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Research paper

Fouling at post desalter and preflash drum heat exchangers of CDU preheat train

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HIGHLIGHTS

- Severe fouling at PDPF exchangers experienced at EORC and 4 major industrial cases.
- Data over 2 shutdowns revealed +50% wt foulant content were inorganics: $CaCO_3$ and FeS.
- A 6-step mechanism based on Lambourn–Durrieu's proposed for PDPF exchangers fouling.
- At PDPF exchangers contrary to other preheaters, shell-side fouling is significant.

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ABSTRACT

Following an 8-year field study at EORC refinery including visual inspection, operational data and fouling resistance analysis, as well as foulant chemical characterization, it became clear that post desalter and preflash drum (PDPF) exchangers experience irregular severe fouling. To find effective factors for examination in future pilot tests, literature was studied and four industrial cases with the same problem were identified. Notably in this type of fouling, more than 50% of the foulant contents sampled in two shutdowns at EORC were inorganics, and similar to Yanbu and Chevron cases consisted of iron compounds and calcium carbonate. Considering EORC results and reported causes and remedies employed in the cases, a 6-step mechanism based on that of Lambourn and Durrieu is proposed in which asphaltene interactions with water, salts and iron sulfides (i.e. collaboration of physical and chemical processes) lead to deposition of severe, tenacious and stable foulant on the tube surfaces of PDPF exchangers. Desalting performance and water injection, brine chloride hydrolysis and caustic injection, asphaltenes solubility dependence on temperature variation, and its molecular structure as a surfactant agent as well as non-negligible shell-side fouling deposited off the vacuum gas oil have been identified as the effective factors discussed here in detail.

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1. Introduction

Preheat exchanger fouling in crude oil distillation unit (CDU) remains costly in terms of operation, environment and economics, and difficult to tackle due to ambiguity in origin. In a typical preheat train (PHT) arrangement, crude oil is heated up by distillation column products in shell-and-tube exchangers, while a desalter unit removes salt, water and sediments. To manage crude hydraulics, especially for lighter crudes, a flash drum is employed to vaporize the lighter portion of the components. Various mechanisms however, are known to be responsible for fouling at different exchangers of a PHT. Several studies suggest major changes in these mechanisms occur post and predesalter unit as summarized for the sake brevity in Table 1.

As far as associated field studies are concerned, most refineries surveyed to date for fouling studies process heavier crudes, in which flash drum is often omitted from their PHT arrangements. In such designs, considerable fouling occurs commonly at exchangers located towards the end of PHT, just before the furnace, where the dominant mechanism is thought to be chemical reaction with asphaltene playing an important role. As such, relevant recommendations and solution techniques discussed in the literature may only be appropriate for exchangers at the hot end of PHT.

However, in a field study at Esfahan refinery (EORC) [5] which treats a relatively light crude feedstock (SG = 0.86) piped from Maroon oilfield, it became clear that the most severe fouling along

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Nomenclature

R_f	fouling resistance, m^2 K/W
Re	Reynolds number, dimensionless
SG	specific gravity
Ts	heat transfer surface temperature, °C
t	time, s
u	velocity, m/s

Abbreviations

CDU	Crude Oil Distillation Unit
PHT	Preheat Train
EORC	Esfahan Oil Refining Company
PDPF	Post Desalter and PreFlash drum
LOI	Loss on Ignition
XRD	X-Ray Diffraction
VGO	Vacuum Gas Oil
HVGO	Heavy Vacuum Gas Oil
WAT	Wax Appearance Temperature

the PHT takes place at exchangers located post desalter and preflash drum (PDPF) units. Interestingly, the same excessive fouling is confirmed by other case studies reported in the literature, suggesting perhaps that a special type or mechanism/s of fouling is in action here. Hence, it is suggested to study fouling mechanism in preheat exchangers based on their location along the PHT in three categories: a) desalter upstream exchangers, b) PDPF exchangers, and c) flash drum downstream exchangers. Based on Table 1, in the first category, inorganic fouling caused by salts, particulate matters, and corrosion products is significant, while in third one, organic fouling and asphaltene characteristics are influential. The second category (PDPF exchangers) had not been addressed adequately in literature and merited specific investigations.

To determine the prevailing mechanism/s in PDPF exchangers, EORC's field study data was extended over two major shutdowns (including visual inspection, operational data and fouling resistance analysis, foulant chemical characterization, and shell-side fouling) as presented here, while other similar industrial cases were also investigated to identify the main affecting factors. These are discussed in two fouling categories of inorganic and organic, of which desalting performance, salt precipitation, caustic injection and brine chlorides hydrolysis relate to the former, and asphaltenes solubility influenced by temperature variation beside their role as surfactant agents for the latter. Finally, a 6-step fouling mechanism based on that of Lambourn and Durrieu is proposed where the followings are considered: a) water remained in the desalted oil act as emulsified droplets carrying calcium carbonates (if caustic was injected post desalter), b) asphaltenes precipitate from the bulk, c) insoluble entities are formed due to emulsified brine droplets being surrounded by amphiphilic asphaltene molecules, d) insoluble entities deposit on the tube wall, e) water droplets evaporate leaving $CaCO_3$ compounds enclosed by asphaltene molecules, which lead to f) tubes being blocked as a result of tenacious foulant deposition and its aging. This mechanism could explain the effective mitigation remedies employed in the industrial case studies investigated here.

2. Fouling in PDPF exchangers at EORC

Fouling field study at preheat exchangers in one of the EORC's CDUs (see Fig. 1) started in 2008, with the most severe fouling observed at E155A-B (Fig. 2) which are indeed PDPF exchangers. The foulant sample deposited from crude oil inside the tubes of these exchangers had 0.095%wt asphaltene and 80% inorganic content including Fe_2O_3, and $CaSO_4$ with the latter deemed to be indicative of desalter inefficient performance and possible 2-phase fluid formation [5]. The study was extended to cover another major shutdown as expressed below:

2.1. Visual inspection

In the last shutdown, similar to the previous one, visual inspection following the pre-dismantling wash revealed that crude oil deposit was removed from tube-side of the upstream desalter exchangers, while little foulant remained in exchangers located just before the heater, downstream of flash drum, where crude flows at the shell-side. However, in PDPF exchangers (E155A-B), more than 90% of tubes were so heavily blocked that no light could pass through them, indicating that tube-side crude deposit here was extremely stable.

2.2. Operational data and fouling resistance analysis

As for operational data analysis in the PDPF exchangers, the followings were noted: at least 22 °C decrease in temperature difference across tubes at any operational period (Fig. 3), and increase in tube side pressure drop of 2.5 bar from the start-up for the next three years (Fig. 4).

The developed spread sheet for fouling resistance determination (described in Ref. [5]) was further improved using viscosity correlation for heavy fractions [6], thereby allowing R_f to be obtained for PDPF exchangers for 5.8 m^2 °C/kW, reached only 8 months into the operating period. For comparing fouling at PDPF exchangers with others along the PHT using SigmaPlot™, a three dimensional graph of R_f versus surface temperature (T_s) and average tube-side velocity (u) indicates the highest fouling resistances belonged to E155A-B (Fig. 5).

In a preliminary attempt to determine fouling threshold curve for EORC crude oil and positioning its preheat exchangers (where crude flows in the tube-side) on the related plot (T_s versus u), the

Table 1
A summary of prevailing fouling mechanisms in exchangers of a PHT.

Author	Predesalter fouling factor	Post desalter fouling factor	Ref
Costa et al.	Presence of particulate matter and salts	Chemical reaction fouling associated with presence of asphaltenes	[1]
Yeap	Depositions of salts, waxes and corrosion products	Deposition dominance by chemical reaction	[2]
Ishiyama et al.		Formation of gums and production of insoluble asphaltenes, possible presence of other reactions such as those catalyzed by FeS and other corrosion products	[3]
Wang and Watkinson		'Inorganic fouling' in which FeS and salts are the main deposit constituents, and 'organic fouling' due to asphaltenes leading ultimately to coke deposits. These could occur simultaneously or separately depending on the circumstances.	[4]

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