EXPERIMENTAL EVALUATION OF THE FOULING BEHAVIOR OF CRUDE OIL IN A REFINERY HEAT EXCHANGER NETWORK

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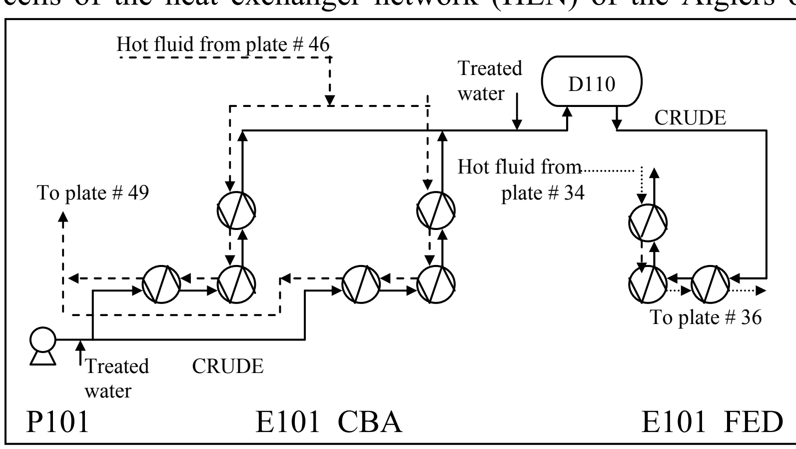
Fouling of heat exchange equipment is the deposition of all sorts of undesired material on its heated surfaces. The deposits may be of diverse nature and composition: rust, sand, coke, calcium carbonate, crystals, polymers, etc.... . The deposition of such particles or substances when it occurs has unfortunately a series of negative effects on heat transfer and in more severe cases on the mechanical design of the equipment itself. From the stand point of heat transfer, fouling has for effect the addition of a heat transfer resistance to the existing process in which heat has to be transferred from one fluid to another in a typical heat exchanger. In general, the thermal conductivity of deposits being quite low the thermal resistancegets even higher and heat loads must overcome such limitations. Therefore, pumping costs for the process industries are to be increased considerably to maintain the equipment operating correctly. In Algeria, an approximate evaluation of the financial losses in all its oil refineries is estimated to vary between 1.4 and 3.8 million dollars annually (Masri, M.A., 1998).

The present work has for objective the experimental measurement of the fouling resistance in the various cells of the heat exchanger network (HEN) of the Algiers oil



refinery. The HEN shown in the figure consists of nine shell and tube heat exchangers all forming the preheating section of the crude before its introduction in the distillation tower. The crude settling in the storage tanks is sent by a centrifugal pump toward two cells placed in parallel and consisting each of three heat exchangers placed in series: Cell E101 CBA and Cell E101 FED. The crude circulating in the tube side is heated from ambient temperature to about 105-110°C by a mixture of gazes and light liquids coming from plate #46 of the top distillation tower. At the exit from the two heat exchanger cells, the crude goes through a electrostatic desalination process (D110) in which it is mixed to 12%volume of treated water. The crude passes then in the tube side of three shell and tube heat exchangers placed in series. These exchangers constitute the cell E102 CBA in which the temperature of the crude is increased from 105° to about 160°C. The hot shell side fluid passing through this cell is a mixture of jet fuel and heavy solvents coming from plate #34 of the distillation tower.

The caracteristics of the shell and tube heat exchangers used are summarized below:
- Material :carbon steel Shell ID: 1.07 m #Shell passes: 1
- Tubes OD: 1.9 cm Tubes thickness : BWG14 Tube length: 6.1m
- Total # tubes: 1100 #Tube passes: 4 for E101 and 2 for E102
- Total outside surface of the tubes: about 401 m^2.
- Total outside surface of each cell: about 1204 m^2.

The study was aimed at following the course of fouling as it occurs in real time operating conditions of the refinery. In order to be able to do so, it was decided to consider each cell of three exhangers as one exchanger of the type 3-12 for E101 and 3-6 for E102. Temperatures of the hot and cold fluids at the inlet and outlet of each cell were recorded. Calculation of the overall fouling resistance in each cell was done according to the relation: $R_d = 1/U' - 1/U$, where U' and U are respectively the overall coefficient of heat transfer for the fouled and clean conditions. The coefficient U' for the fouled conditions is determined in time by a heat balance on the cold fluid (crude) as:

$$U' = m.C_p(T_{c,out} - T_{c,in}) / A.F.\Delta T_m$$

The coefficient U for the clean conditions is calculated each time for the present operating conditions which may change during operation as:

$$1/U = 1/h_i + (D_e/D_i).(1/h_o)$$

The results obtained consist of plotting the fouling resistance-time curves for the three cells and for the time periods of refinery operation summarized below:
Run #1: E102 CBA: From April 2000 to January 2001
Run #2: E101 CBA: From April 2000 to June 2000 (4-day cleaning operation occured on june13)
Run #3: E101 CBA: From June 2000 to January 2001
Run #4: E101 CBA: From March 2001 to August 2001
Run #5: E101 FED: From March 2001 to August 2001

Note: For Runs #1 and #2, the data start was possible only after 409 days of heat exchanger operation.
The results obtained in this study showed that fouling occured in all runs although the crude under study is considered among the lightest on the world market. For Run#1 and after 300 days, the fouling resistance observed constant variations around the value of

1.4±0.094 m^2°C/kW . For Runs#2 and 3 (Cell E101CBA) fouling was even more evident. In Run#2, the fouling resistance started and kept increasing linearly after 75 days operation reaching a relatively high value of 2.820±0.101 m^2°C/kW . This made it necessary for the operators to take the decision about shutting down the cell to proceed with a cleaning of its exchangers. When Run#3 was started after such clean up, the fouling resistance again showed a linear increase from time zero to reach a high value of 3.400 m^2°C/kW after six months. A second shut down was therefore decided by the operators. It has to be noticed that fouling started more rapidly during that run than during the others. It is suspected that the reason for that is probably an inefficient clean up of the tubes after the first shut down. In fact, the overall heat transfer coefficient calculated at the start of Run#2 gave a value of 0.269kW/ m^2°C whereas the design value is 0.329 kW/m^2°C which supports our analysis.

The last runs performed on site were conducted simultaneously on the cells E101CBA and E101 FED and lasted for about six months. In both cases, the fouling resistance-time curve follow an exponential form with an asymptotic value of about 2.057±0.121m^2°C/kW for the first one and 0.924±0.129 m^2°C/kW for the second one. Moreover, it should be pointed out that no induction time was observed in both runs and the shut down is in that case decided because of extra problems related to the distillation tower. Therefore, the runs were terminated after 362 days for E101CBA and 179 days for E101FED.

Finally, an analysis of the deposits obtained from the E101CBA and E101FED inside tubes at the end runs was completed. The results are summarized below:

Constituent	Content wt% E101CBA	Content wt% E101FED	Constituent	Content wt% E101CBA	Content wt% E101FED
Insolubles	52.44	50.40	Fe^{2+}	10.04	7.43
SO_4^{2-}	18.46	17.40	Hydrocarbons	4.07	4.00
Cl^-	14.20	10.65	Silica	0.07	0.30
CO_3^{2-}	0.72	9.82	S^{2-}	0.00	0.00
			Total	**100.00**	**100.00**

Observation of the deposit composition shows that it is clearly and mostly formed of insoluble materials which presence is probably due to a poor settling of the crude in the refinery storage tanks . At this point, it should be known that the concerned refiney is directly supplied in crude via a pipeline coming from the Hassi Messaoud oil wells. Sulfates,chlorates and carbonates seem also to be highly present. These salts were either present in the crude or in the cleaning water used. This second alternative may explain the high calcium carbonate content in the E102CBA deposit because of the higher water injection in that cell. Moreover, the relatively high presence of Cl^- ions is an indication that the tubes may be damaged if these ions are able to combine with water molecules to produce acids (corrosion effects).