Low-cost methods to improve FCCU energy efficiency

The first step to finding low-cost ways of improving FCC unit efficiency under new environmental regulations is to determine the true limits of the existing process equipment and flow scheme, say the authors. They describe ways of influencing heat source temperatures and modifying the flow

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Improving FCC unit energy efficiency is becoming more important as refiners try to comply with new government environmental regulations. European and US government mandates are dramatically reducing FCC gasoline sulphur, refinery total NO_x and CO_2 emissions. Without improved energy utilisation within the FCC, reducing gasoline sulphur will actually increase energy use in the refinery. This will increase NO_x and CO_2 emissions by increasing the consumption of boiler or new fired heater fuel gas.

Most FCC units were built before the 1970s, when energy costs were considerably lower than today. Low capital cost was the primary investment objective, not efficient energy utilisation. With few exceptions, the capital cost of rejecting heat to air or water is lower than recovering it.

While refinery energy consumption is a significant operating cost and is closely monitored, investment in improved energy utilisation often cannot be justified by economic factors alone. In today's competitive market, many refiners require revamp payouts of one year or less and the cost of energy does not often meet investment hurdle rates. Increasingly, environmental issues are driving energy efficiency improvements.

Improving energy efficiency in a cost effective manner requires a thorough review of the existing unit process and major equipment design [Martin G R, "Keeping down the cost of revamp investment", *Petroleum Technology Quarterly*, Summer 1999]. Pinch studies, while addressing important theoretical issues, often do not consider constraints imposed by the existing equipment and process flow schemes and fail to determine all the equipment changes that must be made to improve energy efficiency.

A more practical revamp approach is to consider energy efficiency improvement options, process flow scheme changes, and equipment system limits concurrently to find a minimum cost solution [Barletta T, "Practical considerations for crude unit revamps", *Petroleum Technology Quarterly*, Autumn 1998].

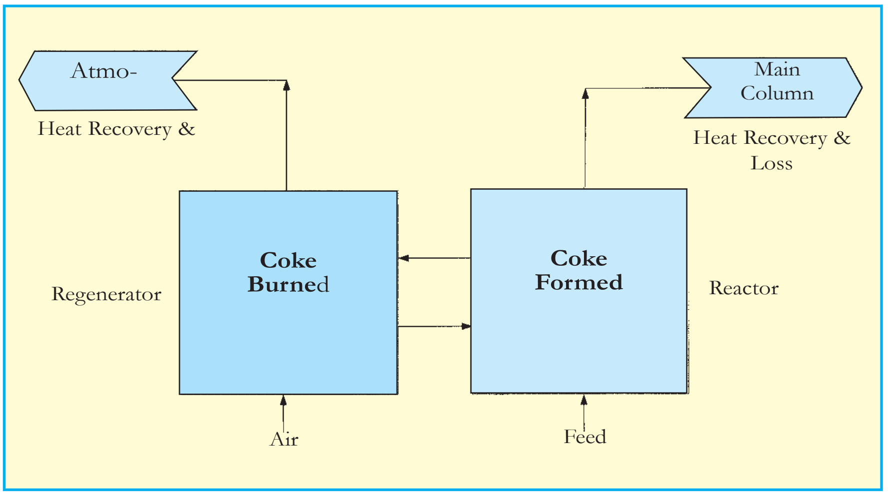

***Figure 1** FCC reactor/regenerator*

This requires a thorough understanding of the existing unit bottlenecks, integrating specific process unit knowledge, and general process engineering skills of hydraulics, heat transfer, compression, distillation and process control. Also, a rudimentary understanding of cost estimating is important to separate high and low cost solutions.

Evaluating alternative process flow schemes should be part of this practical design approach. An FCC unit will have a finite number of potential pumparound and product stream heat sources and certain available heat sinks such as riser feed, gas plant reboilers, or utility streams such as BFW, condensate, and waste heat steam generation.

Matching the heat sources and heat sinks while minimising major equipment changes or additions is the key to practical energy efficiency improvements. For instance, using HCO pumparound heat to reboil the FCC gas plant deethaniser is not an effective use of high temperature heat. Also, energy users (heat sink) temperatures should not all be considered fixed.

Any potential process flow scheme change must be tempered by the reality of the existing process and major equipment design. Most revamps, including energy efficiency improvements, are done in the comfort of a design office with little or no details on the current unit and equipment performance available.

Understanding real unit limitations requires a comprehensive benchmarking that starts with a field test run. Test runs include field-measured pressure, temperature, and composition profiles throughout the unit. The engineer responsible for the revamp should be in the field installing pressure gauges and portable thermocouples to get a feel for the existing plant operation. Ultimately, computer modelling must include the realities of the existing plant; otherwise the model results may not match reality and the investment cost may be much higher than required, or the revamp might not work.

Existing major equipment constraints must be circumvented or the equipment

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modified to minimise capital costs. This requires evaluating alternative energy efficiency options, understanding the existing unit bottlenecks in detail, and having sufficient equipment knowledge to understand the difference between high and low cost equipment changes.

Equipment modifications must be identified. Identifying and designing low cost equipment changes can make the difference between revamp success and failure. Some of the practical energy efficiency improvement considerations involve:

Distillation: heat source and sink temperatures

—Number of pumparounds

—Product draw location

—Gas plant side and once-through reboilers.

Exchanger LMTD: increasing pumparound circulations rates

Process flow changes: adding an exchanger service or changing an existing exchanger service

Low cost equipment changes: pump impellers/motors and heat exchanger tube bundles

FCC energy consumption

FCC units consume a considerable amount of energy. The FCC reactor uses regenerator heat to vaporise the feed and provide the endothermic heat of reaction. Figure 1 (on previous page) is a simple block diagram of the FCC reactor/regenerator.

The reactor feed is atmospheric/vacuum gas oils, coker gas oil, and other heavy hydrocarbons. The reactor products are a mix of hydrocarbons, hydrogen, hydrogen sulphide and coke. The reactor product stream feeds the main column and contains a large quantity of heat. Coke leaves the reactor on the catalyst and is burned in the regenerator.

Catalyst flows back and forth between reactor and regenerator to exchange heat, burn the coke, and provide energy for the reactor. The FCC reactor effluent stream enters the main fractionator at temperatures between 950-1050°F (510-565°C).

The main fractionator feed contains a large amount of energy, which can be recovered by exchange with other refinery streams. Heat that is not recovered through exchange with other FCC unit streams must be rejected to air and water. The FCC main fractionator condenser and product and pumparound air/water coolers are all sources of heat loss.

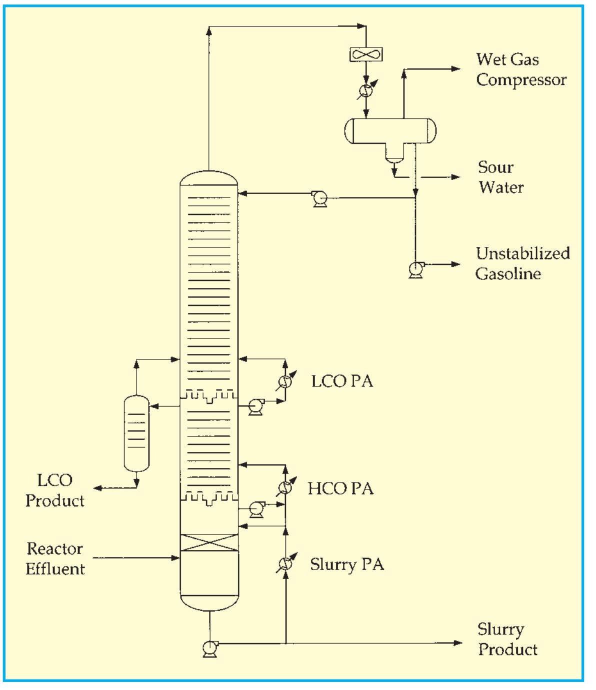

***Figure 2** Typical FCC main fractionator*

Identifying potential energy efficiency improvements begins by quantifying specific heat loss areas.

Reactor product yields: effect on energy consumption and recovery

FCC reactor and catalyst technology improvements have increased conversion, reduced gas make, increased gasoline production and increased the yield of olefins for alkylation unit feed. There is more gasoline and lighter hydrocarbons and less slurry and light cycle oil in the reactor effluent.

These reactor composition changes have made energy recovery more difficult. Gasoline condenses at low temperatures, while LCO and slurry condense at much higher temperatures in the main fractionator.

Reactor effluent is first fractionated in the main column while the gasoline and lighter components are separated in the gas plant. Figure 2 shows a main fractionator that separates gasoline, light cycle oil (LCO), and slurry product.

Historically, product D86 endpoint has been 430-445°F (221-229°C) for gasoline and 680-700°F (360-371°C) for LCO. Main column bottoms product (slurry) includes everything heavier than LCO. These product compositions determine the operating temperatures in the main fractionator. Environmental regulations that reduce the gasoline endpoint, such as Drivability Index, further decrease operating temperatures in the main fractionator.

Increasing the gasoline and olefins yields while decreasing gasoline endpoint further increases the amount of low temperature heat that must be recovered or rejected to air or cooling water. Improving energy recovery requires that the heat be available at a temperature where it can provide heat to another process stream. The quantity of heat available in the main fractionator at a given temperature level is a function of reactor composition. Gasoline boiling range material condenses at temperatures between 100°F and 360°F (38–182°C). LCO product condenses between 360°F and 460°F (182–238°C), and slurry between 460°F and 680°F (238–360°C).

As gasoline production increases, the gasoline/LCO reflux requirements also increase to maintain the fractionation. This increases the heat removal requirements between 100°F and 360°F (38–182°C).

Large quantities of low temperature heat make energy efficiency improvements more difficult. The FCC main fractionator design is a critical component of any energy efficiency improvement work. The overhead condensers and pumparounds provide the reflux to fractionate the gasoline, LCO, and slurry products.

Pumparound heat removal location and the quantity of heat removed sets the reflux between the various products. As the product yields are shifted to gasoline and lighter components, more low temperature heat must be removed to provide sufficient reflux for gasoline and LCO fractionation. Producing more gasoline in the reactor and decreasing gasoline endpoint often results in inadequate low temperature heat removal in the top of the main fractionator.

Shifting the reactor yields towards gasoline and olefin products also

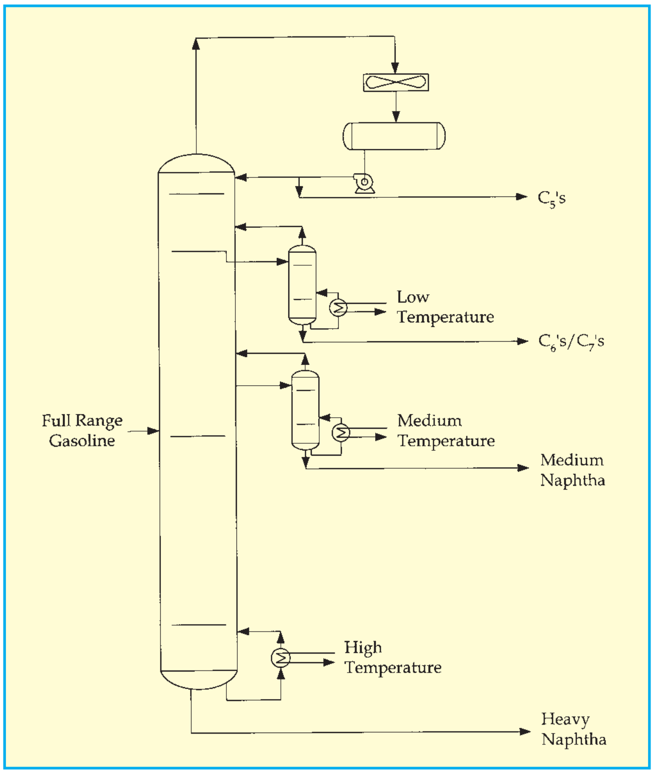

Figure 3 *Four-product gasoline splitter*

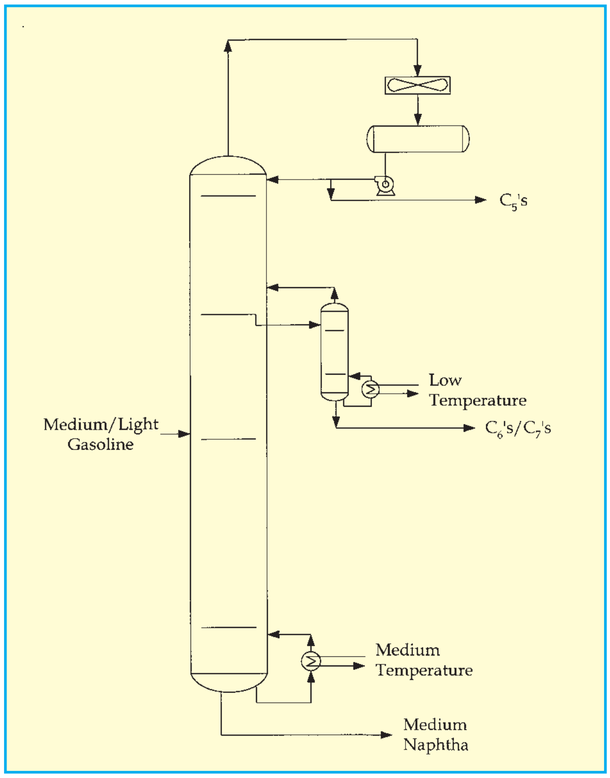

Figure 4 *Three-product gasoline splitter*

increases the gas plant energy requirements. Further increasing the gas plant energy requirements are recent gasoline sulphur regulations, which will require additional fractionation prior to, or concurrently with, sulphur removal. The sulphur treating strategy will determine the gasoline fractionation requirements.

Many gas plants will need a new gasoline splitter that will use a large amount of heat. Depending on the process flow scheme, this heat will be medium to high temperature. Process flow scheme changes such as adding a heavy naphtha product in the main fractionator may be required to optimise reboiler duties and temperatures. Figures 3 and 4 show a four and three product gasoline splitter, respectively.

Energy efficiency options

Efficient energy utilisation matches the heat sources with heat sinks. Ideally, low-temperature heat sources are exchanged against the lowest temperature heat sinks. High temperature heat sources, such as the slurry pumparound, should be used to generate high pressure steam and provide high temperature feed preheat.

There are numerous FCC process flow schemes. Therefore, the heat source and heat sinks will be different for each unit. Evaluating the existing process flow scheme's heat sources and heat sinks is an important aspect of any energy improvement study.

The gas plant design and FCC utility system will largely determine the available heat sinks, assuming no integration with other process units. Gas plant deethanisers and the fractionating column reboilers consume large amounts of heat. All FCC gas plants have a debutaniser that separates the alky feed from the gasoline. Increasingly, FCC product fractionation includes C_3/C_4 and gasoline splitters.

Most FCCs have waste heat steam generation from the regenerator flue gas stream, catalyst cooler, and/or main fractionator pumparound systems. The boiler feed water (BFW) for waste heat steam generation is supplied from the utility system de-aerator; therefore, the temperature is fixed at approximately 250°F (121°). Waste heat steam pressure varies from 150–600psig (10.5–42.2 kg/cm^2-g). Another potential utility stream is condensate from the air blower and wet gas compressor condensing turbines. Some FCC units charge cold feed from storage at 180-200°F (82–93°C), which provides yet another heat sink.

Table 1 shows potential heat sinks. Fractionation, product recovery targets, or utility system operation fixes some of these heat sink temperatures. However, gas plant reboiler temperatures may have variability due to distillation product compositions and the type and location of the reboilers.

The amount of heat that can be exchanged at a given temperature is a

Potential heat sinks

Stream/Location	**Temperature °F**	**°C**
C_3/C_4 Splitter reboiler	210	115
Deethaniser feed preheat	100-155	38-68
Deethaniser reboiler	190-255	88-124
Debutaniser feed preheat	255-300	124-149
Debutaniser reboiler	320-380	160-193
Gasoline splitter	310-450	154-232
BFW	250	121
Condensate	100	38
Cold feed	180-200	82-93

Table 1

Heat sources

Stream/Location	**Temperature °F**	**°C**
Top pumparound	280	138
Heavy naphtha product	300-350	149-177
Heavy naphtha pumparound	300-380	149-193
LCO product	380-460	193-238
LCO pumparound	380-460	193-238
HCO pumparound	560	293
Slurry pumparound	650-700	343-371
Slurry product	650-700	343-371
Debutanised gasoline	350-400	177-204
Gasoline splitter bottoms	330-450	166-232

Table 2

function of the service, duty requirements, or limitations of the heat sinks such as flow and/or temperature.

The next step is to quantify the amount of heat that can be exchanged. Gas plant reboiler duties and utility system limitations must be determined. Reboiler heat sink temperatures can be manipulated by using side and once-through reboilers. Utility system heat sinks must be evaluated against overall refinery utility balances.

Producing more 150psig steam when it is being vented in another part of the refinery does not justify additional BFW heat exchange. Nonetheless, within the FCC unit the quantity of BFW and low temperature condensate will determine potential utility heat sinks.

Once the energy users are defined and quantified, the recoverable energy must be identified. Quantifying all heat losses to air/water will help pinpoint opportunities. Table 2 shows potential heat sources in an FCC and the associated temperatures.

The main fractionator is a potential source of recoverable energy. Its process flow scheme largely determines the heat sources, quantity of heat, and their respective temperature.

The pumparound duties are a function of the column heat balance. The product yield targets set the heat balance. Fractionation improves as more heat is removed higher up in the column. This, in conjunction with increased reactor gasoline yield, further increases the amount of low temperature heat required if the gasoline/LCO product fractionation is to be maintained.

Typically, revamps that are bare-bones investment have installed fin-fans and cooling water exchangers to remove this low temperature heat. Energy efficiency will dictate more equipment and higher capital investment.

The main fractionator pumparound and product heat must be matched with the available heat sinks. These heat source and heat sink selections will depend on the process flow scheme and the specific equipment limits. Specific equipment limits must be determined from benchmarking evaluation, which includes process flow sheet and equipment modelling.

Pumparound and product exchanger services can be designed to operate in parallel or series depending on fractionation objectives and hydraulic limitations.

Table 3 shows the potential heat source and heat sink pairings.

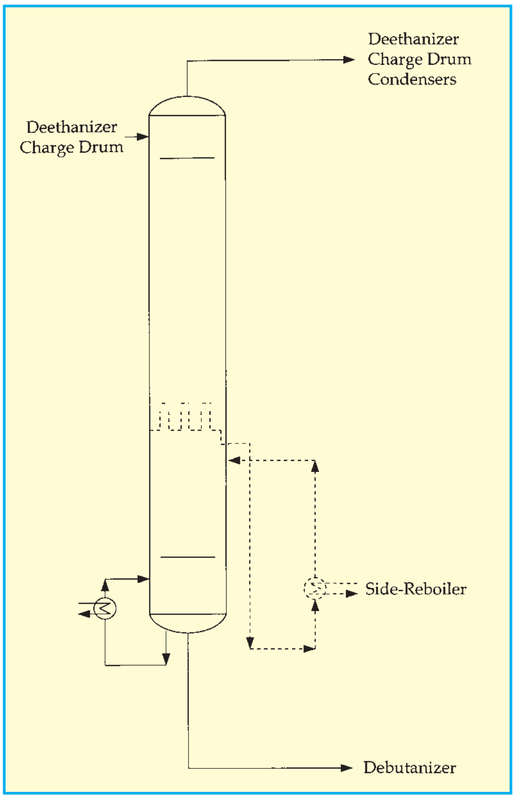

Figure 5 Deethaniser side-reboiler

Specific process flow scheme and equipment limitations will determine the feasibility and capital costs of these pairings. Knowing the process and equipment limits in detail is necessary to understand what is feasible, what can be circumvented by low cost modifications, and what will require large capital investment.

Potential heat source/sink

Heat source	Heat sinks
Top pumparound	Cold feed Condensate Deethaniser feed preheat
Heavy naphtha product	Cold feed Condensate
Heavy naphtha pumparound	C_3/C_4 splitter reboiler Deethaniser reboiler Cold feed
LCO product	BFW Cold feed
LCO pumparound	Deethaniser reboiler C_3/C_4 splitter reboiler Debutaniser side-reboiler BFW Cold feed
HCO pumparound	Debutaniser reboiler Waste heat steam
Slurry pumparound	Waste heat steam Hot feed preheat
Debutanised gasoline	Debutaniser feed Deethaniser reboiler Deethaniser feed preheat
Gasoline splitter bottoms	Debutaniser feed preheat Deethaniser reboiler
Low temperature sources	Cold feed

Table 3

Flow scheme changes

Process flow scheme changes can improve energy efficiency with minimum capital investment. In some cases, simple piping changes such as moving the deethaniser reboiler from the HCO to LCO pumparounds may be all that is required. In others, new pumparounds, product draw locations, and gas plant column/reboiler design changes should be considered.

The number of pumparounds and the pumparound locations have a significant effect on energy efficiency. Increasing the number of pumparounds is a common means of improving energy efficiency. Many FCC units produce all the gasoline from the overhead receiver (Figure 2). The condenser system rejects heat to air and water.

Adding a naphtha pumparound can provide an additional source of heat and recover some of the reflux heat lost to air/water without materially changing gasoline/LCO fractionation. Naphtha pumparound heat can potentially be used in the gas plant to displace LCO pumparound heat. The LCO pumparound heat can then be used in another service, which requires higher temperature heat.

The pumparound draw temperature, duty, and pump capacity dictate where the pumparound heat can be recovered. Increasing a pumparound draw temperature or pumparound rate can improve LMTD and better match available heat sources with the heat sinks. Typically, main fractionator product and pumparound streams are withdrawn from the same location. Therefore, the product composition determines the draw temperature.

Alternatively, the product stream can be withdrawn above the pumparound return to increase the pumparound temperature. Increasing pumparound rate can increase an exchanger service LMTD and increase its capacity. Changing pump impeller diameter and/or motor size can increase pump capacity and eliminate hydraulic bottlenecks.

Increasing pumparound temperature by withdrawing the product from two locations is another option used to

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Process flow scheme changes that better match heat source with heat sinks can improve heat recovery driving force. For instance, LCO product can be withdrawn from two locations: one above the pumparound return and the other at the pumparound draw location. The amount of LCO withdrawn above the pumparound can be used to control the LCO pumparound draw temperature.

Assuming 50 per cent of the LCO is withdrawn at each location, the pumparound draw temperature will increase by 40–50°F (22–28°C). As government regulations reduce gasoline endpoint and gas plant reboiler duties increase, the main fractionator design will be a critical factor in meeting the energy efficiency targets.

Making reboiler design changes or installing feed preheat services can reduce heat sink temperatures. While these options can improve overall energy efficiency, they all increase the total heat required to meet the distillation column fractionation target. Gas plant deethanisers and debutanisers can use side reboilers, once-through reboilers, and feed preheat services that allow a lower temperature pumparound heat to be used, thus freeing higher temperature heat. Figure 5 shows a deethaniser side-reboiler.

Gas plant heat requirements are increasing. New gasoline regulations will require treating the gasoline to remove the sulphur. Fractionating the gasoline prior to treating and customising the treating to the specific sulphur species will lower octane-barrel losses.

Most FCC units produce all the gasoline from the overhead receiver and have only LCO, HCO and slurry pumparounds to control fractionation and remove the reactor effluent heat. These units will have gasoline splitters that fractionate the full range gasoline. The reboiler operating temperatures will be 450°F (232°C), which requires either high pressure steam or a fired heater.

Process flow scheme changes that better match heat source with heat sinks can improve energy efficiency. As an example, an FCC processing 50 000bpd of feed and making 30 000bpd of 430°F (221°C) endpoint gasoline can be made more energy efficient by changing the flow scheme. Producing the heaviest portion of the gasoline from the main fractionator can lower gasoline splitter reboiler duty and operating temperatures.

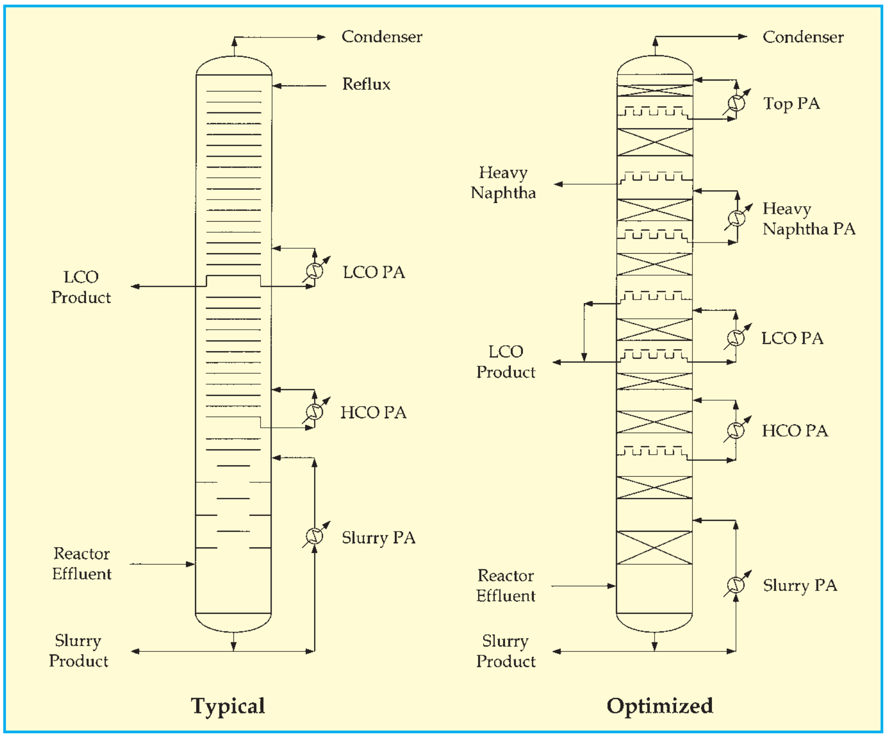

***Figure 6** FCC main fractionator designs*

Figure 6 shows a typical FCC main fractionator and a possible optimised design. Adding a new pumparound reduces the gasoline splitter reboiler temperatures and provides an additional heat source in the main fractionator. The optimised design also shows the naphtha product withdrawn above the pumparound and the LCO drawn from two elevations to increase pumparound draw temperatures.

Table 4 shows a comparison of the gasoline splitter reboiler duty and operating temperature when 30 per cent of the gasoline is produced from the main fractionator, with three products produced from the gas plant splitter, and a four-product gasoline splitter processing full range gasoline. The reboiler duty is much lower and the operating temperature is 140°F (60°C) lower when heavy naphtha is produced from the main fractionator. Changing the process flow scheme has a significant impact on the gasoline splitter energy consumption and possible heat source/sink pairings.

Gasoline splitter duty and temperatures

Reboiler duty/Temperature	Three product	Four product
Splitter reboiler, MMBtu/hr (MMkcal/hr)	43 (10.8)	58 (14.6)
Splitter temperature, °F (°C)	310 (154)	450 (232)
#1 Side stripper reboiler, MMBtu/hr (MMkcal/hr)	15 (3.8)	15 (3.8)
#2 Side stripper reboiler, MMBtu/hr (MMkcal/hr)	N/A	8 (2.0)

Table 4

Equipment design

The existing process flow scheme and major equipment design will determine whether the optimised design shown in Figure 6 is feasible. The revamp engineer will need to address these constraints while evaluating energy efficiency options. Determining maximum pumparound circulation rates and main fractionator limits will need to be done early in the evaluation.

Pumparound pump capacities will determine whether significant flow rate increases are possible. Pumparound

Main fractionator overhead temperature		
% of gasoline*	Temperature °F	Temperature °C
0	282	139
10	260	127
20	234	112
30	209	98

* LV% of heavy naphtha on total FCC gasoline

Table 5

piping is another important cost issue. Changing pumparound control valve sizes are low cost solutions, while major piping changes involve significant cost.

Producing heavy naphtha from main fractionator requires enough vessel height to add the new equipment. Adding a new pumparound and changing draw tray locations, while maintaining fractionation, requires space in the vessel. Additionally, the overhead temperature drops as the quantity of heavy naphtha increases.

Overhead temperatures vary from as high as 300°F (149°C) to as low as 170°F (77°C) when producing heavy naphtha. Table 5 shows the effects of increasing heavy naphtha product yield on the overhead temperature for one FCC unit.

In addition to the new pumparound equipment, the main fractionator design must be capable of dealing with salt formation. At some temperature salt begins to form in the top section of the fractionator. The H_2S, HCl, and NH_4 formed in the reactor will form solids at low temperature and plug the column internals. If the overhead temperature drops low enough, water condensation can cause severe corrosion.

At some point, solid salts must be removed. The main fractionator may need a water draw tray installed to intermittently water wash and remove the salts.

Conclusion

FCC energy efficiency improvements will be required to meet the new government emissions and gasoline sulphur reduction mandates. Today's competitive market dictates low-cost solutions that work. The first step to finding these solutions is determining the true limits of the existing process equipment and flow scheme. Once this has been determined, the heat sources and heat sinks can be examined. As shown here, there are several ways to influence heat source temperatures, such as changing the number of pumparounds and varying product draw locations.

There are also techniques to control the temperature requirements of the heat sinks, such as changing a reboiler configuration. Other "knobs" that can be used to improve energy include increasing pumparound circulation rates and modifying the process flow scheme.

All of these methods require a thorough understanding of the existing process equipment and flow scheme. A practical approach, which simultaneously considers energy efficiency improvement options, process flow scheme changes and major equipment system limits, will minimise capital investment.

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