40°C
Hydrogen production unit	20~30°C

Source: [13]

Gas oil hydrotreater can be targeted on 30~40°C for the ΔT_{\min} . Gas oil hydrotreater is dominated by feed-effluent exchanger, high pressure exchanger which is expensive might be required, therefore it might require the need for separated target for high-pressure section at 40°C and low-pressure section at 30°C. Residue hydrotreater is similar with caution with gas oil hydrotreater. As for the rest, hydrogen production unit, requires high ΔT_{\min} (30~50°C) while the other processes are 10~20°C.

2.3 Grand Composite Curve

Hot and cold composite curves while they are important for determining the baseline of maximum potential heat recovery from the process and minimum utilities requirement which is also called as Minimum Energy Requirement (MER), cannot visualize the selection and placement of utilities. This limitation can be overcome with Grand Composite Curve which describes the overall heat cascades of each temperature interval. It shows the energy flowing on segmentation of interval temperature. Grand Composite Curve may represent the selection of utilities as for further action to have more efficient utilities saving [25]. The usefulness of Grand Composite Curve is to help in determining utility limit such as maximum and minimum temperature, amount of minimum hot and cold utilities requirement; investigating and evaluating of different utilities combination to fulfil the heating and

cooling duty; and evaluating whether low pressure steam raising is possible as well [60].

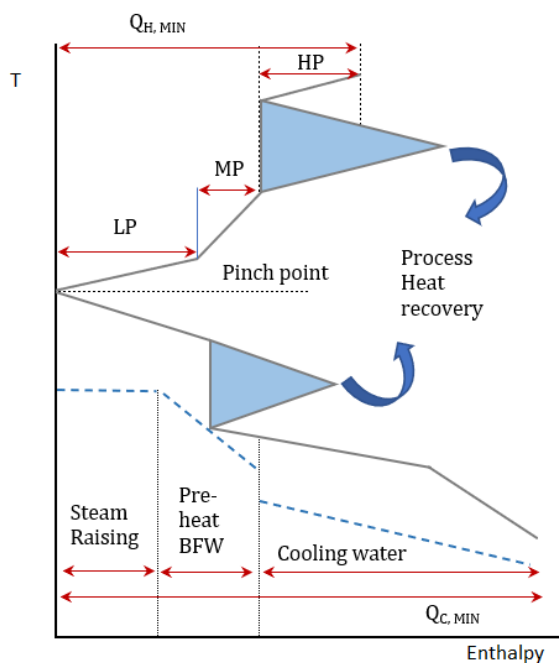


Figure 3. Grand Composite Curve allows for selection of utilities and placement.

As can be seen on Figure 3, Grand Composite Curve is able to visualize for the strategic selection and the placement of utilities, for example at above pinch region, instead of using high pressure steam for whole hot utility energy requirement ($Q_{H, MIN}$) which will be costly, to fulfil amount of required hot utility can be split using high pressure steam (HP), medium pressure steam, and or low pressure steam (LP) so that as total hot utilities usage will be more efficient in term of operating cost since medium or low pressure steam is easier to be handled and cheaper compared to high pressure steam. However, it is still needed to be considered from the capital cost point of view due to the increasing the amount of required-heat exchanger. When amount of minimum hot duty is fully supplied by high pressure steam, it will only require one heat exchanger. The splitting into three level of pressure steams will require additional two heat exchangers. At below pinch region, strategic of fulfilment of cooling heat duty can be various. The 1st strategic is fully supplied with cooling water, while the other strategic may include utilization of various coolants.

Steam raising is possible at below pinch area. The visualization of Figure 3 at below pinch region indicates the strategic for achieving energy recovery via steam raising. The 1st part of fulfilment cooling duty is fulfilled by cooling water, says to absorb heat of process stream

that made cooling water increases from 10°C to 30°C (cooling water region). Then boiler feed water (BFW) is introduced to the system, says at 90°C to absorb more heat (sensible) of the process stream which undergoes temperature changes to 130°C (pre-heat BFW region) when it reaches evaporation point and starting to be vaporized resulting low pressurized steam which can be utilized for other processes.

2.4 Grid Diagram

Grid diagram is another tool of pinch technology. It helps for designating frame for developing of heat exchanger network [14]. Example of simple grid diagram is displayed on Figure 4. The grid diagram represents the placement of heat exchangers following the flows of temperature changes of hot streams from above the pinch (left side) to below the pinch (right side), vice versa for cold streams. It is also having benefit for targeting the minimum number of heat exchanger units to cover minimum energy requirement [32], which is also in return will reduce the investment cost for heat exchanger.

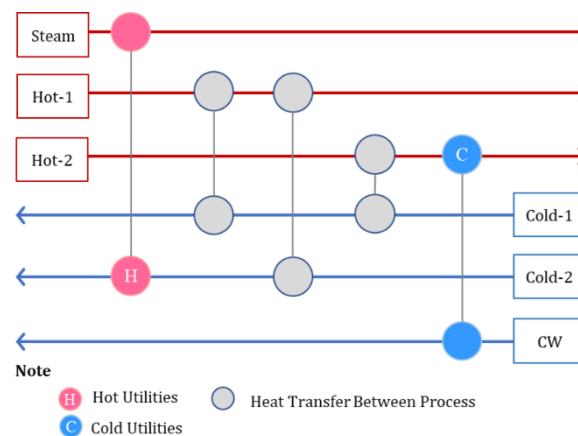


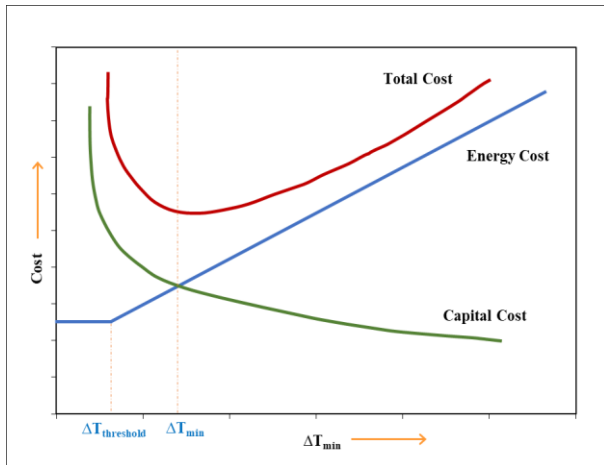
Figure 4. Grid Diagram of Heat Exchanger Network

Some guidance are used for the right placement of heat exchanger on the grid considering the and heat capacity of the stream. Many textbooks of process integration describe step by step on how to synthesize the heat exchanger network for obtaining the optimum number of heat exchanger considering its MER.

2.5 Trade-off

The changes in composite curves position relatively to each other will impact to ΔT_{min} and influence the cost as well, as can be seen on Figure 5. As the driving force (ΔT_{min}) between the composite curves decreases, energy cost will also decrease since the minimum energy requirement decreases, but as the consequences, the capital cost of heat exchanger will be increases as the need for increasing heat transfer area is required. Meanwhile the

increment of temperature differences due to the driving force between composite curves increases, the energy target will increase which will impact to the increasing of energy cost, however at the same time, the investment cost or capital cost of heat exchanger will be decreased due to the decrement of heat transfer area requirement.



Source: [50]

Figure 5. Trade-off capital cost and energy cost as function of ΔT_{min}

Therefore, there is a trade-off between energy requirement and capital cost of heat exchangers. There is an economic degree to which energy recovery can be done with considering the capital cost required for the heat exchangers to get optimum cost.

2.6 Typical Pinch Problems

2.5.1 Cross temperature

Cross temperature between area above and below the pinch will lead to the consequences of increasing both hot and cold utilities [13] as illustrated on the Figure 6.

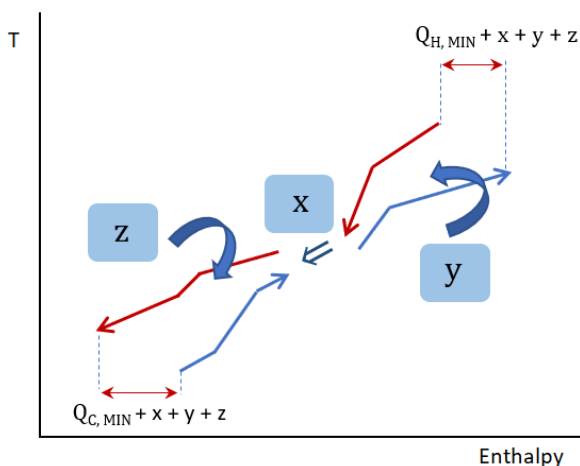
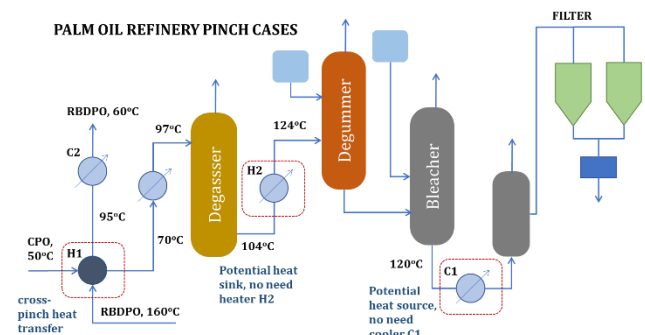


Figure 6. Violation of Pinch rules – cross temperature

When “x” amount of heat is transfer across from area above the pinch, the area will suffer loss heat as same as “x” amount, as compensation, to restore the balance some of heat utilities shall be added by the same amount of heat loss. Meanwhile the area below the pinch will receive the excess heat of “x” amount, and as the consequences, it needs additional cold utilities. Finally, making cross temperature between heat exchanger across the pinch will end up in additional energy consumption which is inefficient heat recovery process.

2.5.2 Incorrect Placement of utilities

Placement of hot utilities at area below the pinch and or cold utilities at area above the pinch, which Manan [40] mentioned them as heating below the pinch and cooling above the pinch are violation to the pinch rules which may lead to inefficient use of energy. His work on Palm Oil Refinery found that these violations of pinch rules resulted on large losses of energy usage as there were unnecessary heater (extra hot utility) and unnecessary cooling (Figure 7) which was potentially to be the heat source and heat sink in the process, and any cross pinch of heat transfer. Avoiding this misplacement of utilities will save 66% steam dan 48% cooling water.



Source: [40]

Figure 7. Palm Oil Refinery – Pinch Problem

2.5.3 Threshold problem

In some cases, pinch point couldn't be obtained for the determined ΔT_{min} , where one of minimum requirement of energies (either hot or cold) is not available on MER design. Critical temperature below the ΔT_{min} , where there is no pinch point is called as threshold approach temperature ΔT_{thres} [50].

Moreover, on the threshold pinch problem, in the unavailability of one of the utilities supplies, before the threshold temperature, the energy cost will be remaining the same (constant) regardless ΔT_{min} chosen as can be seen on (Figure 5), it shows that until the $\Delta T_{threshold}$ is passed, the minimum energy requirement remain flat. The trade-

off for this threshold problem is in the selection of heat exchangers since the energy cost will be remain flat before the $\Delta T_{\text{threshold}}$ is passed. Thirumalesh et al. suggested that for the threshold problem, optimum temperature difference was below the threshold value [55].

2.7 Pinch vs Energy Optimization

Since early study of pinch analysis, estimation of the optimum value of energy saving is obtained by a trade-off between utility cost (hot and cold utilities) and capital cost. It is not merely about taking as smaller as ΔT_{min} for obtaining minimum energy consumption, since the construction of heat exchanger with the smaller ΔT_{min} will result in huge investment of capital, which is not profitable as for industry to run its operation. The increment of ΔT_{min} has an impact on the increment of utilities requirement ($Q_{C_{\text{min}}}$ and $Q_{H_{\text{min}}}$) as showed on the Figure 5, but in the meantime higher ΔT_{min} may reduce the cost of investment of heat exchanger itself since the required area of heat exchanger will be reduce, so the intercept between the two would be the optimum cost.

Pinch method also allows for the optimum number of heat exchanger network design by elimination of heat loops existence [13] [50]. Heat exchangers which form a heat loop can be combined, therefore it will reduce the number of heat exchanger required. However, it is needed to consider the violation of the ΔT_{min} during heat loops elimination. When the number of required heat exchanger is decreased, the capital cost for the investment of the facilities will also reduce.

The later study proposed by Akbarnia [2], was to include piping cost as part of capital cost. Akbarnia in 2019, studied about the effect of the piping cost which affects to the total capital cost. On his paper, it is mentioned that while the energy requirement increases, the required area of heat exchanger will be decreased resulting in lower capital cost. However, as the mass flow rate of the energy streams increase, so does with the piping size, which lead to the increment of piping cost.

Moreover, recent study of Sovic et al. [53], covers the assessment of inherent safety of Heat Exchanger Network during the design stage. They suggested after the development of HEN design, it shall be considered the detail of heat exchanger geometry. Their study on enhancement inherent safety assessment during HEN synthesis conclude that risk assessment covering toxicity of fluid, flammability and explosiveness were reduced up to 73% after optimization of heat exchangers geometry taking into consideration of logarithm mean temperature, velocity and pressure drop, type of flow, number of passes.

It was also already covered the Net Present Value as consideration for investment decision making.

3. OPERABILITY AND FLEXIBILITY OF HEAT EXCHANGER NETWORK

Several studies showed that pinch analysis can be applied in various industries in the effort of energy optimization. However, maximizing heat recovery of process, while benefiting for energy saving, it increases difficulties in other area of operability and flexibility of operation. Energy optimization in general will increase the complexity of the plant operation which impact on the operability and the handiness of process control [34]. Despites of many success stories of pinch application, still there a lot of issues need to be solved during design or retrofitting of Heat Exchanger Network (HEN), especially related to plant layout, pressure drop, fouling, flexibility operation, maintenance [11] [57], as well as safety operation and process controlling, inherent safety [12], [53].

It commonly known that pinch analysis method is applied typically based on clean condition of heat exchanger (without fouling) and on fixed parameter operation such as temperature of stream supply and target as well as the flow rate of stream. In practical, operation condition at site is fluctuated and it is influenced by several condition such as start up or shut down condition, any changes in feed flowrate, fouling after several period of operation, etc. Without flexibility of operation, it would be harder for operation to maintain stable plant operation which required to achieve maximum productivity as well as efficient energy consumption. Comparing to designing of HEN, operating of retrofitting unit may encounter numerous challenges such as fouling and reduction of temperature output while trying to improve productivity for having optimum cost, material, and energy consumption efficiency [52].

Fouling or dirty condition of heat exchanger is naturally happened due to formation of unwanted material on the surface of heat exchangers. This fouling layer will lead to the increment of energy consumption and CO₂ emission as Loyola-Fuentes et al. [39] mentioned on the paper. Layola proposed a new method for regressing of fouling modelling of shell and tube heat exchanger using simulated plant-data of crude oil HEN, combined with reconciliation and gross error detection. The modelling is important for indication of operating condition setting such as velocities and temperature. Layola concerned about the effect of error in measurement and the limitation of measurement number availability. Fouling matter has become challenging problem for many industries, it is not

only having unbeneficial impact on amount of energy usage, but further operation of HEN may lead to severe carbon deposit which will result in another production problem.

Besides fouling, other parameter has been studied was related to controlling of the HEN operation-anticipating changing on temperature targeting. Earlier concept was introduced such as by Floudas and Grossmann [17], Yee and Grossmann [59], Galli and Cerda [20], followed by works of Mathisen [44] on bypass-selection for controlling HEN, Aguilera and Marchetti [1]. Recent study was done by Hafizan et al. [23] related to utility temperature fluctuation. His work on how to manage temperature disturbances of HEN for achieving maximum heat process recovery by considering fluctuation of temperature supply on utility consumption, heat exchanger sizing and bypass placement. Hafizan proposed two heuristics (bypass placement and heat exchanger sizing) for HEN design to allow for the flexibility and controllability in achieving effective energy recovery from HEN. These two heuristics are described as the following. As for bypass placement, he proposed a bypass should be placed at the disturbed stream when the temperature disturbance value increases or decreases on either above or below the pinch and when the temperature difference is not equal with zero, and on the contrary a bypass should be placed on the other side of the disturbed stream when the temperature disturbance value is touching the pinch point and when the temperature difference is equal with zero or its enthalpy is less than the enthalpy of another side of disturbed stream. As for the size exchanger, he proposed size a heat exchanger dan utility exchanger to serve to the highest amount of energy to be exchanged and to the highest amount of utility needed, considering all disturbances scenario. This method was tested for two cases of previous study of methanol synthesis process and Escobar's work in 2013 [15].

Furthermore, Marton et al. [43] mentioned whilst heat integration is important for energy efficiency, on the other hand it can result on operability issues of process. Knowing what operability issues need to consider in estimating reliable heat saving potential whilst maximizing possibility of operation implementation is very important. Although many cases of study shown the possibility of great potential of energy saving, there are implication of heat integration on the operational condition such as network complexity, pressure drop, change in stream balance, reduced load on furnace, etc. based on their work on investigation of operability and flexibility of Heat Exchanger Network, suggested classifications of the two terms above for better

understanding which of the two items give larger effect on heat saving potential for oil refinery industry.

Table 5. Connection matrix retrofitting & operability

Retrofit implication	Operability Factor				
	Flexibility	Controllability	Startup/Shutdown	Reliability	Practical
De-bottlenecking	✓				
Stream splitting		✓			
Complexity of network	✓	✓			
Reduce furnace load	✓	✓			
Reduce air cooler load	✓	✓			
Pressure drops	✓	✓			
Steam balance change	✓	✓			
Shutdown of furnace	✓	✓	✓		
HE between process unit	✓	✓	✓		
New equipment installs				✓	✓
Rebuild existing facility				✓	✓
Pressure difference				✓	✓

Source: [43]

Marton defined the operability as the ability to operate facilities, process units at different external and operating condition without giving negative impact on safety or product quality, and it is divided into four sub-categories: flexibility, controllability, startup/shutdown, and reliability/availability. It is recommended for retrofitting project to consider the matrix (Table 5) as a checklist to evaluate the impact and ensuring the most important factors have been considered during the retrofitting proposal. For example, complexity of network (on table above), with many interconnections between processes units, controlling of network by operation would be difficult and the dependency of each unit will highly potentially lead to the decrement of process flexibility. The other implication such as pressure drop, might be potential issue since will affected by the increment area of heat exchanger. It is needed to be compensated, for example whether necessary to increase pumping power for enabling fluid transport around the plant.

The study of pinch for heat integration as well as flexibility and controllability of HEN seems extensive for oil refinery industry, however it is rarely found for the Petrochemical and Chemical industries application.

4. PINCH ANALYSIS IN VCM INDUSTRIES

VCM manufacturing companies produce Vinyl Chloride Monomer (VCM) product which is required for

production of PVC product. VCM plant complex are consist of EDC reactor, EDC cracking furnace and distillation units for purification of EDC and VCM. By product of HCl is also produced as the result of cracking process of EDC to form VCM. The plant units consume energy in a quite high amount which is the second largest contribution to its operating cost [54], and for the sake of competitiveness of operation as well as commitment to clean industry, the energy efficiency activities are potentially to be implemented.

Pinch analysis in VCM plant is quite limited, especially in Indonesia context. Bokan & Pople [10], studied about design of heat exchanger network for VCM distillation unit using pinch technology, and the study result revealed that the optimum network is the one with ΔT_{\min} 9°C, which saving 15.38% hot utilities and 47.52% cold utilities with the payback period of the new design is 3.15 years. Akgun & Ozcelik [3], investigating the debottlenecking and retrofitting VCM plant in Turkey, with the target of ΔT_{\min} is 10°C.

The ΔT_{\min} of each study conforms to the experienced of global ΔT_{\min} , on which mentioned as for Petrochemical industries is around 10~20°C. However, despites of these success studies of potential cost saving of VCM plant operation, no further information of the operability and controllability of operational itself which can be referred for the application of optimization of Pinch technology application for real implementation at site considering flexibility and controllability of its processes.

5. CONCLUSION

Pinch analysis has been studied for decades and can be applied on numerous industries in the effort for maximizing process heat recovery to obtain energy saving as well as achieve cost saving. Heat integration has beneficial impact for this purpose. However, it also increases the complexity of operation which lead to difficulty in achieving reliability of plant operation on the viewpoint of productivity, environment, and safety point of view.

Moreover, the project of increasing productivity (de-bottlenecking) may lead on benefit of increasing output of production while maintaining energy consumption, but it should be considered from a lot of aspects to include plant operability, flexibility operation which will result in save and reliable plant operation.

Economical point of view also is needed to be considered, not only from the reduction of operating cost on lowering energy consumption but also plant reliability and investment point of view. Future works on pinch technology is promising to cover many disciplines studies

to include financial calculation, not only in term of payback period but also Net Present Value (NPV) and Internal Rate of Return (IRR) to obtain more reasonable figure of heat recovery project.

6. FUTURE OPPORTUNITIES

This review of previous works upon the pinch methodology, heat exchanger network synthesis as well as the operability and flexibility consideration are intended for gathering data in the attempt of looking for potential new improvement ideas for trouble shooting of heat exchanger network operational problems in a VCM company. The information gathered from this review could potentially be applied within VCM industries and various chemical industries.

7. TERMS

MER : Minimum Energy Requirement

ΔT_{\min} : Minimum temperature different to avoid *cross temperature* on HEN (the smallest driving force temperature for heat exchange)

ΔT_{thres} : Threshold temperature where no pinch point exists and one of required energy is not available

HEN : Heat Exchanger Network

NPV : Net Present Value

IRR : Internal Rate of Return

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