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Design of Heat Exchanger Network in Olefin Unit of Oil Refinery

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Abstract –*The main purpose of this study is to propose a new design of oil refinery that shall be more optimum and efficient. In designing the optimum system, there are four steps to be done which are analysis of the existence exchangers, fixing the bad exchangers, replacing new exchangers and doing final changes on the refinery. This research is to analyse on an Iranian refinery (Isfahan refinery) and investigate all the exchanger conditions and locations which need to be fixed or changed. As a results, none of the flows has been separated and the change that has been done is very minimum. The temperature on the main tower has been reduced almost to 52°C, the cooling system numbers 108, 123 and 161 have been removed from the network and the temperature on cooler number 101 and water cooler number 172 has been reduced. Seven new exchangers with the surface temperature of 1807M^2, have been installed and 2 new shells have been added to exchanger 155. The position of this exchanger has been changed and has been moved in between exchangers' numbers 157 and 158. All new exchangers also have been installed in the old place of exchanger number 155.*

Keywords: Heat Exchanger Network, HEN, Optimization, Design, PINCH Method, Retrofit

1.0 INTRODUCTION

Iran (Isfahan) refinery has not made any changes after the war in the country since 1970. This research is very important to solve the problem in the refinery, in order to save energy and save money for the refinery. This research is expected to make a big change in the refinery, which can save much time and money. It also enhances the refinery and it can be done without sacrificing efficiency. As is known, fuel consumption is essential in everybody's life. Therefore, this research can help to stabilize the price of fuel, increase production (line) and eventually benefit the city and the government. Several issues would prevail if the refinery does not apply the method. First, there is a probability that this refinery might stop its operation at any time because of high temperature. Second, the production cannot be maximized and would incur more cost to the government. With this study, the researcher has achieved the optimization in the refinery, reduced the heat on the exchanger and reduced the temperature on the main tower. The money that can be saved is approximately about 1,337,200 US dollars per year. One of the steps to start the optimization is to check the energy use of cold and hot streams from the HEN to utility. In this process, the movement can be either from the first layer to the last layer or from the last layer to the first layer with the purpose of achieving the optimization

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results in the system. After the establishment of this analysis, researchers started to develop a new process that is called process integration. In this system, all the processes are integrated into a system to calculate and optimize the use of energy. The prerequisite of this process was a preliminary research on the following two subjects which are pinch technology and energy analysis.

2.0 LITERATURE REVIEW

In June 2009, Jimmy D. Kumana was working for a consulting engineering company in Texas [1]. The company provided energy optimization solution to the big industries to improve the efficiency of those companies. By applying the PINCH analysis for energy optimization, their solution could reduce energy usage by15 to 30 percent. In May 2007, Geldermann *et. al* worked on heat exchanger transfer and they applied it on a company in China; and after getting the result, Linnhoff and Flower compared it with the other companies to see the difference of percentage done in the optimization [2]. In the year 2010, the Chemical Engineering Department, King Fahad University of Petroleum and Minerals, Saudi Arabia started working on the optimal design of heat exchanger network in oil refineries and they worked on the formulation that accounted for the anticipated schedules and heat integration during the FCC-HEN in the design. The result, as shown in this paper, was that the efficiency was 81%, with $\Delta T_{min}$of 12˚C. In May 2013, K. Manjunath worked on the construal heat exchanger. Linnhoff started redesigning the structure of the oil olefin, and by changing the places of tubes and checking the rational efficiency, he came up with a new design which worked more efficiently. In November 2010, P. Stenhlik started working on different strategies to improve industrial heat exchange and he presented three of exchangers for optimization on heat exchangers which were: Global intensification, local intensification, helix changer.

Different ΔT_{min} for the system to be optimized has been given and knowing the value of the temperature and energy usage in this system can easily help find where this system stands in the optimization process and the image can easily show where this system stands. If the X mark as shown in Figure 1 stands on the curve or stands by a 10% difference in the curve, it can be said that this system is doing well and is well designed, but if the X point is far away from the curve, that means this system needs to be optimized[3].For example, the B point is taken as the optimized point, the best design is to push the X point to the B point because it makes the system use less energy and also reduces the heat transfer in the system. However, normally not much changes can be made because of the existing network and the invested money. The design for when the mean target is optimizing the energy, is to move from the X point to the A point because will not have any extra heat transfer added to the network and the energy will be used to the minimum. However, optimization process in the network without money to be invested, is not possible. Moving from the X point to the other point in the figure is going to increase the heat transfer, so it is not efficient to do so because the reduction of energy has to be done by not making the system use more energy. It is also not possible to change the whole network and build a new one because the old one will be useless. Hence, as shown in Figure 1, the only way to optimize the network is to move the X point in the figure. Doing the work is not easy but as shown in Fig. 2, there are ways to fix the network. Some of exchangers are impossible because these changes to the network and the finding of the best point to be changed are very costly.

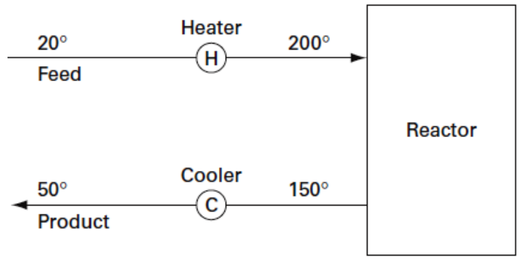

Figure 1: Process Flowsheet [4]

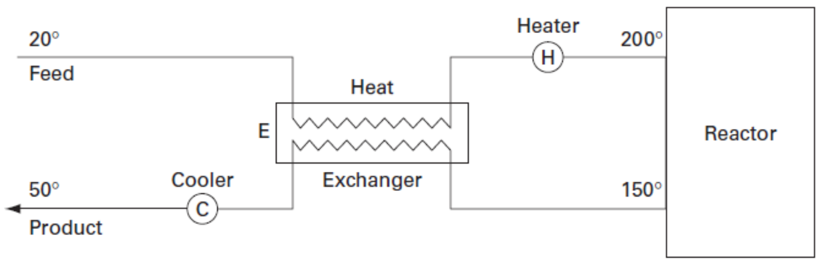

Figure 2: Heat exchange process [4]

For example, the best way to do this work is shown in Figure 3, which shows that if increase the investment, can have a better and more optimized network. It means if invest more money, can get better efficiency in the network. To illustrate this work better, figures A-E can be changed as energy saving based on investment. Therefore, if the existing network saves energy and transfers more heat and if this is repeated in different ways, as well as having the price of energy and component needed, can come up with the answer to how much investment or cost is needed and how much the network will be optimized.

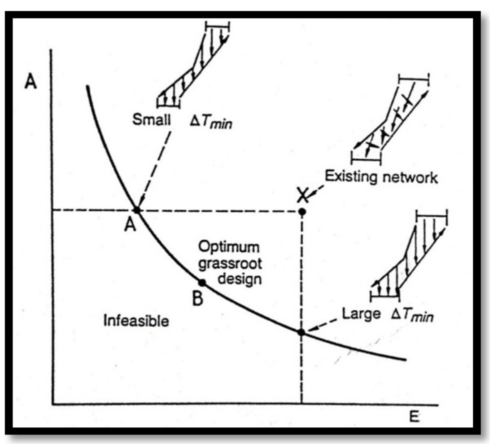

Figure 3: Minimum value of energy usage and the temperature, the area (A) and energy (E), Linnhoff, 2010

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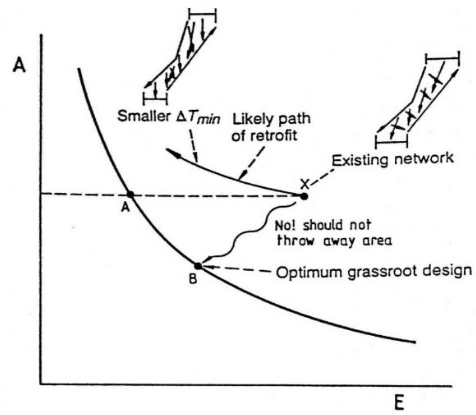

Figure 4: The best way of doing the project, Linnhoff, 1988

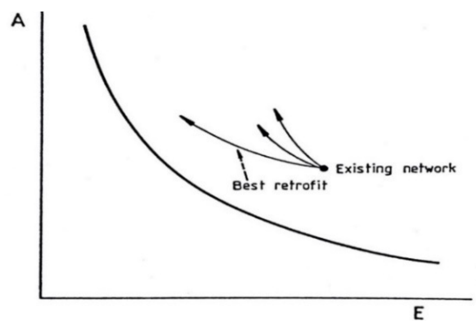

Figure 5: Different ways for doing the project, Linnhoff 1988

The best method to find out the payback time is shown in Figure 6, which shows that if the investment is increased, the network is more optimized. It means if more money is invested, better efficiency in the network can be achieved. To illustrate this, figures A-E can be changed as saving energy based on its investment. Therefore, if the existing network now saves energy, transfers more heat, has the price of energy, has the component needed and repeats this work in different ways, the needed investment or cost can be determined and the network will be optimized to a certain extent.

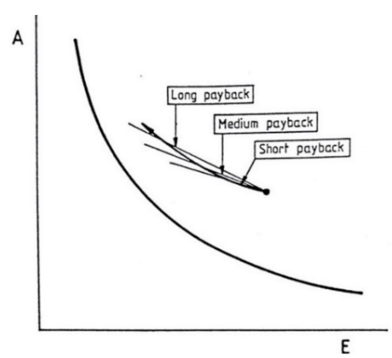

Figure 6: The time for getting the investment back will be faster by investing more, Linnhoff 1988

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This Fig. 7 shows the saving of energy every year based on the new investment and times 1, 2 and so forth. It shows the payback time based on year 1or year 2. For example, for the investment on A1 (investing money) the value of saving B1 (saving energy) is getting back in one year. This is a good way to find the best base on the figure.

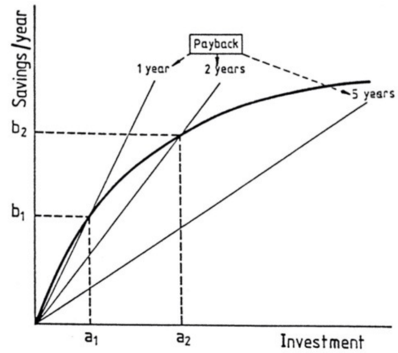

Figure 7: Finding saving (S) based on investment (I) by doing it the best way,Linnhoff 1988

2.0 METHODOLOGY

2.1 Steps for Design

Optimization in the network is mostly related to the design and the way component is used. This can be divided into 4 parts which one shown in a table.

Table 1: Steps to design in retrofit projects

Steps for design
1) Analysis of the heat exchangers in the network
2) Fixing inappropriate exchangers
3) Replacing new exchangers
4) Making changes in the design

Analysis of the heat exchangers in the network designing by checking the existing problem in the network, and checking the efficiency of every exchanger in the network. After that the designer will check if every exchanger is in a good place for both efficiency and safety. Hence, it is the first step that the designer has to come up with along with all the errors from the energy in the network in the form of a chart. This is shown in Fig. 8.

Fixing exchangers: in this part, the designer has to check the sufficiency of the exchangers. The driving force technique and changing the place of the exchangers can be used. The fixing of every exchanger has to be done on the condition of checking the remaining problem in the network and checking how successful it will be, as explained in Fig. 8. For replacing new exchanger: the main work in this part is to find the place to replace that exchanger.

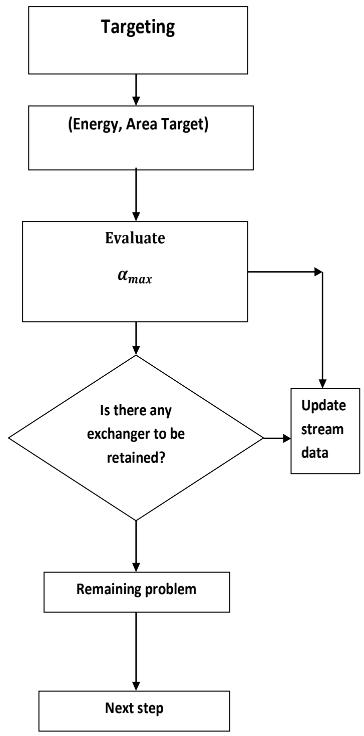

Figure 8: Flow Chart of checking the exchangers

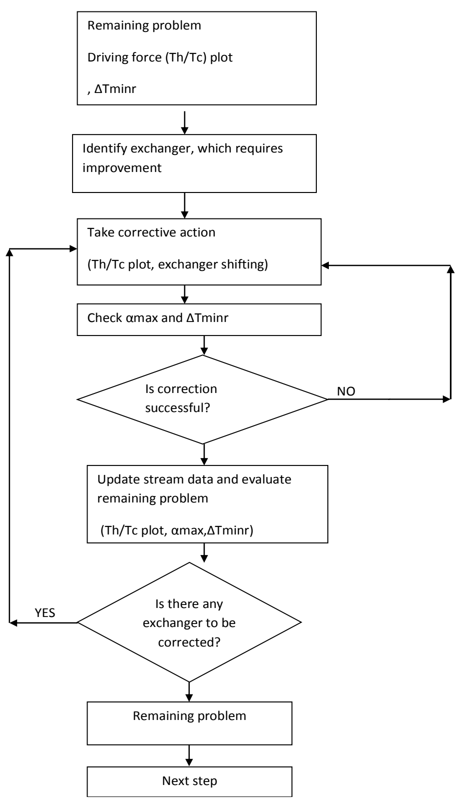

Figure 9: Flow Chart of fixing bad exchangers

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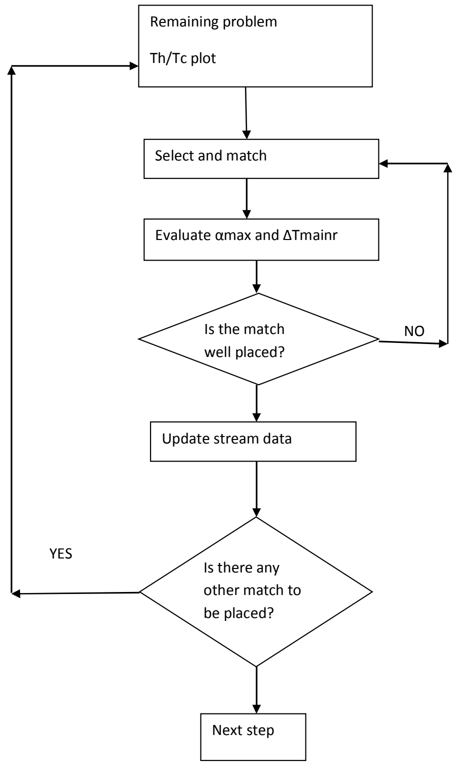

Figure 10: Flow Chart of replacing exchangers

The driving force technique and changing the place of exchangers can be applied here. Three things need to be checked when replacing the exchangers:

1) The new exchangers have to be placed in a way that makes stand on the line of the figure designed; if there is a different result, the exchanger that stands on the figure line has to be chosen.
2) The quality of that exchanger has to be checked with the rule of the remaining problem and (Surface temperature).
3) When the exchanger has been chosen, all the incoming current has to be removed and a driving force with the remaining current has to be designed. Otherwise, the new exchanger will be chosen according to the first rule as explained in Fig. 9.

In every design, there are different ways which can help the designer to come up with the best idea to do the optimization in the network. However, for the designer, it is very important to choose the best of the ideas which can produce the best result in order to save energy.

3.0 RESULT & DISCUSSION

Based on the method discussed, the possible strategy is to find non-sufficient exchangers and then run the optimization process on exchangers, but this can be only a possible strategy. Different network has different method and thus, different strategy has to be applied. In some of the projects, optimization can be done on non-sufficient exchangers or before running the method of finding bad exchangers. This method is carried out by checking the temperature on every exchanger. The new method can help us to do it in a better way. It begins with designing a basic design (grass root) and moving to an existing design. The design move can be made on

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expected lines. Optimization of network should be done on existing element and component. Using the network is the starting point for the researcher to use the existing component. The new method can demonstrate the existing component as being more useful for this study. Therefore, it can do better optimization in this study.In this section, a new method that can check every exchanger working separately has been introduced. This can be a very flexible method, and if there is any method that can be done on that network and give a good result, it should be used on that network. This way, the designer is able to recognize the start point to begin the optimization process in the network.

3.1 Steps for Design

There are 4 steps to be done; analysis of the existence exchangers, fixing the bad exchangers, replacing new exchangers and doing final changes on the refinery. In this part, all these conditions will be applied on the Isfahan refinery and the result will be discussed.

3.2 Analysis of the Existing Exchangers

The first step in designing an exchanger at retrofit is to analyse the existing exchangers that will be using ($\propto_{max}$ andΔT_{min}) and using the window diagram of the network exchangers at the ΔT_{min} to fix the extra heat. For this condition, the window diagram for the exchangers at ΔT_{min}=52^{o}C and considering the temperature of the cold and hot will be shown in Fig. 11. In this figure, the exchangers that will pass from pinch will be shown.

3.3 Final Changes at the Refinery

Final changes at the refinery will be the changes from one process to another and the final result is shown in Table 3.

As can be seen in Table 3, all exchangers are at a good temperature of$\propto_{max}$bigger than α in the entire network (α = 0.53). This is also close to number 1. Also, all exchangers, except 155 and 158, have good ΔT_{min}r but exchangers 106, 107,155, 159, 116, and 119 will pass the heat from pinch point. Therefore, it is obvious that all exchangers except 106, 107, 155, 159, 116, and 119 are at a good position and do not need to be changed or fixed. However, the figure of T_h/T_c will not prove that because all the lines have crossed on the figure and they are known as bad exchangers.

If this condition happens without changing the exchangers, fixing is not possible. It is because the heat temperature will change on the exchangers, some of the exchangers need to be changed. However, as has been said before, need to invest lesser and try to make as little changes to the exchangers as possible. Therefore, all exchangers cannot be changed and need to only work on exchangers that are really suitable.

As mentioned, exchangers 116 and 119 do not stand in a very important part of energy wasting comparing to others, and exchangers 106, 107,155, 159, 116, and 119 are separated from the rest and work on the other exchangers of the network. Although exchangers numbers 105, 154, 156, and, 157 are chosen to be good exchangers; there might be changes in their temperature because they are connected to bad exchangers. These temperature changes will happen while the bad exchangers are being fixed at the refinery. This will give some error at the end of the work. Therefore, this exchanger will also be considered while working on the other exchangers. Exchangers' numbers 127, 104, 103, 114, 116, and 119 have been chosen as good exchangers and will be not touched or changed. The rest of the exchangers will be considered in the research and will be fixed.

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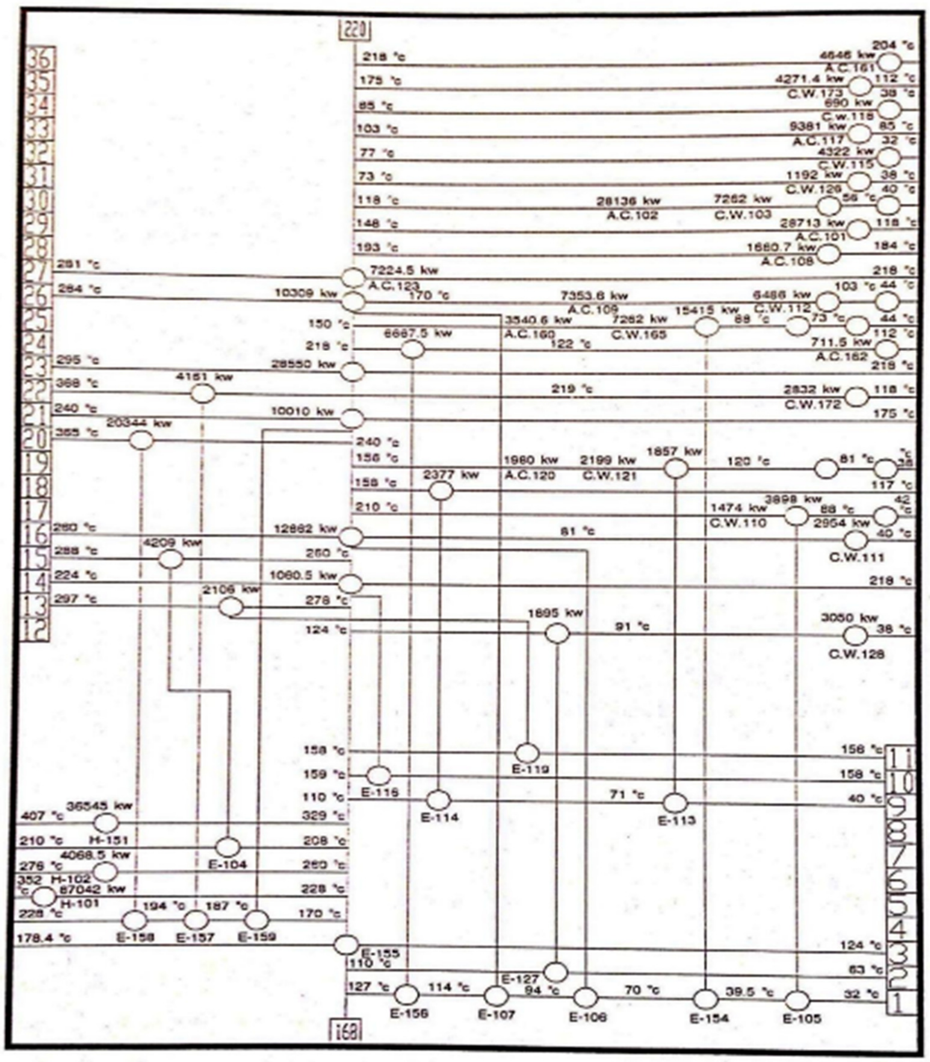

Figure 11: Window diagram for the exchangers at ΔT_{min}=52°C, Isfahan refinery

For the existing exchangers, the rule of final fixing has to be used. The result is shown in Table 4. As can be seen again, the result of the temperature is suitable. ΔT_{min}r for all the exchangers except exchangers numbers 155 and 158 is good and only exchangers numbers 106, 107, 155 and, 159 will pass the heat from the pinch point.

Table 3: A summary of the result for the final changes at the refinery

Ex. No	EX. Name	A (M^2)	$A_{tr}(M^2)$	$\propto_{max}$	ΔT_{min}r(°C)
1	E-104	49	7124	1	52
2	E-105	102	7137	0.99	52
3	E-106	365.2	6482	1	46
4	E-107	380	6336	1	45
5	E-113	30.7	7150	1	52
6	E-114	114	7090	0.99	52
7	E-116	442.6	6721	1	52
8	E-119	224	6737	1	50
9	E-127	243.4	7025	0.96	52
10	E-154	737	6717	0.96	52
11	E-155	1546.8	3025	1	32
12	E-156	954.8	6375	0.98	52
13	E-157	161	6824	1	49
14	E-158	684	4741	1	34
15	E-159	1982	6381	0.86	52

* $A_{tr} = 7157\ M^2$
* ΔT_{min}=52°C

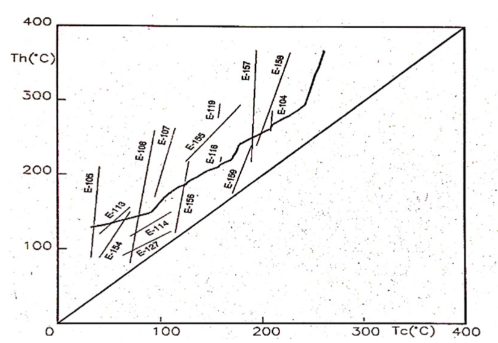

Figure 12: Figure for T_h/T_c for the exchangers in the refinery, Isfahan refinery

Table 4: A summary of the result of the rest of the exchangers

Ex. No	EX. Name	A (M^2)	$A_{tr}(M^2)$	$\propto_{max}$	ΔT_{min}r(°C)
2	E-105	102	6185	0.99	52
3	E-106	365.2	6160	0.95	51
4	E-107	380	6274	0.93	50
10	E-154	737	5747	0.96	52
11	E-155	1546.8	2706	1	26
12	E-156	954.8	5484	0.96	52
13	E-157	161	5766	1	48
14	E-158	684	3704	1	27
15	E-159	1982	5464	0.83	52

* $A_{tr} = 6204\ M^2$
* ΔT_{min}=52°C
*$\propto_{max}$ (127,104,113,114,116,119) = 7157/[6204+(1103.7)] = 0.98
*ΔT_{min}r(127,104,113,114,116,119)= 50°C

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Calculation of the value of $\propto_{max}$ and ΔT_{min}r shows the removed exchangers which will be 127, 104, 113, 114, 116 and, 119. The results also show that moving or changing their place will not make any change in the final result. A study of Table 4 shows that exchangers 155 and 158 are not good and need to be fixed or removed. Also, Figure 13 shows that exchangers 155 and 158 are not good exchangers from the place and work. They need to be removed or have to be replaced.

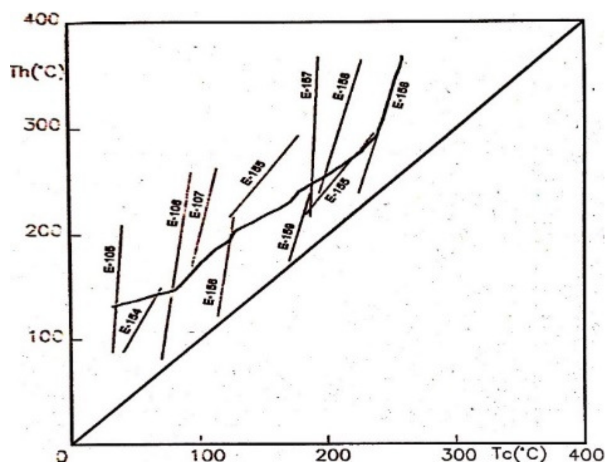

Figure 13: Fig.ure for T_h/T_c for the existing problem of exchangers, Isfahan refinery

3.3 Fixing Insufficient Exchangers

As can be seen, exchangers' numbers 155 and 158 are not good and need to be fixed. The fixing of these exchangers should be done. That does not affect the entire network and also makes the system reach the point of target. It should also be done one way or another which will not make exchangers get separated from each other. Exchanger number 158, as shown in the Figure 19 fixing this exchanger can be moved in a parallel way in the network. This movement will not separate the flow and the only important part in moving it is to keep the temperature the same. For this, by using the driving force curve ΔT at the end of the hot part of the exchanger and with the use of (ΔT=T_i-T_{co}), and using equation below,

$$\propto_{max}(i) = \frac{At}{A(i) + Atr(i)} \qquad (6)$$

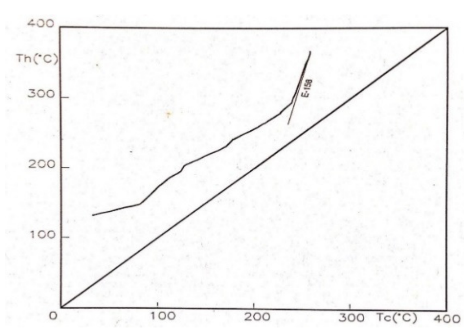

Figure 14: Moving exchanger number 158, Isfahan refinery

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Knowing that the temperature on the exchanger 158 is 16385KW. Knowing the temperature on the exchanger and by using formula in equation 1, the cold temperature can be found therefore, the final result can be seen where the exchanger is standing on the figure T_h/T_c. This work is done and shown in Fig. 14.

The exchanger which is at a good position in the figure might be an insufficient exchanger and it needs to be checked by the formula of the problem. Sometimes doing this can show that the temperature has not been changed ($\propto_{max}$=1) but ΔT_{min}r is from 27^0C have been increased to 52^0C . Therefore, the exchanger has been fixed and it stands in a new position that is optimized. It should be noted that because of the fix in exchanger number 158, the flow has been changed from line 4 to 5. Also should be mentioned is that this is movement of the exchanger, and not a change in the workings of the exchanger because the flow of numbers 4 and 5 are continuous in the network and the only different will be in the value of CP that will separate.

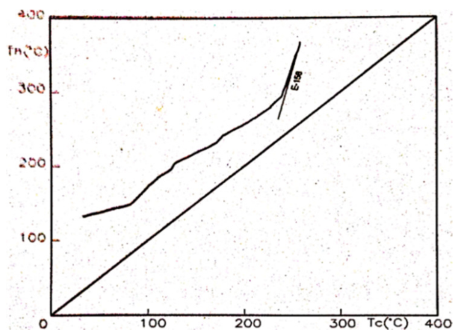

Figure 15: Moving exchanger 158, Isfahan refinery

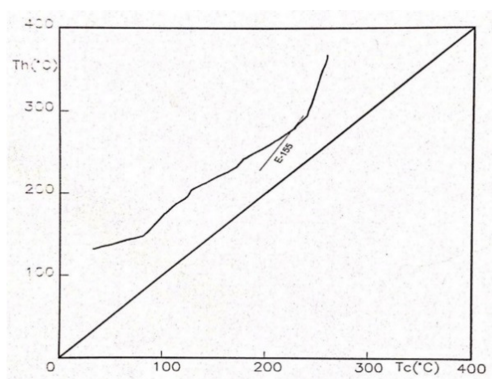

Figure 16: Moving exchanger 155, Isfahan refinery

Exchanger 155: Figure 15 shows that fixing this exchanger cannot move in a parallel way and cannot divide the flow. Formula 6 demonstrates this. The value of temperature on exchanger 155 will be 14,582KW but this much of temperature cannot make a balance on the flow of 4, because exchanger 155 is standing between exchangers 158 and 157. Also, because the value of temperature on these two exchangers are fixed, the temperature which is needed for exchanger 155 should be 24,994KW and this is at a condition when the maximum temperature on the exchanger 155 is 28,550KW before fixing. Increasing the temperature to 24,994KW on exchanger number 155 will increase the temperature. It will also increase the temperature of ΔT_{min}r, but it will reduce the temperature on the main tower and this can be acceptable for this

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study. After finding out the temperature, the cold driving force and where the curve will be in the figure of T_h/T_c can also be known as shown in Fig. 16.

As is shown, the result is well between the figures and solves the rest of the problem. The random temperature has not been changed ($\propto_{max}$=1) but ΔT_{min}r has increased from 26 ^0Cto 34^0C. ΔT_{min}r has not been increased a lot and still has a long distance of up to 52^0C but this was guessed from before. Can conclude that the moving of exchanger 155 was successful and now it stands at a good point in the network. It should be noted that because of this change on exchanger 155, the flow from number 3 has been moved to line flow 4 and this change its only at passion of the flow in the exchanger is.

4.0 CONCLUSSION

The finalization of result as what has been done in the networks. The result can explain the conditions as:

1) $\Delta T_{\min,opt}$of the network has not been changed a lot. ($\Delta T_{\min,opt}$of the network in production of 150,000 barrels per day 52°Cand for the base production of 100,000 barrels per day will be 55°C).
2) Exchangers numbers 119, 116, 104, 114, 113, and 127 have been removed from the network.
3) Exchangers number 158 and 155 have been chosen as bad exchangers and they have been studied and fixed.
4) The position of exchanger 155 has been changed and moved between exchangers' numbers 157 and 158.
5) New exchangers are all added on flow number 3 (between the flash drum and desalter).
6) The temperature for flow number 3 will be provided by flows 36, 28, and 27 (P.As. Ker, A.G.O, and Iso feed)

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