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A new crude processing method for increasing distillate yield and energy efficiency of the crude distillation unit

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A new flash drum (FD) integrated crude distillation column (CDU) design has been conceptualized. Benefits of this new design have been illustrated using the techno-economics of a case study on existing FD integrated CDU designs. It is observed that new design increases the significant atmospheric distillation column (ADC) distillate yield in comparison to existing FD integrated and conventional CDU design. New Method also reduces the noticeable overall energy consumption compared to conventional design. There is a total profit of more than Rs. 14 crore due to increase in distillate yield and energy saving compared to existing CDU design for a small refinery of 3 MMTPA crude unit capacity. This profit will increase with the size of CDU. The implementation of the new method shall also facilitate the lower carbon footprint of CDU in proportion to energy savings.

Keywords: Crude distillation unit, Distillate yield, Energy reduction, Energy saving

Crude Distillation Unit (CDU) separates crude oil in different distillate products. The distilled products from the CDU are then processed as per the requirements in other processing units. The CDU has the maximum capacity in the refinery and consumes huge energy. Gadala *et al*., 2013 reported that the CDU accounts for the energy consumption equivalent of 2% of the total crude oil processed. Thus, a small improvement in the energy efficiency of CDU shall result in significant savings[1]. The furnace and the steam are the major energy utilities to be used in CDU. Efforts are being concentrated to reduce the energy consumption in the furnace and stripping steam. Integration of flash drum (FD) in crude distillation unit is commonly done to reduce the energy consumption in furnace duty[2]. There are two different designs of the crude unit with FD. In one design FD vapour without any preheating is routed to the atmospheric distillation column at a location between the kerosene draw stage and flash zone. In other design vapour without any preheating is routed to the atmospheric distillation column at flash zone location. However, this also results in lower distillate yields, more reduced crude oil (RCO), increases in the vacuum load and column diameter[3].

CSIR-IIP has developed a new method for processing the crude in CDU for a significant increase in atmospheric distillate yield and reducing the energy consumption. This new method has been patented in the USA (US9546324B2) and India. In the proposed method, vapour from the flash drum is preheated and fed to ADC bottom.

Present work illustrated a techno-economic study of already existing FD containing CDU designs and patented CDU design.

Experimental Section

Existing CDU configurations

There are three types of CDU configurations in refineries. One configuration is based on atmospheric and vacuum distillation columns which shall be referred as the base case (BC). The schematic of the BC is shown in Fig. 1.

The second configuration is based on the pre-fractionation column, atmospheric and vacuum distillation columns in which distillate obtained from pre-fractionation column top is routed to naphtha stabiliser. This configuration shall be referred as fractionation case (FC). The schematic of the FC configuration is shown in Fig. 2.

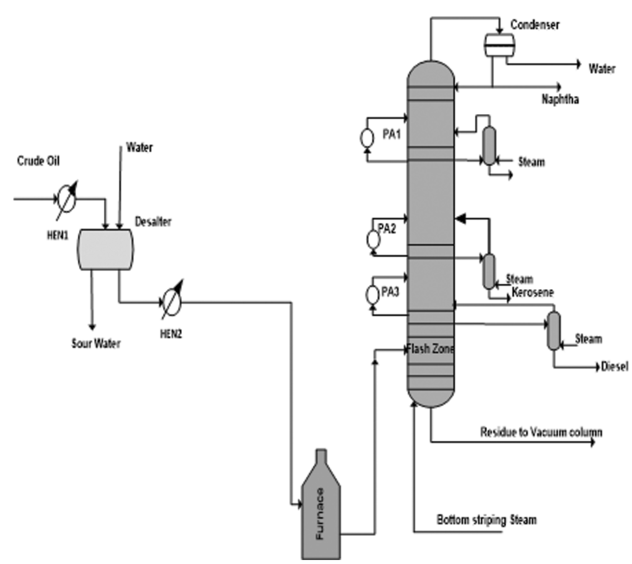

Fig. 1 — Schematic of BC configuration of CDU

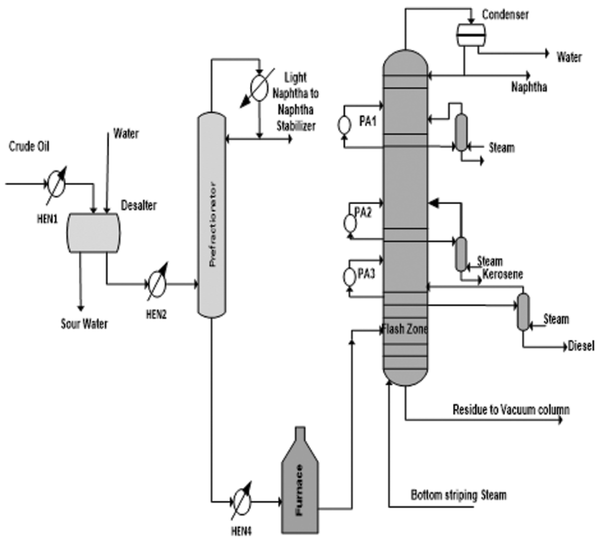

Fig. 2 — Schematic of FC configuration of CDU

The third configuration is based on the flash drum, atmospheric and vacuum distillation columns in which flash drum vapour is routed to atmospheric distillation columns either at some location above the flash zone or in flash zone. The configuration in which FD vapour is routed to a location above the flash zone shall be referred as FDC1. The schematic of the FDC1 configuration is shown in Fig. 3.

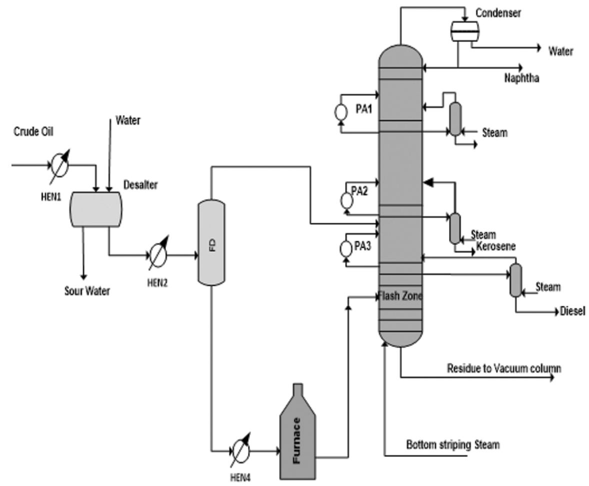

Fig. 3 — Schematic of the FDC1 configuration of CDU

The configuration in which FD vapour is routed to the flash zone shall be referred as FDC2. The schematic of the FDC2 configuration is shown in Fig. 4.

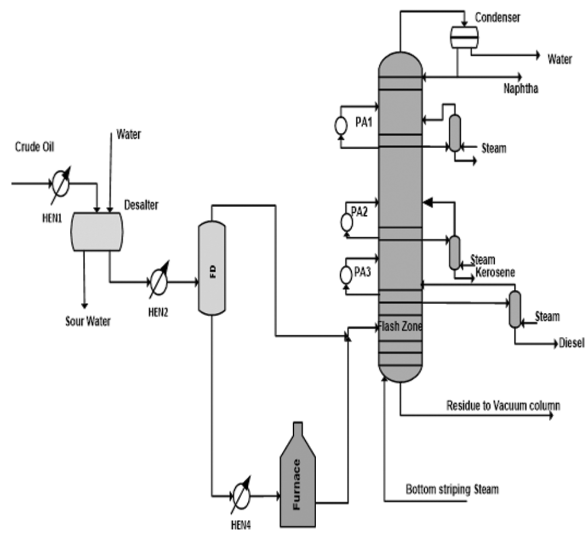

Fig. 4 — Schematic of FDC2 configuration of CDU

However, in the present study, BC and FD based CDU configuration were studied.

Proposed CDU configuration

CSIR-IIP developed a new method for a simultaneous increase in ADC distillate yield and the energy efficiency of CDU. This configuration shall be referred as proposed case (PC). This method uses the novel application of lighter fraction of crude through its superheating and its injection in the stripping section of atmospheric distillation column which has not been used in existing design of any crude distillation unit. The schematic of the PC of CDU is given in Fig. 5.

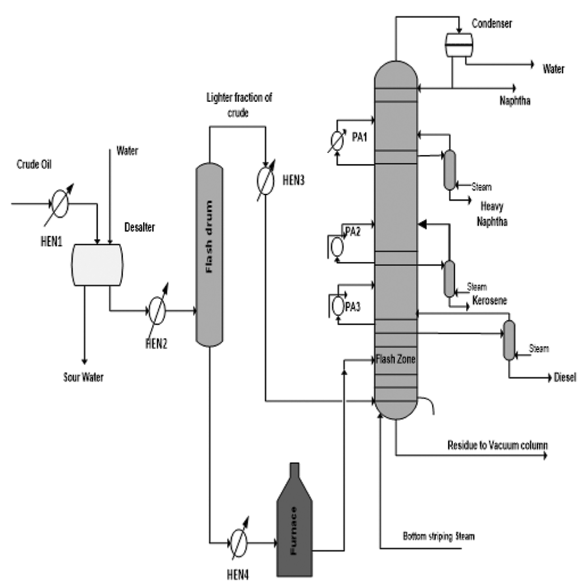

Fig. 5 — Schematic of PC configuration of CDU

In the proposed configuration, the vapour of the flash drum was superheated to 365°C before injecting into the atmospheric distillation column bottom. Superheating is used to avoid the condensation of vapour in the bottom of the column. The vapour also provides the striping effect and thus results in a sharp decrease in bottom stripping flow rate.

Results and Discussion

Techno-economic analysis

A techno-economic study on an Indian refinery's CDU unit processing capacity of 3.0 MMTPA was carried out to illustrate the commercial benefit of the patented crude processing method. The crude has API of 39 and a 95% boiling point of 545°C. Product's 5% and 95% temperatures were maintained the same in each design. The coil outlet temperature (COT) and bottom stripping steam (BSS) were also kept the same in each design. Moreover, pump-around duties and stripping steam rates were fine-tuned to maintain the same distillate quality by matching 5% and 95% ASTM D86 temperatures.

The ADC product 5% and 95% temperatures and the 5-95% gap are given in Table 1. The pump around duty in the atmospheric distillation column is given in Table 2.

The ADC products yield and stripping steam requirement are given in Table 3. Results show that ADC distillate and gas oil yield are significantly lower in FDC1, FDC2 compared to BC. However, in the proposed case, ADC distillate yield is significantly higher compared to FDC1, FDC2 and BC. The increase in the ADC distillate yield was attributed to the additional stripping effect of superheated vapours introduced at the bottom of the ADC.

Results reveal that stripping steam requirement in FDC1 and FDC2 cases increased by 21.9% and 24.6% compared to BC to meet the distillate product quality. The price of distillate from ADC is higher than the long residue. Therefore, it is clear that that lower distillate rate and higher stripping steam in FDC1 and FDC2 shall lead to the lower gross margin of CDU.

Atmospheric distillation column's vapour profile

The effect of the introduction of FD vapours in the ADC was observed by tracing the vapour traffic throughout the column. The vapour profile of the ADC along the trays is given in Fig. 6.

The ADC vapour flow in FDC1 and FDC2 was found to be lesser than the BC above the flash zone. The reduced vapour flow can be the result of the

Table 2 — Pump around duty in the atmospheric distillation column (MMkcal/hr)

	BC	FDC1	FDC2	PC
Top PA Duty	6700	6700	6700	6700
Kero PA Duty	11900	11900	11900	13000
Diesel PA Duty	8700	8200	8200	8700

Table 3 — The products yield and stripping steam requirement in ADC

Products	BC	FDC1	FDC2	PC
Products rate, TPH (Tonne per hour)				
Light Naphtha	52.2	52.1	52.1	51.5
Heavy Naphtha	23.8	23.0	23.0	23.4
Kerosene	94.0	95.4	95.1	92.4
Diesel	75.8	73.2	70.4	81.3
Long residue	122.3	124.4	127.4	119.2
Total ADC Distillate	245.8	243.7	240.8	248.7
Striping steam, TPH				
Heavy Naphtha	0.4	0.6	0.7	0.4
Kerosene	1.8	2.3	2.4	1.7
Diesel	1.1	2	2	1.1
Bottom	4	4	4	4
Total Striping steam	7.3	8.9	9.1	7.2

Table 1 — Atmospheric distillation column product quality

	BC	FDC1	FDC2	PC
Product 95% temperatures				
Top 95	118.00	118.00	118.00	118.00
HN 95	165.00	165.00	165.00	165.00
Kero 95	246.00	246.00	246.00	246.00
Diesel 95	360.03	360.01	360.00	360.00
Product 5% temperatures				
HN 5	127.13	126.95	127.08	126.94
Kero 5	161.35	161.11	161.25	161.39
Diesel 5	246.90	247.13	246.89	247.19
RCO 5	356.83	342.26	325.88	377.35
Product (5-95) gap				
HN-Top	9.13	8.95	9.08	8.94
Kero-HN	-3.65	-3.89	-3.75	-3.61
Diesel-Kero	0.90	1.13	0.90	1.19

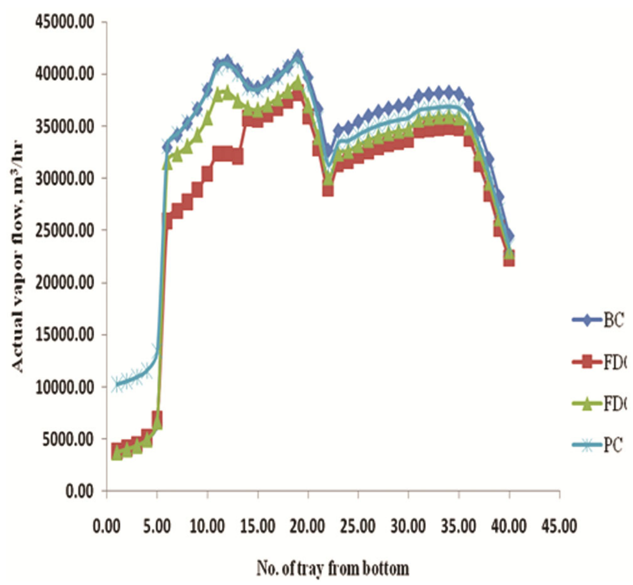

Fig. 6 — Atmospheric distillation column vapour profile

introduction of the FD vapours at or above the flash zone of the ADC. The higher vapour flow in the PC over BC below flash zone can be due to the introduction of the superheated vapours at the bottom of the ADC. The vapour flow in PC was observed to be gradually reduced from the flash zone to the top of ADC.

Comparative analysis of quantitative benefits

A detailed economic analysis was carried out to estimate the quantitative benefit of implementing this new method in CDU. Steam price of Rs 1300 per tonne and furnace fuel prices of Rs 1300/MMBtu were used in the economic analysis. The price difference of Rs 5 per kg between diesel/distillate yield and the long residue was taken during analysis. The results are given in Table 4.

The economic analysis reveals that there is a financial profit of ~1451 lakhs by implementing the proposed crude process scheme in comparison to existing conventional CDU unit for the crude processing capacity of 3.0 MMTPA. It is known that nowadays most of the refineries have the CDU unit capacity much higher than 3 MMTPA. Thus, the sensitivity analysis for the effect of capacity on the quantitative benefits is shown in Fig. 7.

Carbon saving in the crude distillation column (CDU)

The carbon saving was calculated by taking account of energy requirement through stripping steam and furnace duty. The stripping steam of 2 ton is considered to be equivalent to 1 MMkcal/hr.

Table 4 — Quantitative benefits for crude processing (distillate and reduced crude oil price gap: 5 Rs/Kg, stripping steam: Rs. 1300/tonne, fuel gas: Rs. 1300/MMkcal)

Parameters	Loss (-) and benefits (+), Lakhs Per Year		
	FDC1	FDC2	PC
Increased ADC Distillate	-847.3	-2041.3	1237.3
Striping steam	-166.4	-187.2	10.4
ADC furnace fuel	537.7	548.3	271.1
VDC furnace fuel	-35.3	-216.3	-67.5
Total utility price	335.9	144.8	214.0
Overall benefits	-511.3	-1896.5	1451.3

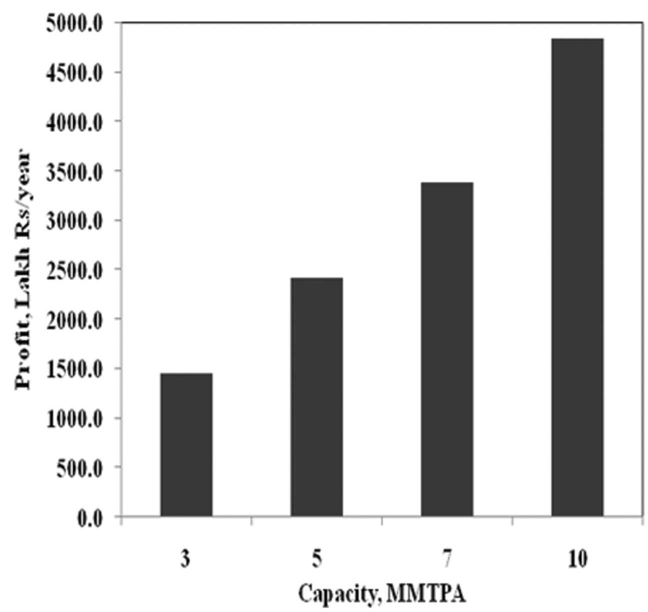

Fig. 7 — Effect of CDU capacity on financial benefits

The energy is converted to the natural gas required with the help of the calorific value of the natural gas. The carbon dioxide emission from the natural gas was then calculated with the help of the stoichiometric equation.

The carbon saving for FDC1 and FDC2 was observed to be 7.5 and 5.3 % respectively over the BC. The carbon saving for the PC over BC was observed to be 3.9%. The higher carbon saving in FDC1 and FDC2 compared to PC was due to the lower furnace duty requirement as compared to the PC.

In a nutshell, it shall be mentioned that the proposed design of CDU can save the significant energy and carbon emission. The proposed process has the potential to implement in both existing CDU unit by revamping the heat exchanger network and in Grass root CDU at the design stage.

Conclusion

Simulation and economic analysis of a new method for crude processing in CDU reveal that there are energy savings when FD is integrated into CDU. However, the existing FD integrated designs result in reduced atmospheric distillate yield for fixed coil outlet temperature and bottom stripping steam. However, the proposed method not only reduces the energy consumption but also increase the valuable distillate yield. Overall, there is a financial benefit of ~14.51 Crores/annum by the implementation of proposed FD based CDU design compared to existing conventional CDU unit design for the capacity of 3.0 MMTPA. Moreover, this benefit will increase with the capacity, and this shall be of 48.4 Crores/annum for most common CDU capacity of 10 MMPTA currently available in the refineries. The proposed method has the potential to implement in both existing CDU unit by revamping the heat exchanger network and in Grass root CDU at the design stage.

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