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Simulation & Optimization of Preheat Heat Exchangers (E-01008A/B) in Distillation Unit of Bandar Abbas Refinery

Jamshid Khorshidi[1], Ahmad Rezazadeh[2], Afshin Behroozi[3], Mohsen Pirzadeh[4]

[1] Department of mechanical engineering Hormozgan University Bandar ABBAS-IRAN
[2]Senior Mechanical Engineer - Bandar ABBAS Oil Refining Co
[3]Research and Technology Director – Bandar ABBAS Oil Refining Co
[4]Senior Process Engineer - Bandar ABBAS Oil Refining Co

ABSTRACT

The capacity enhancement plan of Bandar Abbas Refinery is one of the successful plans conducted amongst Iran refineries. Alongside the great achievements obtained after the implementation of this plan, some of the heat exchangers network didn't match such changes. In this work, the performance evaluation of the preheater heat exchangers of refinery distillation unit from thermal and fluid mechanics standpoints with regard to conducted changes after capacity enhancement plan is discussed. In this regard, two sets of heat exchangers which have more severe conditions than others are studied and analyzed. Accordingly, the entire refinery distillation unit is firstly simulated using PetroSim software. To review and redesign the heater heat exchangers, the computational methods offered by Kern and Ludwig are employed. Having performed various tests on the existing heat exchangers and after evaluation of different scenarios through simulation performed in PetroSim software, the current conditions of heat exchangers are analyzed and the optimum conditions of desired heat exchangers are determined. Finally, while comparing the results obtained from the above evaluations with the results obtained from experimental data from unit, a solution for optimization of the functional conditions of these heat exchangers is presented.
KEYWORDS: optimization, heat exchanger, PETROSIM software, efficiency, distillation.

INTRODUCTION

The changes performed in the capacity enhancement plan brought positive and valuable achievements for the refinery, but some of the thermal heat exchangers network didn't properly match such changes and as a result, an operational instability was appeared in some part of the distillation unit. In order to temporarily resolve this problem, a portion of the preheater heat exchangers of distillation unit has been bypassed. Although bypassing these heat exchangers caused the stability of distillation unit conditions, but the thermal load of fluids which should be extracted by this portion of thermal heat exchangers is exerted on the coolers and this caused energy loss. So, the approach of this paper is to specify the reasons of this instability and to propose a suggestion for performance optimization of these heat exchangers. Therefore, after studing the changes performed on the thermal heat exchangers network in the capacity enhancement plan, various scenarios are also considered in order to reach the optimum conditions through performing different simulations. Having known the problem, many solutions have been evaluated to resolve this problem. Finally, because of the special conditions of the refinery; one of the solutions is determining the optimum flow rate in tube side that provides the allowable ΔP and thermal condition.

1- An Introduction to Bandar Abbas Refinery Distillation Units

Bandar Abbas Refinery with the capacity of 320,000 barrels per day has two oil crude distillation units and each unit has the capacity of 160,000 barrels per day. The feed of each distillation unit includes 110,000 heavy crude oil barrels per day and 6,000,000 barrels of gas condensates per day which were increased to 147,000 bbl/day heavy crude oil and 13,000 barrels of gas condensates after implementation of the capacity enhancement plan. The refinery distillation unit is shown in Figure (1) considering the performed changes after conducting the capacity enhancement plan.

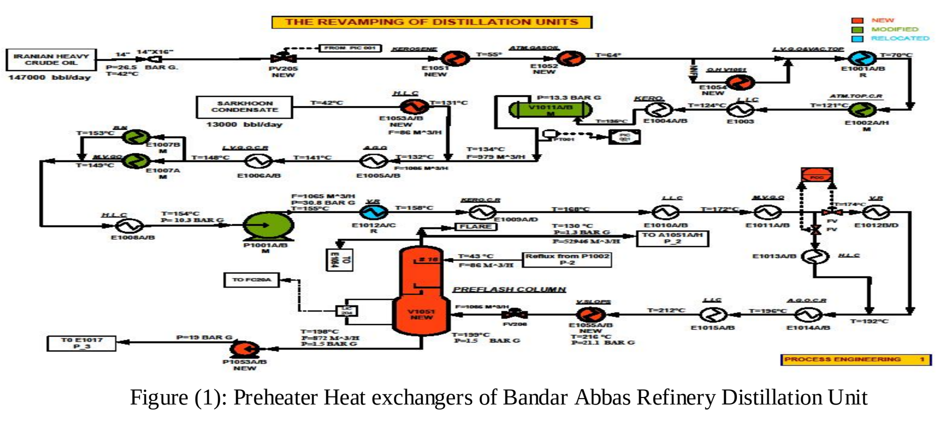

Figure (1): Preheater Heat exchangers of Bandar Abbas Refinery Distillation Unit

Corresponding Author: Jamshid Khorshidi, Department of mechanical engineering Hormozgan University Bandar ABBAS-IRAN.

2- Evaluation of Heat exchangers Conditions before and after Capacity Enhancement Plan

The changes performed following the capacity enhancement plan are as follows: adding up new equipment (*red-colored equipment*), performing changes on a number of existing equipment and displacement of some existing equipment and installing them in a new place (*green-colored equipment*). According to the specification of plan designers, some of the equipments are left without change (such as the studied E-01008A&B heat exchangers) which is shown with white color in Figure (1).

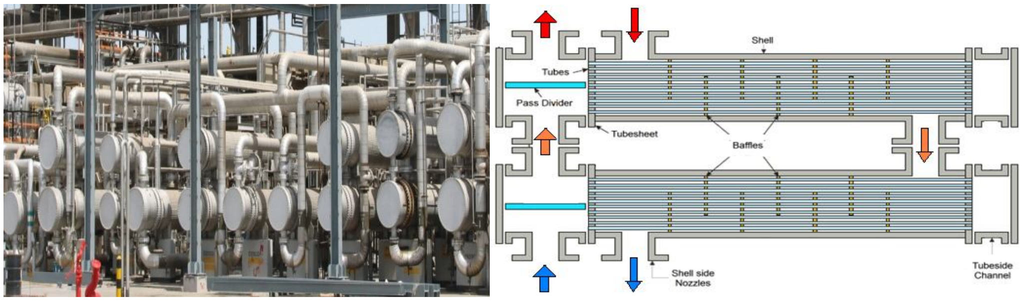

Figure (2a): preheater heat exchangers after desalting vessel (2b): Schematic of operation process of E-01008A/B

Figure (2a) shows the preheater heat exchangers after the desalting vessel of distillation unit. In present work, the E-01008A/B heat exchangers which have more severe conditions than others are studied. The studied heat exchangers are of shell and tube type in which the shell has one pass and the tube has two passes. According to Figure (2b) the crude oil is transferred through the tube and the heavy lube cut (HLC) is transferred through the shell. These heat exchangers are installed in series to each other. After implementation of the capacity enhancement plan The E-01008A/B show the serious problem such as excessive pressure drop, excessive vibration and low thermal efficiency. These problems due to increasing of velocity in tube side and the goal of this work is obtaining the optimum condition that omitted the above problems.

3- Simulate the heat exchangers (E-01008A/B) with regard to exist datasheet (before implementation of the capacity enhancement plan)

To ensure the accuracy of computational methods used in this paper, first the heat exchanger simulation is implemented using the existing data in the datasheet and its results are compared with the results presented by initial designer (accessible in heat exchanger datasheet). Table (1) illustrates the datasheet of E-01008A/B.

Table (1) datasheet of E-01008A/B

Heat Exchange TEMA Type	AES	Tube inlet temperature (ºC)	155.8
Shell ID	40”	Tube outlet temperature (ºC)	160
Tube No	662	Shell inlet temperature (ºC)	211
Tube OD / Length	1” / 4900mm	Shell outlet temperature (ºC)	160
Tube Gage BWG	12	Tube inlet pressure (barg)	13
Tube Pitch	1 1/4"	Shell inlet pressure (barg)	13
Cross Baffles Type	SEGM	Shell inlet flow (kg/hr)	52269
Baffle Spacing	203	Tube inlet flow (kg/hr)	667515
Baffle Segment Cut	% 17		

To simulate the heat exchanger, the methods presented by Ludwig and Kern are used [1, 2]. In this simulation, regarding the high temperature changes in the heat exchanger, the fluid's physical properties were calculated based on caloric temperature. To analyze the fluid in the shell side, a model which was presented by Tinker and developed by Aspen Company are used. In the model presented by Tinker, the flow distribution inside the shell is divided into five flows of A, B, C, D, E and F (according to Figure (4)) [4].

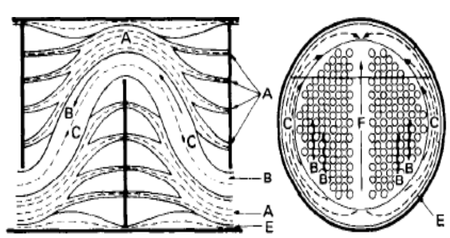

Figure (2) flow distribution inside the shell according to tinker model

Table (2) illustrates the comparison of the simulation results of studied heat exchangers with the design results existing in the heat exchangers datasheets [1, 4, 5, and 7].

Table (2) comparison of the simulation results of studied heat exchangers with the design results existing in the heat exchangers datasheets

		Simulation results	Datasheet results
Velocity (m/s)	tube	2.33	2.33
	shell	0.19	0.16
Pressure loss (bar)	tube	1	0.96
	shell	0.15	0.13
Heat transfer coefficient (clean) w/m^2K		288	284.3
Heat transfer coefficient (dirty) w/m^2K		198	202

As it can be seen in Table (2), the results of the simulation indicate a maximum of 3% deviation in comparison with the results presented by the initial designer of heat exchanger. So, the results of the above Table specify the accuracy of the methods considered for the simulation.

4- Optimization of heat exchanger conditions with regard to implementation of the capacity enhancement plan

One of the solutions is determining the optimum flow rate in tube side that provides the allowable ΔP and increasing heat exchanger performance. For measurement of the flow rate; the portable flow rate measurement device is used. Table (2) shows compare the process information presented in new data sheet (presented by the designer of capacity enhancement plan) with the actual measured information. As shown in Table (2), the pressure drop of the crude oil passing through the tube is 0.1 bars based on the results presented in new data sheet, while based on the results of the performed experimental tests, the amount of pressure drop in these heat exchangers is equal to 2.5 bars. One of the major problems occurred in distillation units (after implementation of capacity enhancement plan) appeared cavitation in unit's main pumps (P-01001). During the performed evaluations, it was found out that the reason for cavitation phenomenon is the reduction of pump inlet pressure [1]. The reason for reduction of pump inlet pressure is unpredicted increase in pressure drop of the E-01008A/B preheater heat exchangers.

Table (2) illustrates Comparison of the procedural data presented by designer and the measured actual data (after capacity enhancement)

	the measured actual data	the data presented in new data sheet
Tube inlet temperature (°C)	145	**151**
Tube outlet temperature (°C)	146	**154**
Shell inlet temperature (°C)	180	**194**
Shell outlet temperature (°C)	160	**159**
Tube inlet pressure (barg)	11.4	**11.4**
Tube outlet pressure (barg)	8.9	**11.3**
Shell inlet pressure (barg)	15.8	**14.4**
Shell outlet pressure (barg)	15.4	**14.2**
Shell inlet flow (kg/hr)	58966	**82810**
Tube inlet flow (kg/hr)	933306	**921904**

In order to make clear the contradiction existing in the pressure drop presented in new data sheet and the actual pressure drop, the heat exchanger simulation with process conditions after capacity enhancement was implemented. Table (3) shows the comparison of simulation results of the E-01008A/B heat exchanger by this paper with the design results presented in new data sheet.

Table (3): comparison of simulation results of the E-01008A/B heat exchanger by this paper with the design results presented in new data sheet

		The Simulation results	The result presented in new data sheet
Velocity (m/s)	tube	3.26	-
	shell	0.3	-
Pressure loss (bar)	tube	2.2	0.1
	shell	0.3	0.2

According to Table (3), two points are worth noting. The first is considerable difference between the pressure drop presented in new data sheet and the pressure drop calculated in this work. Secondly, based on the new results, the fluid velocity inside the tube is 3.3 m/s which cause vibration inside the tubes. This amount is out of the standard limit mentioned in the heat exchanger standards such as TEMA [3]. Having known the problem, many solutions have been evaluated to resolve these problems that finally, because of the special conditions of the refinery, one of these solutions was put into practice as follows: "to separate a portion of the flow and to design a new heat exchanger for additional flow".

In this suggestion, a portion of the crude oil, before entrance to E-1008A/B heat exchangers was separated and the rest of the crude oil is entered the existing heat exchangers. Figure (5) shows the PFD diagram of this suggestion.

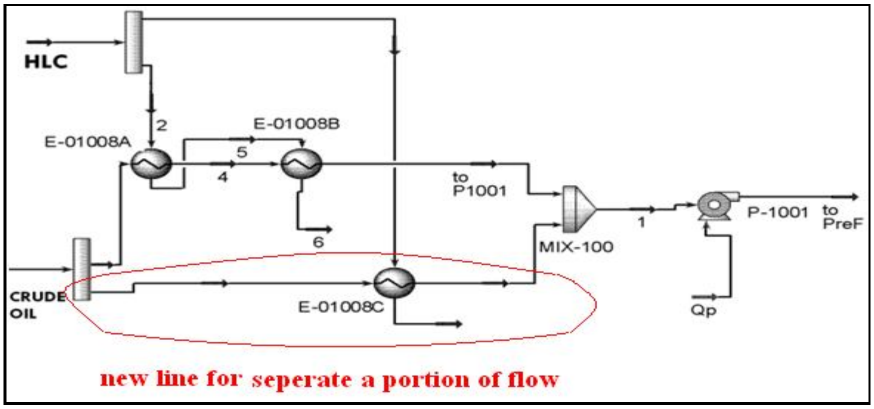

Figure (5) PFD diagram of suggestion

The implementation of this suggestion requires specification of the proper amount of the separated fluid that the optimum conditions can be developed for the heat exchangers. In order to evaluate the optimum conditions, in addition to performing more tests on the heat exchanger, the distillation unit of refinery was simulated using PetroSim software and the proposed suggestion was applied in the simulation. Figure (6) shows the actual simulation of the refinery's distillation unit.

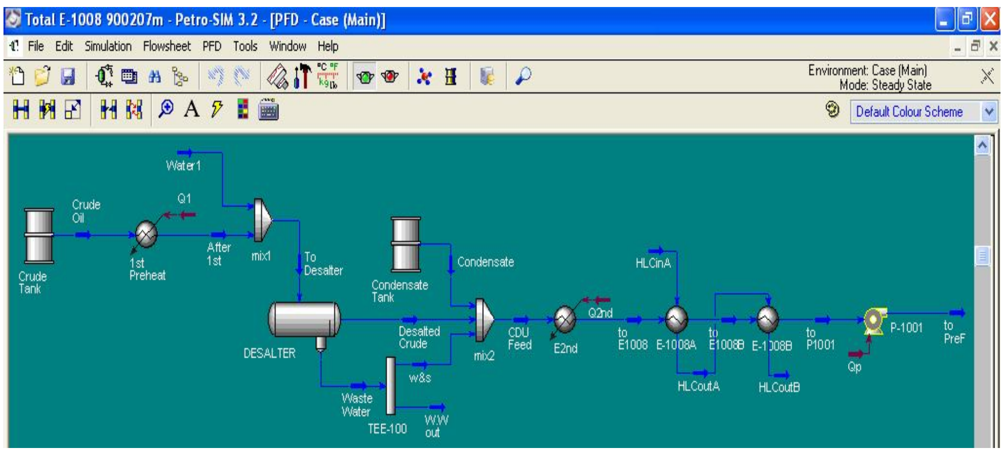

Figure (6) shows the actual simulation of the refinery's distillation unit.

In the above simulation, the reason for the yellow color of pump P-01001 was the emergence of cavitation phenomenon that the PetroSim software could properly predict this phenomenon.

In order to calculating the best operating condition, the simulation performed in variety of flow rate in tube side. New bypass pass was considered for tube fluid in the performed simulation. Then, during 12 stages and within each stage an amount of 5% of the crude oil passing the heat exchanger tubes was reduced. To determine the accuracy of the results of the simulation, the same procedure was experimental tested with designing and creating a bypass pass for the studied heat exchangers and the results were recorded. Diagrams (1) & (2) shows the results of these tests.

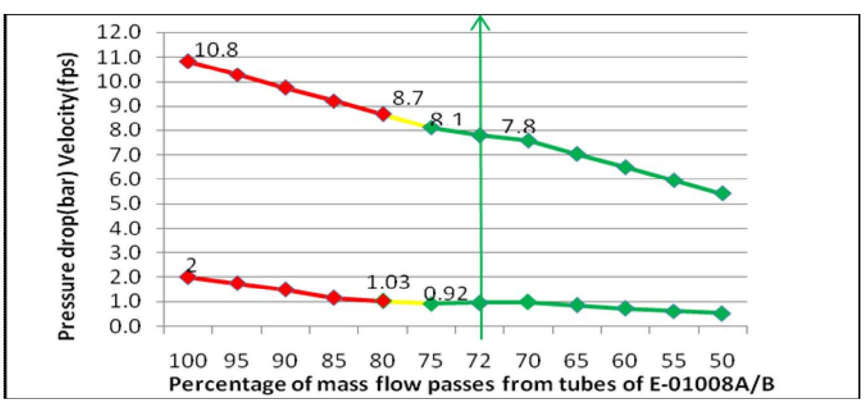

Diagram (1) shows the Percentages of tube mass flow VS. Velocity & Pressure Loss (E-01008A/B)

The above diagram illustrates the variations of fluid velocity inside the tube as well as the pressure drop in twelve stages of the abovementioned test. As shown in this diagram, when the mass flow rate of the tube reaches 1,646,070 lb/hr, starting point for the pump from cavitation conditions, but at the same time the fluid velocity of the tubes is 8.7 ft/sec which is higher than the permissible velocity. Based on the above diagrams, when the mass flow rate of the crude oil passing through the tubes reach 1,481,463 lb/hr, the pump is completely exited from cavitation range and the velocity of the crude oil inside the tube is also in permissible range. Regarding the fouling nature of the crude oil, the higher the fluid velocity inside the tube, the lower the fouling activities and this gives rise to increase of the heat exchanger's thermal efficiency and also the increase of the heat exchanger's life cycle [1, 5]. Diagram (4) shows the output temperature of the shell and tube fluid in terms of various percentages of the crude oil passed through the E-01008A/B heat exchanger.

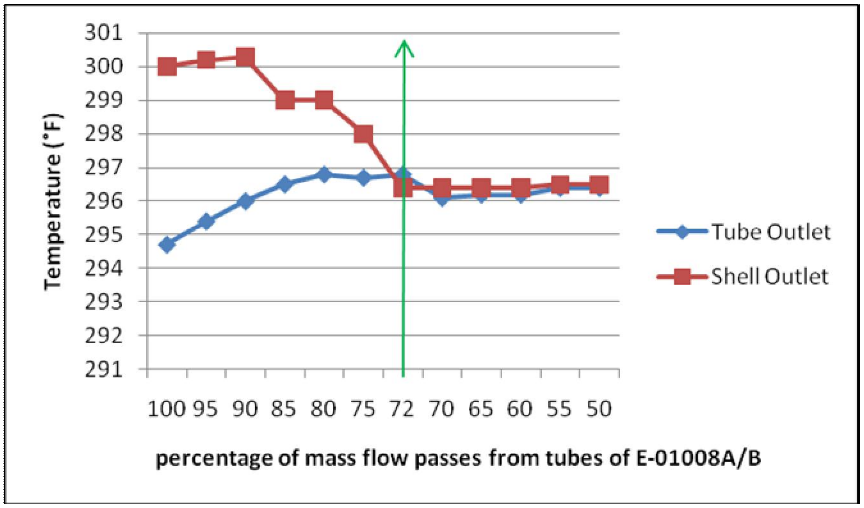

Diagram (2) shows the Percentages of tube mass flow VS. Shell & tube outlet temperature (E-01008A/B)

As shown in Diagram (4), when the amount of the flow rate passing through the heat exchanger tube is 72%, the output temperatures of the tube and shell fluids match each other. That indicates the heat exchanger's optimum thermal efficiency [3]. Considering all of the above conditions as well as the existing limitations in operational conditions of the studied heat exchangers, the optimum flow rate is obtained in passes of 72% crude oil through the tube. Based on the results of the above diagrams, the optimum amounts of the flow rate passing through the shell and tube are according to Table (4):

Table (4) shows the optimum amounts of the flow rate transiting through the shell and tube

	Shell mass flow	**Tube mass flow**
optimum flow rate passing through the tubes of E-01008A/B	34200 kg/hr (75399 lb/hr)	**671980 kg/hr (1481463 lb/hr)**
flow rate passing through the By pass	24766 kg/hr (54599 lb/hr)	**261316 kg/hr (576125 lb/hr)**

Table (5) shows the results of simulations of E-01008A/B heat exchangers with regard to the optimum flow rate.

Table (5) shows the results of simulations of E-01008A/B heat exchangers with regard to the optimum flow rate

Velocity (m/s)	**tube**	**2.4**
	shell	0.13
Pressure loss (bar)	tube	1
	shell	0.1
Heat transfer coefficient (clean) w/m^2K		261
Heat transfer coefficient (dirty) w/m^2K		144

The results of the simulation for optimum conditions of the heat exchangers are shown in Diagrams (3) to (5).

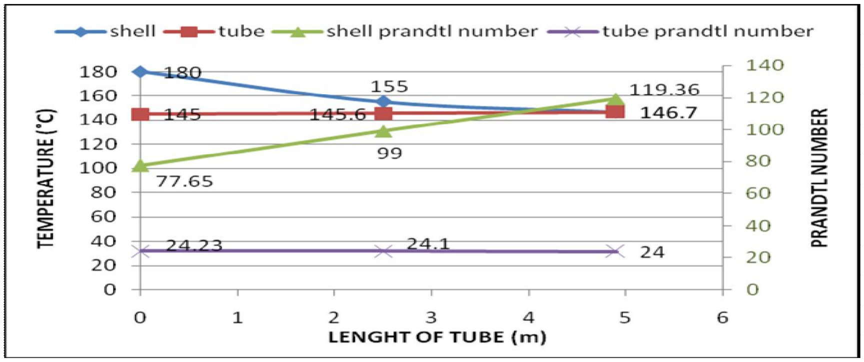

Diagram (3) the distributions of the temperature and the Prandtl number in shell and tube of the heat exchangers

Diagram (3) shows the distributions of the temperature and the Prandtl number in shell and tube of the existing heat exchangers in optimum mass flow rate conditions. As shown in this Diagram, the tube Prandtl number has almost constant value due to the low temperature gradient of the crude oil alongside the heat exchanger. Because of high temperature gradient of the shell, many changes have been made in the Prandtl number of the shell fluid alongside the heat exchanger [2, 6]. Diagram (4) shows the caloric temperature distribution inside the shell and tube.

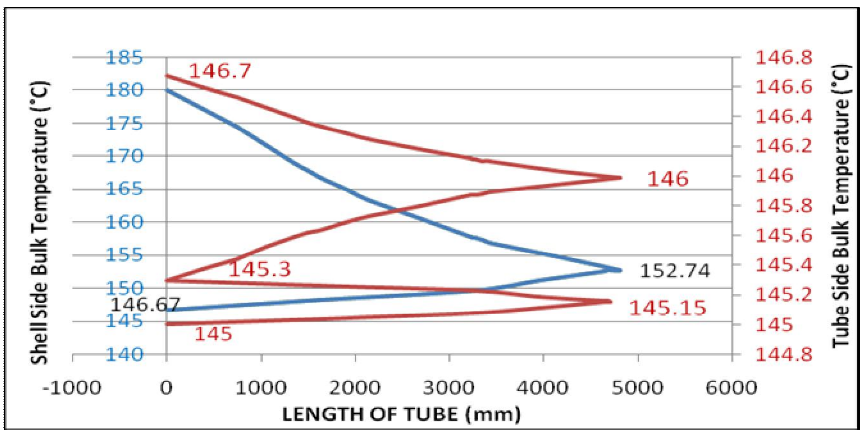

Diagram (4) shows the caloric temperature distribution inside the shell and tube of the existing heat exchangers

As it can be observed in Diagram (4), major portion of the heat exchange is occurred in the first (E-01008A) heat exchanger. The total temperature difference of the shell fluid is 33°C that 27°C is occurred in the first heat exchanger and only 6°C is occurred in the second heat exchanger. This also applies with regard to the thermal load transferred in these heat exchangers which is shown in Diagram (5).

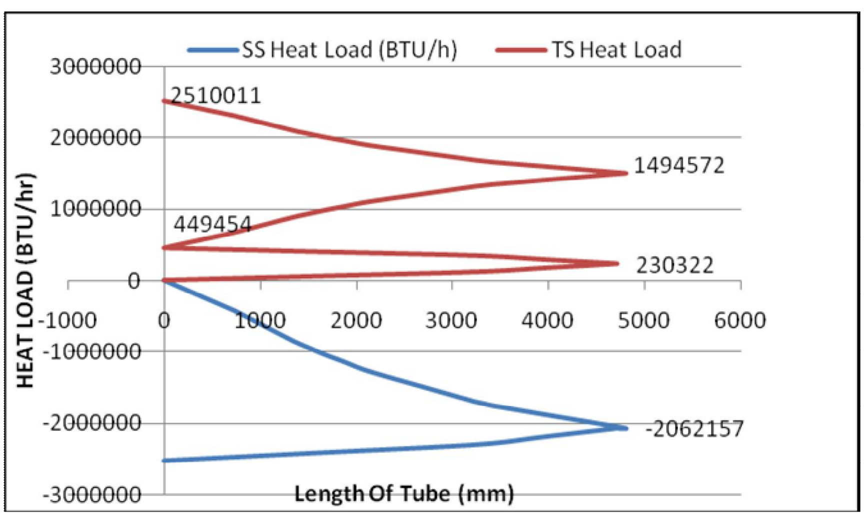

Diagram (5) distributions of the heat load in shell and tube of the existing heat exchangers

The total thermal load transferred in E-01008A/B heat exchangers is near 2,500,000 BTU/hr that 2,000,000 BTU/hr is exchanged in the first (E-01008A) heat exchanger and 500,000 BTU/hr is exchanged in the second heat exchanger. The temperature gradient in the first heat exchanger results in a considerable portion of the heat transfer to be occurred in this heat exchanger. In order to examine the implementation impact of the abovementioned suggestion on the overall performance of distillation unit and also evaluation of the heat exchangers as well as the studied pump, the simulation of distillation unit was repeated using Petrosim software with regard to new conditions. Figure (7) illustrates the results of this simulation.

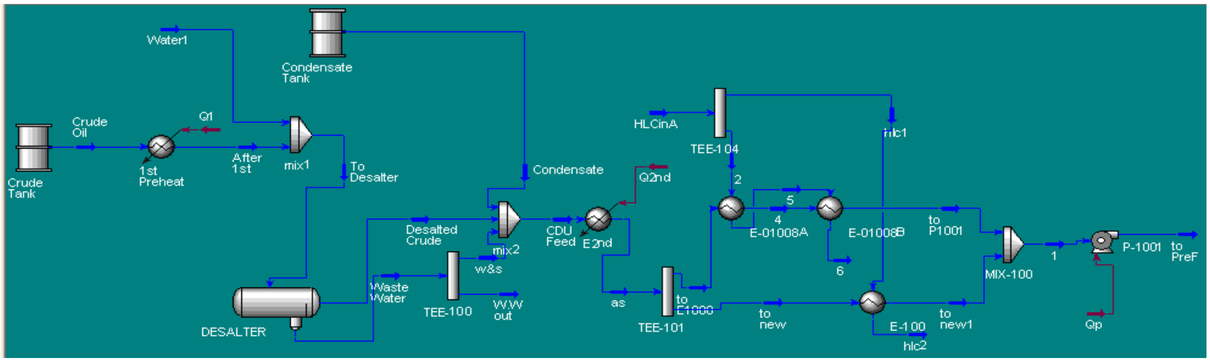

Figure (7) the simulation of distillation unit with regard to above suggestion

As shown in the simulation of Figure (7), the pump's color is changed from yellow color and the performance of the existing heat exchangers is considerably improved in terms of thermal efficiency and pressure drop.

5- Conclusion

Based on the performed simulation and calculations, the main reason of the cavitation phenomenon in the feed pump of distillation unit is reduction of pump inlet pressure which itself is the result of pressure drop increase due to preheater heat exchangers. The increasing of ΔP is due to increasing of crude oil flow rate. If some modification in heat exchanger network was performed, this problem might be omitted. The one of the main reason of this work is fixing the ΔP. The velocity in tubes has exceeded the standard limit and has increased the vibration in the heat exchangers. Considering all the conditions obtained from simulation and the results of the actual tests, different solutions are examined to obtain the optimum operational conditions. However, due to the special process conditions in distillation unit, the best practical solution is to separate a portion of input fluid of studied heat exchangers. So, a bypass pass for shell and tube of studied heat exchangers is designed and implemented. Having implemented this bypass pass and separating the additional fluid, the operational conditions of the existing heat exchangers are optimized and the pump is brought out from the cavitation mode. Using the results obtained from simulation of different scenarios and comparing these results with actual tests performed on the heat exchanger, the optimum flow rate for heat exchanger E-01008A/B should be considered according to Table (4). By applying the optimum flow rate, the operational conditions of the distillation unit is brought out from the instability and these heat exchangers can preheat the crude oil with the best thermal efficiency.

Acknowledgments

Finally, I feel it my duty to appreciate the Managing Director of Bandar Abbas Refinery and all respectful colleagues in Departments of Technical and Engineering, Operational Affairs, Laboratory as well as Research and Technology who despite several problems provided me with necessary grounds in all research fields in terms of preparation the unit conditions for performing different procedural tests, different fluid thermo physical tests and informative consultations in order to bring about the results of this work to implementation phase.

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