CHEMICAL ENGINEERING TRANSACTIONS Volume 21, 2010
Editor J. J. Klemeš, H. L. Lam, P. S. Varbanov
Copyright © 2010, AIDIC Servizi S.r.l., ISBN 978-88-95608-05-1 ISSN 1974-9791
DOI: 10.3303/CET1021243

Process Simulation for Improve energy efficiency, maximize asset utilization and increase in feed flexibility in a crude oil refinery

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In our days the most important factors for the competitiveness of a crude oil refinery are the efficient energy and capacity utilization, feed flexibility and contribution to the sustainable development (reduction in emission of green house gases). Paper presents results of a feasibility study for increase in crude processing capacity, improve of energy efficiency and feed flexibility of a crude oil atmospheric distillation unit. Results show that boosting up the distillation capacity was solved while improving the flexibility of unit for processing different type crude oils. Analysis of heat exchanger network contributed to debottleneck the atmospheric furnace capacity constrains and for the significant reduction in fuel consumption and in CO_2 emission (11.3 % for heavy type crude and 10.5 % for medium type crude).

1. Introduction

Nowadays the petroleum refining industries have to face several challenges. The more and stricter legislations on the climate change force the refineries to take action reducing in their carbon dioxide emission. Actions those can be made by the refining industry to contribute the reduction in CO_2 emission are the following. Improve of energy efficiency of existing processes (Sikos and Klemeš, 2010); use of alternative energy sources as well as fuel blending components being produced on renewable basis; application of some kind of CO_2 capture technologies to extract CO_2 from the refinery flue gases (Parkinson, 2008). The most attractive and economical way to reduce the green house gas emissions is the decrease in the energy consumption. Additionally, the negative effects of the world economy force the companies to maximize the utilization and efficiency of their existing assets and optimize the feed supply and product slate. Furthermore, the hectically change in price of crude oil and products make inevitable to make capable the refinery process units for processing different type of crude oils.

The objectives of the presented work were to investigate the increase in the crude oil processing capacity by 20 %, improve in the energy efficiency and investigate the application of different types of crude oil (heavy and medium type) for one of the atmospheric distillation units (ADU in the following) of the company.

Please cite this article as: Varga Z., Rabi I. and Kubovics Stocz K., (2010), Process simulation for improve energy efficiency, maximize asset utilization and increase in feed flexibility in a crude oil refinery, Chemical Engineering Transactions, 21, 1453-1458
DOI: 10.3303/CET1021243

2. Methodology

Steps being carried out during the study are summarized in the following. Test run was prepared to collect all of data are required for modelling. For example yield and quality of products, process parameters (e.g. temperature, pressure, flow rates etc.) and constrains of parameters (e.g. min/max desalter and column inlet temperatures, maximum pump capacities etc.). Data sheets and drawings of equipments of the unit were collected, too. On the basis of these data detailed model of the ADU was built up with PRO II process engineering tool.

After validating the model on the basis of heat and material balances it was modified to introduce crude oil in higher capacity of 20 % or rather to feed different type crude oil. Processing of a heavy and a medium type of crude were investigated. Their product yields are summarized in Table 1. Then all of existing equipments were checked to applicable for processing crude in higher capacity and/or different types. Capacity of tower internals was checked with company specific software according to their vendor. Furnace of the ADU was also checked for the new cases with FRNC-5 software.

Model of the distillation unit was applied to heat exchanger network (HEN) analysis, too. The object of the retrofit case for an existing HEN is to check and to narrow the gap between the ideal and current energy consumption. Retrofit of HEN is more common in the everyday practice than the grassroot design of HEN (Linnhoff, 1994). The following generalised steps were covered during the study. First step of this analysis is to establish how much energy can be recovered by applying the installed surface area. Then, the existing design is analysed in terms of which exchangers transfer heat across the pinch. The remaining exchangers are analysed as to the use they make of driving forces. Those units that are transferring heat across the pinch and/or make inappropriate use of driving forces are selected to be repositioned. In most cases the result of the study suggests to add new heat exchangers to compensate the suboptimality of the existing structure, HEXTRAN software was applied for design new heat exchanger in this study.

Tedious calculation work of HEN analysis was saved with using SUPERTARGET software. On the basis of results the original model was changed and the applicability of the suggested HEN structure was checked with rigorous modelling.

Table 1 Yield of products of the investigated crude oils

Product	*Yield, %*	
	Crude “A”	Crude “B”
Gas and LPG	0.33	0.94
Naphtha	13.23	16.52
Kerosene	14.89	13.88
Atmospheric light gasoil	15.72	20.88
Atmospheric heavy gasoil	8.89	9
Atmospheric residue	46.94	38.78

Then the economic analysis was followed. Retrofit of a HEN is a trade-off problem between the energy saving and the capital investment. If a new HEN suggested by the design improvement step satisfies given economic criteria, then the detail engineering step was followed. After implementing the new HEN structure test run is carried out to evaluate the “real” saving in the energy consumption.

3. Results and Discussion

3.1 Study for processing heavy crude

Firstly, the model of the ADU based on the test run data processing Crude “A” at base capacity was prepared. Results of feed preheating line showed the actual heat being exchanged between the feed and products (46.62 MW) well below than that is possible considering the total heat exchanger area and accepted fouling of the units (51.67 MW), see Test run and Case 1 in Table 2. This difference was caused by the bypassing of some HX units due to their high pressure drop. The excess heat should be transferred to the crude oil in the atmospheric furnace resulting higher fuel consumption and emission of CO_2 and other flue gases. The firing rate of the atmospheric furnace can be decreased by 4.1 MW and emission of CO_2 by 7.8%. The most critical HX units (2 pieces) were determined and spare ones connected paralelly to them was suggested. Economic calculation showed that the return on the investment is lower than 1.5 y. Additionally, preparation of a heat exchanger cleaning study and continuous monitoring of HEN was suggested, too. Calculation of column by 20 % higher capacity of Crude “A” was prepared, too. Data obtained with PRO II showed that the Flooding Factor was below 80% and down comer backup was lower than 50 % of tray spacing for every tray. In contrary to this the results of KGTower indicated that down comer flood in the Top Pumparound section exceeds the design limit.

Then the crude oil preheating heat exchanger line and the atmospheric furnace were studied (Case 3 in Table 2). During the calculation fouling factors recommended by TEMA were applied and bypass of heat exchangers was not considered.

Calculated temperature of crude oil leaving the preheat line was 258 °C for Crude “A” and the total duty of the HEN was 59.29 MW. Additionally, the result of the investigation of atmospheric furnace showed the firing rate to obtain the required coil outlet temperature (395 °C) is 55.2 MW. However, this value is considerably higher than the normal firing rate of 53.34 MW. If the normal firing rate and coil out temperature was fixed in the furnace model calculation showed 262 °C of coil inlet temperature should be reached for Crude “A”. This clearly showed that the atmospheric furnace is inadequate to heat up the feed of higher rate to the necessary temperature.

Table 2 Summary of results of investigated cases for heavy type crude oil

Property	*Test run*	*Case 1*	*Case 2*	*Case 3*	*Case 4*
Feed	Crude “A”	Crude “A”	Crude “A”	Crude “A”	Crude “A”
Capacity	Base	Base	Base	Base + 20%	Base + 20%
Duty of HEN, MW	46.62	51.67	56.21	59.29	64.53
HEN outlet temp., °C	236	253	272	258	275
Firing rate of furnace, MW	53.1	49.0	43.4	55.2	49.9
t CO_2/t Crude	0.039	0.036	0.032	0.036	0.032

Table 3 Summary of the energy saving potential of the atmospheric distillation unit

Utility	*Target, MW*	*Now, MW*	*To Save, MW*
Total			8
Total Hot	28.9	36.9	
Total Cold	6.0	14.0	

To avoid the costly furnace modification we investigated the heat exchanger network with the pinch technique. Results of study of targeting the HEN showed that process-process heat exchange can potentially be increased with 8 MW (see Figure 1 and Table 3). The existing HEN was modified in such a way that four new heat exchangers were implemented with total surface area of 1406 m^2. During the modification the following constrains should be considered: maximum inlet temperature of crude oil into the desalter, storage temperature of products and set temperature of circulation refluxes.

Modifications of HEN were adapted into the simulation model and checked their viability (Case 4 in Table 2). Results showed that the total duty being exchanged between products and crude was increased with 5.24 MW to 64.53 MW for Crude “A”. These data displays that more than 50% of the maximum possible energy recovery was achieved. After the modification the coil inlet temperature of atmospheric furnace was 275 °C well above the required value of 262 °C. Based on the data summarized previously it can be seen that the bottleneck of furnace can be resolved by improving the efficiency of the HEN. Additionally, the load of the furnace should be increased without the modification of the HEN, which results increase in the fuel consumption and in the emission of flue gases (CO_2, NO_x). Improvement of the energy efficiency of the HEN contributes to decrease in the CO_2 emission by 528 t/y.

Furthermore, implementation of the HEN modifications for base capacity improves the energy efficiency of the ADU considerably (see Case 2 in Table 2). As compared to the specific CO_2 emission (t CO_2/t Crude) of Case 2 with Test run case and Case 1 it can be stated that the CO_2 emission can be reduced with 18.2 % and 11.3 %, respectively.

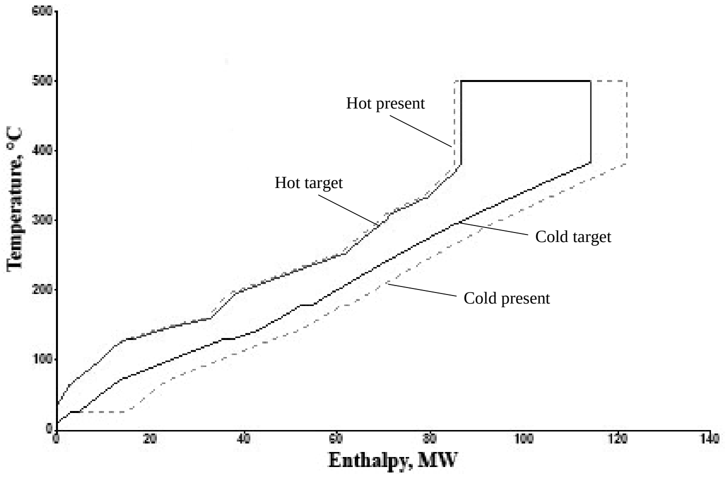

Figure 1 Composite curve of HEN of atmospheric distillation unit

3.2 Study for processing medium type crude

Nowadays one of the important key factors from the aspect of competitiveness of a crude oil refinery is the feed flexibility. From this reason the possible application of medium type crude oil (Crude “B”) at base and increased capacity was carried out, too. First step of this part of the study was to investigate the distillation column for processing of Crude “B”. Table 1 shows the yield of atmospheric products is higher for Crude “B” than those for Crude “A”. This means higher internal mass flow rate in the atmospheric column, too. However, Crude “B” can be processed without violate any design parameters in the distillation tower at base capacity. On contrary the results of the calculation prepared with PROII software for processing of Crude “B” at higher capacity showed that the Flooding Factor exceeds the 80 % design limit in the upper, narrowed section of the column. Tray hydraulic was investigated with KGTower software, too. The program gave warnings for the top tray where the Jet flood and for the Top Pumparound trays where the Down comer flood exceeded the design limits. This strengthens the previous results indicating that trays in the Top section should be changed. One of the possible solutions to overcome this bottleneck is to replace the presently applied conventional trays to high capacity and high performance trays. We recalculate the critical column section applying Superfrac® trays and all of the obtained parameters were below the design limits.

The crude oil preheating heat exchanger line and the atmospheric furnace for processing Crude “B” at base and increased capacity were studied, too, results for the HEN were summarized in Table 4.

Comparing the results summarized in the Table 2 and Table 4 indicated that at same HEN configuration and feed rate (e.g. Case 1 and Case 5, and so on) the heat being exchanged between the crude and products (duty of HEN) was similar for both crude oils.

Table 4 Summary of results of investigated cases for medium type crude oil

Property	*Case 5*	*Case 6*	*Case 7*	*Case 8*
Feed	Crude “B”	Crude “B”	Crude “B”	Crude “B”
Capacity	Base	Base	Base + 20%	Base + 20%
Duty of HEN, MW	51.75	56.65	59.37	64.38
HEN outlet temp., °C	256	271	258	273
Firing rate of furnace, MW	51.3	45.9	57.4	52.5
t CO_2/t Crude	0.038	0.034	0.037	0.034

However, the required firing rate in the atmospheric furnace was higher for Crude “B” for every case investigated. Reason of this is that the rate of evaporation in the heater is higher for the lighter crude requiring higher heat load.

Table 4 shows that Crude “B” can be processed at base capacity without any modification of the HEN because the required firing rate is lower than the maximum allowable of 53.34 MW.

At increased capacity (Case 7) the calculated temperature of crude oil leaving the preheat line was 257 °C and the total heat being transferred to the crude oil was 59.37 MW, respectively. However, the results of the investigation of atmospheric furnace showed that 265 °C of coil inlet temperature was needed to obtain the required coil outlet temperature (395 C) at normal firing rate of 53.34 MW. This clearly showed us that the atmospheric furnace is inadequate to heat up the feed in higher rate to the necessary temperature.

The aforementioned modifications of HEN (based on pinch analysis) were adapted into the simulation model and checked their viability for processing Crude “B”, too. Results showed (Case 8) that the total duty being exchanged between products and crude was increased with 5.01 MW to 64.38 MW. These data displays that more than 50% of the maximum possible energy recovery was achieved. After the modification the coil inlet temperature of atmospheric furnace was 273 °C well above the required value. Based on the data summarized previously it can be seen that the bottleneck of furnace can be resolved by improving the efficiency of the HEN for processing Crude “B”, too.

Additionally, implementation of the HEN modifications for base capacity improves the energy efficiency of the ADU considerably (see Case 6 in Table 4). As compared to the specific CO_2 emission (t CO_2/t Crude) of Case 6 with Case 5 it can be seen that the CO_2 emission can be decreased with 10.5%.

4. Conclusions

Results of feasibility study for increase in crude oil capacity by 20% and/or improve in feed flexibility of atmospheric distillation unit meantime improve in the energy efficiency were presented. The main bottleneck for increase feed rate for both heavy and medium type crude oils was the atmospheric furnace.

Investigation of the HEN showed that process-process heat exchange can potentially be increased with 8 MW and more than 50% of this value was realized by repositioning some HXs and implementing 1406 m^2 additional surface area. Increase in the total duty of HEN made it possible to avoid the costly heater modification for every investigated case.

Improvement of HEN contributes to increase in the energy efficiency and reduction in emission of green house gases, too. Because of, the emission of CO_2 can be decreased by 11.3 % for heavy type and 10.5 % for medium type crude at base capacity. Additionally, the load of the furnace would be increased without the modification of the HEN resulting increase in the fuel consumption and in the emission of flue gases (CO_2, NO_x).

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