

Carbon brainprint case study
Optimising defouling
schedules for oil-refinery
preheat trains



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Optimising defouling schedules for oil-refinery preheat trains

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Summary

In an oil refinery, crude oil is heated to 360–370°C before entering a distillation column operating at atmospheric pressure where the gas fraction and several liquid fractions with different boiling points (e.g. gasoline, kerosene, diesel, gas oil, heavy gas oil) are separated off. The crude oil is heated in two stages. The preheat train – a series of heat exchangers – heats it from ambient temperature to about 270°C when it enters the furnace, known as the coil inlet temperature. The furnace then heats the oil to the temperature required for distillation.

The purpose of the preheat train is to recover heat from the liquid products extracted in the distillation column. Without this, 2–3% of the crude oil throughput would be used for heating the furnace; with the preheat train up to 70% of the required heat is recovered. It also serves to cool the refined products: further cooling normally uses air or water.

Over time, fouling reduces the performance of the heat exchangers, increasing the amount of energy that has to be supplied. It is possible to bypass units to allow them to be cleaned, with an associated cost and temporary loss of performance. The cleaning schedule thus has an impact on the overall efficiency, cost of operation and emissions.

The group at the Department of Chemical Engineering and Biotechnology at Cambridge developed a scheduling algorithm for this non-linear optimisation problem. It yields a good, though not-necessarily optimal, schedule and can handle additional constraints, such as the presence of desalters with specific temperature requirements within the preheat train. This is now being developed into a commercial software product.

Data from two refineries – one operated by Repsol YPF in Argentina and the Esso Fawley Refinery in the UK – were used to model the systems and test the algorithm.

For the Repsol YPF refinery, when compared with current practice and including a constraint on the desalter inlet temperature, the most conservative estimate of the emissions reduction was 773 t CO₂/year. This assumed a furnace efficiency of 90%. The emissions reduction increased to 927 t CO₂/year at 75% efficiency and 1730 t CO₂/year at 40%. These were based on a stoichiometric estimate of the emissions from the furnace. Using a standard emission factor increased them by 7.4%.

For Esso Fawley, the estimated emission reduction compared to no maintenance was 1435 t CO₂/year at 90% furnace efficiency. This increased to 1725 t CO₂/year at 75% and 3225 t CO₂/year at 40% efficiency.

General description

In an oil refinery, crude oil is heated to 360–370°C before entering a distillation column operating at atmospheric pressure where the gas fraction and several liquid fractions with different boiling points (e.g. gasoline, kerosene, diesel, gas oil, heavy gas oil) are separated off. In many refineries, the part that remains liquid ('bottoms') is heated again and enters another distillation column which operates under vacuum to separate it further. The remainder is bitumen, used for making asphalt, etc.

The crude oil is heated in two stages. The preheat train – a series of heat exchangers – heats it from ambient temperature to about 270°C when it enters the furnace, known as the coil inlet temperature. The furnace then heats the oil to the temperature required for distillation.

Failure to reach the minimum coil inlet temperature will result in 'coking' in the furnace, reducing its efficiency. Additional constraints may apply to the minimum or maximum temperature at different points in the preheat train. These include an upper limit set by the vapourisation temperature of the crude oil, which depends on its composition, and desalters within the train, with specific inlet temperature requirements.

The preheat train consists of a series of heat exchangers that recover heat from the liquid products extracted in the first distillation column. Without this, 2–3% of the crude oil throughput would be used for heating the furnace; with the preheat train up to 70% of the required heat is recovered. It also serves to cool the refined products; further cooling normally uses air or water (Figure 1).

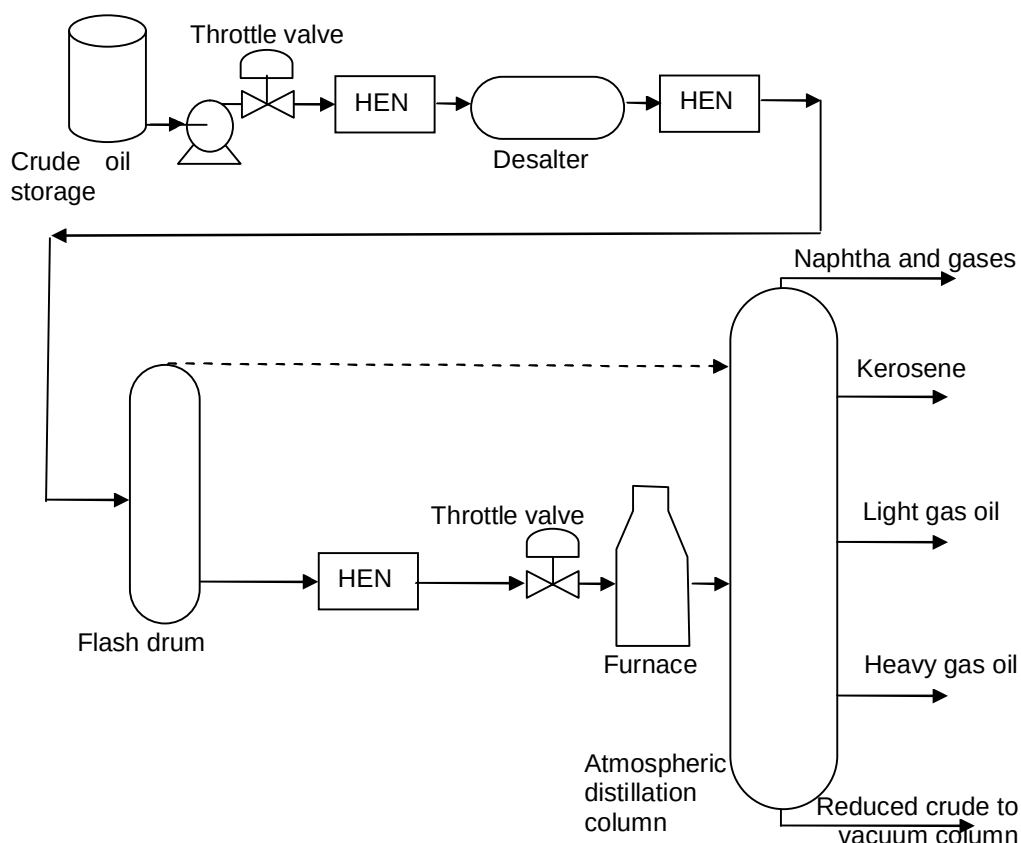


Figure 1. Simplified schematic of an oil refinery from crude oil storage to distillation columns. The rectangles, HEN, indicate heat exchanger networks.

Over time, fouling reduces the performance of the heat exchangers, increasing the amount of energy that has to be supplied. It is possible to bypass units to allow them to be cleaned, with an associated cost and temporary loss of performance. The cleaning schedule thus has an impact on the overall efficiency, cost of operation and emissions.

Dr Ian Wilson, Dr Bill Paterson (now retired) and Dr Edward Ishiyama from University of Cambridge Department of Chemical Engineering and Biotechnology developed a scheduling algorithm for this non-linear problem. It uses a network simulation adapted to a specific refinery by data reconciliation, with scheduling by a 'greedy' algorithm that can handle additional temperature constraints in the preheat train. The greedy algorithm seeks a locally-optimal yet still attractive and robust solution rather than a global optimum, and has been shown to give good results (Ishiyama *et al.*, 2010, Ishiyama *et al.*, 2011). The research was funded by the EPSRC and the university is currently working with IHS-ESDU to include it in a commercial software product. The software, named smartPM, is due to be released in July 2011.

For the Carbon Brainprint project, Dr Ishiyama considered two refineries for which the necessary data were available: a Repsol YPF refinery in Argentina and the Esso Fawley Refinery in the UK. Simulation studies were conducted with and without optimised cleaning schedules to estimate the difference in fuel use for heating.

The complete studies are presented as annexes to this report, which summarises the methods and the main findings.

System boundaries

The only emissions considered were those arising from direct combustion of oil products to heat the crude oil prior to distillation. The predicted changes were small fractions of the total throughput of the refinery, so the resulting change in total output was neglected. The life cycle emissions from anti-fouling chemicals were also assumed to be negligible compared to those from combustion.

The analyses simulated a 3 year period for the Repsol YPF case and 2 years for Esso Fawley. Other than maintenance periods at intervals of 3–5 years, refineries operate continuously for long periods, so it is more appropriate to present annual results than lifetime totals.

Data

The Repsol YPF refinery operates at an average capacity of 68,000 bbl/day, and the preheat train consists of 18 heat exchangers (recovering about 67 MW). There are 8 heat exchangers before the desalter, 5 heat exchangers between the desalter and the flash drum, and 5 heat exchangers after the flash drum (Figure 1). The refinery experiences an average drop of 20–30°C in the coil inlet temperature over a 3 year period. Four operating scenarios were considered (Table 1).

Table 1. Operating scenarios for the Repsol YPF refinery

Scenario	Description
I	Preheat train is operated in the absence of any maintenance activity
II	Systematic cleaning of heat exchangers is scheduled to improve core inlet temperature profile
III	Systematic cleaning of heat exchangers is scheduled to improve core inlet temperature profile, coupled with controlling desalter inlet temperature
IV	Current refinery cleaning practice (clean heat exchanger A and B in Figure 1, every 12 months).

Two methods were used to estimate the emissions: a stoichiometric method based on the net heating value and composition of natural gas, and a simple emission factor of 57.6 t CO₂/GJ (Shires *et al.*, 2009, p 4-17). The emission factor method gave a result 7.4% greater in this case. Three different furnace efficiencies were considered: 90% and 75% representing the typical efficiency range, and 40% representing a poorly operating furnace.

The Esso Petroleum Fawley refinery, located near Southampton, processes about 158,000 bbl/day. The preheat train features 67 individual exchangers arranged in three sections. A preliminary audit of fouling behaviour across the network, involving a review of plant operating data over the previous six years, indicated that the most serious fouling effects occurred in the hot section of the preheat train, downstream of the flash tower and immediately before the furnace. This section is also most important in determining the coil inlet temperature, so the benefit of cleaning exchangers in this section was considered in the case study. Fouling causes the core inlet temperature to decrease by around 5°C over 2 years. The noticeable difference from the Repsol case arises because of the larger number of exchangers (extra capital investment).

Slightly different scenarios were considered for this case (Table 2). These included using a mixed integer non-linear programming (MINLP) method, which is computationally expensive, to seek a global optimum. The same emission factors and efficiency ranges as in the Repsol YPF case were used.

Table 2. Operating scenarios for the Esso Fawley refinery

Scenario	Description
1	Preheat train operation without any maintenance
2	Cleaning scheduled using MINLP method
3	Cleaning scheduled using greedy algorithm
4	Combined fouling management using cleaning and antifouling chemicals. Cleaning scheduled using MINLP method. Anti-foulants are assumed to reduce the rate of fouling by 50%.

Brainprint

Prospective Brainprint

The results of this research have not yet been implemented, so there is no retrospective brainprint.

For the Repsol YPF refinery, compared with current practice (scenario IV), systematic cleaning (scenario II) resulted in an average annual emissions reduction of 1013 t CO₂, assuming a furnace efficiency of 90% and using the stoichiometric method (Table 3). If the desalter inlet temperature was constrained (scenario III), the emissions reduction was 773 t CO₂/year.

Table 3. Total additional emissions due to fouling over 3 years for Repsol YPF refinery using the stoichiometric method

Scenario	Additional emissions due to fouling, t CO ₂		
Furnace efficiency	90%	75%	40%
I	17,780	21,430	39,990
II	12,010	14,480	27,020
III	12,730	15,360	28,660
IV	15,050	18,140	33,850

For the Esso Fawley refinery, the average reductions in emissions for the MINLP method and the greedy algorithm were 1350 and 1435 t CO₂/year respectively, compared with no maintenance (Table 4). Adding the use of antifouling chemicals to the MINLP method produced a further reduction of 600 t CO₂/year, which is not attributable to the brainprint.

Table 4. Total additional emissions due to fouling over 2 years for Esso Fawley refinery using the stoichiometric method

Scenario	Additional emissions due to fouling, t CO ₂		
Furnace efficiency	90%	75%	40%
1	7,950	9,580	17,880
2	5,250	6,330	11,820
3	5,080	6,130	11,430
4	4,050	4,890	9,120

Uncertainties

It was noted earlier that the emission factor method gave results that were 7.4% greater than the ones summarised above using the stoichiometric method. The furnace efficiency had a larger effect. For the Repsol YPF refinery, the average emissions reductions for scenario III were 927 t CO₂/year at 75% efficiency and 1730 t CO₂/year at 40%. For Esso Fawley the reductions for scenario 3 were 1725 t CO₂/year at 75% and 3225 t CO₂/year at 40% efficiency.

The differences between these two refineries in terms of throughput and configuration of the preheat train show that it is not possible to extrapolate directly from these results to other installations. However, they do indicate that a realistic order of magnitude estimate of the likely reduction for each is at least 1 kt CO₂/year.

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