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Optimization in Energy Usage for Refrigeration Systems Using Combined Pinch and Exergy Analysis

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In present paper, that is confidence the application of CPEA analysis in optimizing the energy consumption in a refrigeration cycle. In refrigeration cycles, the major purpose is minimizing the amount of consumed shaft work. It is proposed to set -40°C in refrigeration level instead -20°C in refrigeration level in order to reduce the exergy loss. The modification of refrigeration cycle is caused have a 20 % reduction in exergy loss, that is equivalent with the reduction of shaft work in refrigeration level that is a 5.492 MW. In amount the reduction of shaft work by the modification of the refrigeration cycle is caused to reduce the Fuel Gas that is 24.38 GJ/h in amount. In addition, the obtained revenue of this economy is about 1,174,534 $/y.

1. Introduction

Pinch technology with using its key tools such as composite curve and grand composite curve can set goals for modification and improvement of a process (El-Halwagi and Manousiouthakis, 1989). As a limitation of pinch technology, it just can analysis the thermal systems and can not be able to study power or shaft work. Therefore, in systems like refrigeration cycles and power turbines which need to power or shaft work in addition to thermal energy. Exergy analysis can be used as a helpful tool to evaluation of power or shaft work (Kotas, 1995). In real process energy is not destroyed, but rather transformed in to other forms, less suitable for feeding and driving the processes. Hence, the quality of energy should be evaluated as well as its quantity (Dewulf et al., 2007).

2. Combined Pinch and Exergy Analysis

The concept of Exergy investigates the ability to perform useful work in a natural environment. Technically, exergy is defined using thermodynamics principles as the maximum amount of work, which can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment. Unlike energy, exergy is consumed or destroyed, due to irreversibilities in any real process (Rosen, 2008). Exergy analysis is the traditional method of assessing the way energy is used in some physical or chemical process with transfer and/or conversion of energy (Jaimes et al, 2010).

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In heat exchanger network problem with thermal energy targeting, pinch technology offers the best design using basic concepts of thermodynamic and heat transfer without entering complex design problems. So in power plants design, just pinch technology is not sufficient and another helpful tool is needed for reinforcement (Neto and Pilidis, 1998). With using suitable combination of pinch and exergy analysis, useful and practical solution will be obtained for simultaneously study of thermal energy and shaft work for such systems. This technique entitled "Combined Pinch and Exergy Analysis", briefly called CPEA.

3. Result and discussion

To show how to use the combined pinch and exergy analysis for optimization of energy usage, a refrigeration system of an industrial unit is studied as a case study. The method of required information extraction for targeting and process design, play an important role for the proper performance of it (Rev and et al, 2001). Generally a heat flow has two temperatures, the supply temperature T_{supp} and the target temperature T_{targ} that contains a specified combination of temperature in this range. In addition to supply and target temperature of each thermal stream, flow and physical properties should be determined. The information about process thermal flow is given in table 1. The utility is made of several sections including electricity, cooling water, steam and refrigeration matter at -100 °C and -20 °C levels.

Table 1: Hot and Cold stream data

STREAM NAME	T_{supp} (°C)	T_{targ} (°C)	DUTY(MW)	MCP (MW/°C)
COLD1	-85	55	20.52	0.15
COLD2	-5	-4.9	50	500
HOT1	65	-15	43.96	0.5495
HOT2	-35	-35.1	11.72	117.23
HOT3	-47	-70	10	0.43
HOT4	-86	-97	2	0.18

3.1 Objective Function

Because in a refrigeration cycle shaft work is consumed for cold production or refrigerator fluid's temperature reduction, an ideal cycle has lowest shaft work consumption in the compressors. Therefore, the main goal of refrigeration cycle optimization is minimize the amount of consumed shaft work. Since optimization of refrigeration cycle is influenced by amount of needed shaft work, problem analysis will be studied using combined pinch and exergy analysis. Key tools for this technique are ECC and EGCC diagrams which are accessible using pinch analysis tools such as CC and GCC diagrams. In Figure 1 EGCC diagrams current refrigeration cycle are plotted. It shows the relevant curve is located 7 MW after vertical axis (Carnot coefficient). That distance is exactly equal to the amount of specified heat on the right side of diagram that can be exchanged to the process by process flows (pockets) and set the process exchangers. After inserting required utility level on EGCC curve in Figure 1 and calculation of required heat, it is appeared that the required utility is about 37.2 MW and all of this amounts relevant to cold utility.

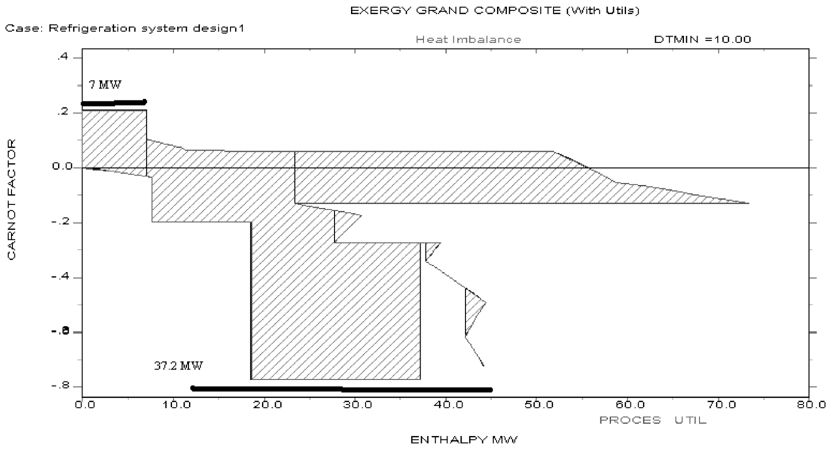

Figure 1: EGCC of current refrigeration cycle

Some of them provide by cooling water (CW) and remained is provide by two refrigerator fluids. Consequently, the amount of required energy in exist system is decreased to 7 MW. On other words, system's hot utility is eliminated very cold process flow with 7MW heat flow, can form process exchangers with hot process flow with same heat and exchange the heat. This matter that is accompany with hot utility reduction cause energy saving equal to 7MW, because in pinch analysis hot and cold utility reduction are equal. Figure 2 shows GCC diagram for modified network.

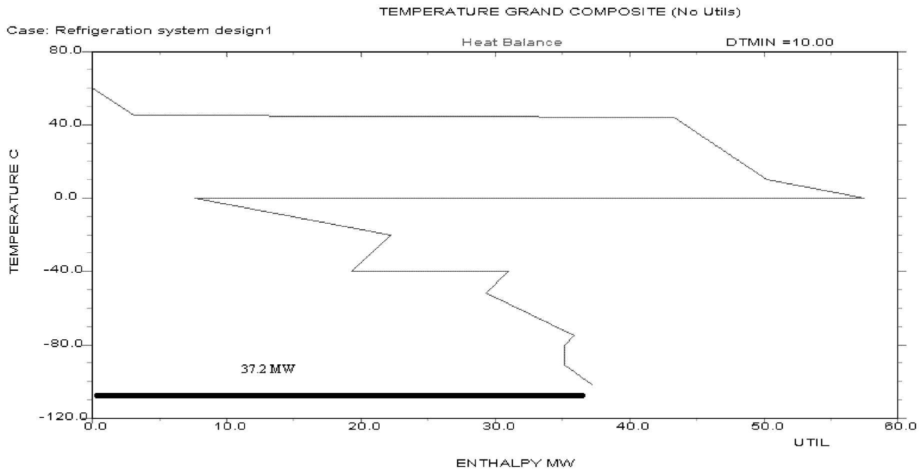

Figure 2: GCC of the improved refrigeration cycle

3.2 Evaluation and Optimization of Existing Refrigeration Level using EGCC

Study of existing thermal system and general reforms trend shows encountering with above threshold problem that amount of thermal energy is equal to zero and amount of refrigeration energy is equal to 37.2 MW. Also thermal energy recovery is equal to 7 MW in this problem. The main goal is optimization of refrigerator level so that the mentioned amount of energy recovery provides not only lead to minimum shaft work losing but also, lead to minimum exergy losing in the system. Figure 3 display EGCC diagram with refrigeration level on it. According to this figure there are two refrigeration temperature levels -100 ^{0}C and -20 ^{0}C in studied refrigeration systems that each of them is doing refrigeration of hot process flow in one or more heat exchanger. Study of refrigerator levels in refrigeration system, show that there are big temperature differences between process, i.e. EGCC curve and refrigerator levels.

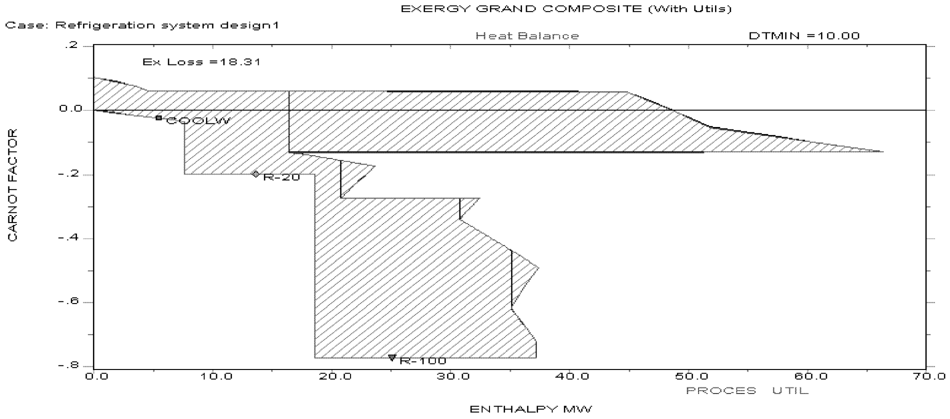

Figure 3: EGCC with refrigeration level on it

This distance indicates $(\sigma T_{\circ\,HEN})$ quantity or exergy losing in the system. This value is obtained 18.31 MW with performed calculations. Since exergy of shaft work loss reduction is directly proper to the area between refrigerator level and EGCC curve, so choose the suitable refrigerator level that has minimum distance or minimum temperature difference with central process is most important.

With respect to basis of $(\sigma T_{\circ\,HEN})$ reduction in existing refrigeration system that is appropriate to area reduction between two curves and refrigerator levels, it is recommended instead of refrigerator level at -20 ^{0}C, temperature level at -40 ^{0}C may be used. In the proposed cycle, temperature of hot process flow decreases from 69 ^{0}C to 49 ^{0}C using CW and the temperature of CW increase from 20 ^{0}C in the entrance to 30 ^{0}C in the output. The refrigerator level is constant at -100 ^{0}C.

Figure 4 shows the modified refrigerator levels on EGCC. As it is clear from Figure 4, amount of $(\sigma T_{\circ\,HEN})$ is equal to 14.63 MW at -40 ^{0}C temperature level. According to the information and design data, the exergy efficiency of compressor is equal to 67% that will be used in next calculations.

The main goal is required shaft work economy in the system, so at first, amount of $(\Delta\sigma T_{\circ\,HEN})$ obtain from equation No. 1 after that, with using equation No. 2 amount of ΔW_{act} will be obtained. Exergy efficiency is the important point of a modified system that Dhole and Linnhoff (1994) obtained it for several different systems with different fluid. He observed the exergy efficiency for all refrigerator systems that use one specific fluid and act in a same temperature range is equal. Therefore, with using an acceptable approximation, exergy efficiency before and after modifications are the same.

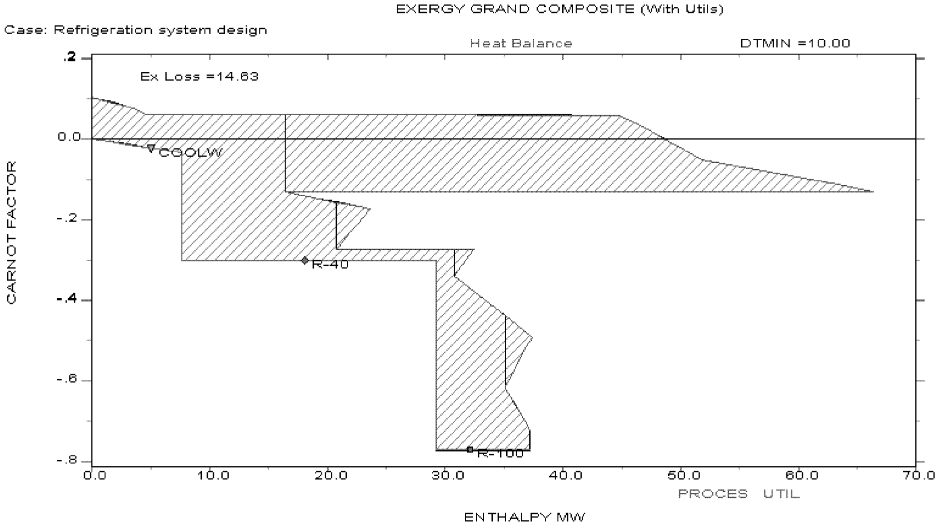

Figure 4: Improved refrigeration levels on EGCC

$$\Delta\ (\sigma T^{\circ}_{HEN}) = \sum EX_1 - \sum EX_2 \qquad (1)$$

$$\Delta W_{act} = 1/\eta_{ex}\ (\Delta(\sigma T^{\circ}_{HEN})) \qquad (2)$$

$\Delta(\sigma T^{\circ}_{HEN}) = 18.31 - 14.63 = 3.68$ MW

$\sum EX_1$ is total exergy changes for existing refrigeration cycle and $\sum EX_2$ is sum of the exergy changes for a modified cycle. Thus, amount of exergy loss reduction in a refrigeration system was determined. Now, shaft work reduction ΔW_{act}, obtains:

$\Delta W_{act} = 3.68 \div 0.67 = 5.492$ MW

Therefore, shaft work reduction in above system that can be achieved is equal to 5.482 MW. In the economic calculations, information about compressor of refrigeration system is needed. Study of existing design data, shows this compressor works with high pressure (HP) steam and about 6.12 t/ h steam flow is needed for production 1MW shaft work. Also about 0.7256 GJ/ h fuel gas is needed for production 1 t steam/h. Thus, amount of economized fuel gas can be achieved instead of 5.492 MW reductions in shaft work.

Total amount of economized fuel gas =24.38 GJ/h

Now, for 8000 working h/y and if the price of energy consumption in a refrigeration system was equal to 6.02 $/GJ amount of economic saving can be determined as follow:

Amount of economic saving= 1,174,534 $/y

Since, it is possible to accomplish any modification on a heat cycle by some changes and also set a series of heat exchanger network, so investment costs calculation and its pay back time on the retrofit design is recommended. Results are shown in Table 2:

Table 2: Total results

Option	Quantity	Units
Exergy loss before modif.	18.31	MW
Exergy loss next modified	14.63	MW
Reduction of shaft work	5.492	MW
Reduce the Fuel Gas	24.38	GJ/h
Reduction in steam	33.61	t/h
Economic saving	1,174,534	$/y

4. Conclusion

In present research, a refrigeration system studied using combination pinch and exergy analysis. Basis of Pinch and exergy principles, with change of refrigerator temperature level from -20 °C to -40 °C, exergy losing is equal to 20 % and shaft work reduction is equal to 5.492 MW. With respect to economic calculations, the amount of economic benefit of this project is 1,174,534 $/y.

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