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Energy Saving Projects Recently Completed at a Large Petroleum Refinery

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ENERGY SAVING PROJECTS RECENTLY COMPLETED AT A LARGE PETROLEUM REFINERY

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ABSTRACT

A significant reduction in energy consumption per barrel of crude oil processed has been effected at Shell Oil's Wood River, Illinois, Refinery during the past two years. Some of the projects which have resulted in reduced energy consumption are:

1. Improved furnace efficiency through closer surveillance and through installation of optimizing controllers on certain furnaces.

2. Lowered reflux-to-feed ratios on certain fractionating columns following reoptimization of operating conditions with current fuel values.

3. Additional heat exchangers purchased and installed on plants originally designed and optimized at lower fuel values.

This paper discusses examples of each of the above projects and the design principles used in developing the projects.

INTRODUCTION

With fuel costs rising and crude oil in short supply, it has become essential for industry to decrease its use of energy. The industrial market uses about 40% of the total energy consumed in the United States today. While only moderate percentage savings are likely to be realized, because of the volume consumed the fuel conserved can still be considerable. Shell Oil Company announced in its 1972 annual report that the goal at Shell's eight refineries was to reduce energy consumption by at least 10% over a period of 2-4 years. This represents a total energy saving by the company of about 3,500,000 barrels per year, which is enough fuel to heat 150,000 homes for an entire St. Louis area heating season.

Fuel costs have risen very rapidly in the past few years. Figure 1 presents the Nelson Cost Index for refinery fuel since 1954, as taken from The Oil and Gas Journal.[1] While the cost was fairly constant during the early part of the period, it has nearly doubled since 1969. The recent rise has been much more rapid than the rise in prices generally, as indicated by the Consumer Price Index[2] which is also plotted in Figure 1 for comparison. Obviously then, saving fuel is becoming increasingly profitable and necessary.

This paper will discuss several of the areas where Shell is reducing fuel consumption at its refinery in Wood River, Illinois. Even though the Wood River Refinery is not new, it has been modernized over the years and is efficient in heat utilization considering its complexity. Nevertheless, the press to conserve energy within the refinery has been a continuing effort. The low relative cost of fuel that was prevalent in the past frequently prevented fuel-saving projects from being attractive. However, with the present higher fuel costs, many projects previously not attractive can now be justified. Since the energy-saving program was announced by Shell in 1972, a reduction in this refinery's fuel consumption of greater than 8% has been achieved.

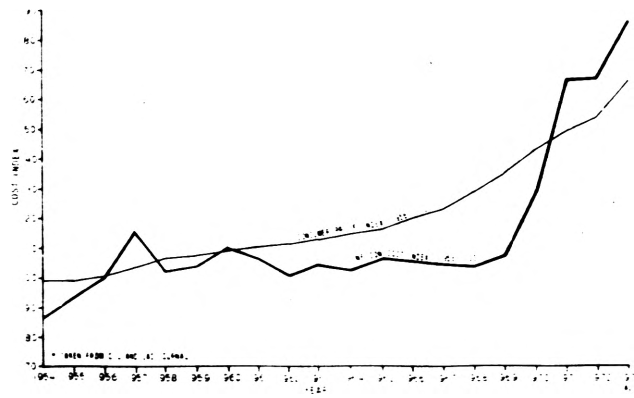

Fig. 1. Nelson Cost Index for refinery fuel.*

ADDITIONAL HEAT EXCHANGERS

One of the more significant ways in which heat economy can be realized in a chemical or petroleum refining process is by returning as much of the heat in the product streams to the feed streams as can be economically justified. As more heat is returned to the process, in general more heat exchange surface is required, and thus the capital cost of the plant is increased. As we have encountered rising fuel costs over the years, we have specified more and more heat exchange surface as each new processing unit has been constructed. An impression of the large amount of heat exchange surface that is being built into newer plants can be obtained from Figure 2. This picture shows the heat exchanger system for our newest crude oil distillation plant constructed at the Wood River Refinery about 5 years ago. As the size of this system suggests, very little heat is wasted in this plant.

A more affirmative indication of the trend toward more heat exchange surface can be seen in Figure 3. This shows how the design approach temperatures, that is, the difference in temperature between hot product streams and cold feed streams, have been lowered on 4 catalytic reformers constructed by Shell during the past 20 years. The first one, constructed in 1955, was designed for a 127°F approach while the most recent one, constructed in 1970, was designed for a 53°F approach. The newer plants are more heat efficient than the older plants. Of course, the capital costs of the newer plants are higher than they would have been if we had designed them to the heat recovery standards of 1955.

One might expect to find a number of opportunities for heat economies in a refinery or chemical plant by examining and reoptimizing the heat exchange systems of older plants using current economic values. Indeed, we have found this to be the case and we have developed a number of projects involving installation of additional heat exchangers on older plants. A typical example is shown in Figure 4. This is a schematic diagram of a lubricating oil vacuum fractionating plant which was constructed at the Wood River Refinery 16 years ago. The plant was designed originally for 13,500 barrels (bbl)/day feed rate, and as shown, some product to feed heat exchange was provided. Feed rate to the plant was later raised to 17,000 bbl/day, however, and the 250 Distillate product side stream draw was increased to twice design flow. As a consequence, its temperature increased 55°F. The product water cooler heat duty increased from 5,800,000 to 13,200,000 Btu/hour, a direct increased heat loss of 7,400,000 Btu/hour.

A design was developed to recover some of the heat wasted in the 250 Distillate water cooler. This is shown in Figure 5. A product to feed heat exchanger for the 250 Distillate stream was added between the two existing bottoms to feed exchangers. This point was selected because of the relative temperature of the hot and cold streams. With this new exchanger, about 7,000,000 of the 13,200,000 Btu/hour which had previously been lost to cooling water were recovered into plant feed, thereby reducing fuel to the furnace. Savings for the project was 13,400 bbl/year fuel oil, after taking into account furnace efficiency and overall plant heat balance. Using a conservative fuel cost of $4/bbl, the new exchanger produces a saving of $53,600/year. Its cost was about $25,000, installed.

Obviously, it was a very attractive undertaking to provide additional heat exchange for the lubricating oil vacuum fractionating plant. This is but one example, however, of quite a number of plants at the Wood River Refinery where new heat exchangers are being installed to recover waste heat. Many more are presently being evaluated as this is clearly an attractive means of saving fuel.

Fig. 2. Heat exchanger system - crude oil dist. plant

Fig. 3. Cat. reformer design approach temperatures

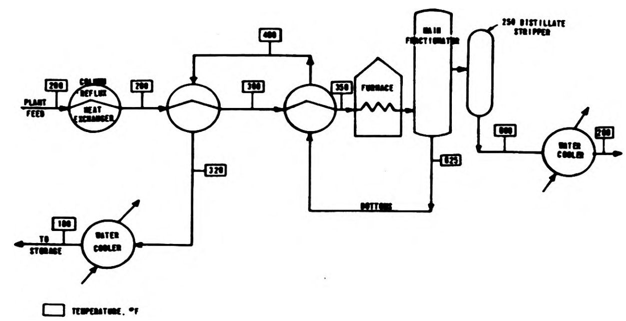

Fig. 4. Luboil vac. fract. plant - as designed.

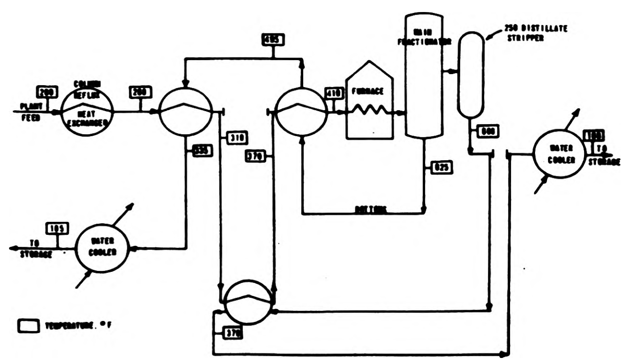

Fig. 5. Luboil vac. fract. plant - revised.

REOPTIMIZATION OF FRACTIONATING COLUMN OPERATION

Reoptimization of fractionating columns is another area attractive for realizing fuel savings. The cost of column operation depends greatly upon the cost of fuel, so certain Wood River Refinery columns optimized in past years at lower fuel values were no longer operating at the economic optimum. It was, therefore, timely to evaluate lower reflux to feed ratios and lower product separation cut points. Such changes can decrease the value of products from the column since lower reflux rates reduce sharpness of separation and lower product separation cut points remove less light material from the heavier products. However, these changes also require less heat input to the column and thereby save fuel.

While there are situations where a change in separation efficiency is unacceptable, in many situations a reduction can be tolerated. When this is the case, reoptimization of a column using current fuel prices will likely be beneficial. The most economical column operation is established at the point where net savings, measured as the difference between fuel savings credit and the lower separation debit, is the greatest. A picture of one column at the Wood River Refinery studied in this fashion is shown in Figure 6 (taller of the two).

This is a column which removes isobutane and normal butane from an alkylation plant product, with an additional sidedraw separation between isobutane and normal butane. The sidedraw, which is primarily normal butane, and the bottoms product are both cooled and routed to storage. The column tops, which is primarily isobutane, is recycled back to the alkylation reaction section.

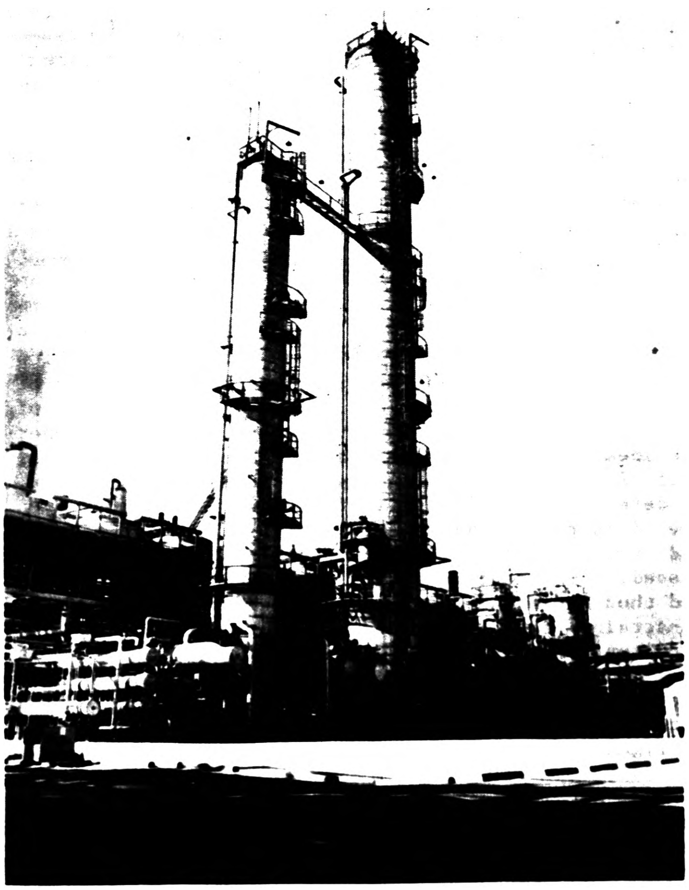

Fig. 6. Alkylation plant deisobutanizer column.

A simplified flow diagram of this system is shown in Figure 7. Normal butane is not desirable in the column tops because it acts as a diluent in the alkylation reaction section. This results in increased acid consumption and lowered alkylate octane number. Value of the column tops is therefore dependent upon its isobutane purity.

At lower fuel costs, this column had been optimized at a reflux to feed ratio of 1.25. The optimization study undertaken recently involved reducing both reboil heat and reflux rate to the column. This lowered fuel costs but decreased column tops value since normal butane in the tops increased due to lower separation sharpness. The economics of this study are presented in Figure 8.

These are plots of column tops isobutane purity versus dollars per day credits and debits. Reflux to feed ratios studied, ranging from 1.25 to 0.78, are shown above the plots. The only credit realized in this optimization was in fuel savings, which is represented by the fuel savings credit plot. A conservative fuel cost of $4/bbl was used. The product value debit plot was constructed using increased cost of operation in the alkylation reaction section. The net savings plot, which is simply the algebraic difference between the other two plots, increases rapidly as reflux rate is initially lowered but then peaks at about $210/day. The optimum range of operation selected was at a reflux to feed ratio corresponding to 88.5 to 89.5%v column tops isobutane purity. This column reoptimization resulted in a net profit of about $70,000/year while saving 40,000 bbl/year of fuel oil.

It was clearly profitable to have undertaken the study of this alkylation plant deisobutanizer column. Other columns at the Wood River Refinery have been reoptimized in this same fashion. In all cases, lower reflux rates or reduced product separation cut points have been profitable due to the higher current cost of fuel.

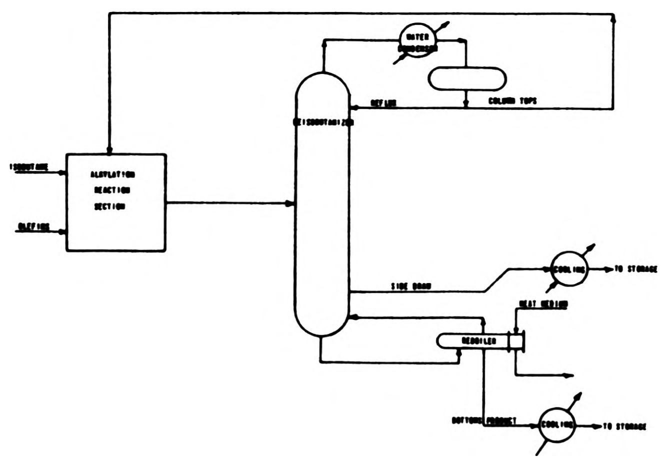

Fig. 7. Alkylation plant deisobutanizer system.

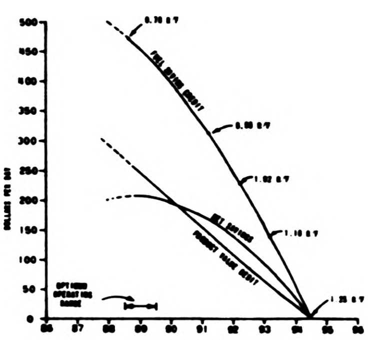

Fig. 8. Reoptimization of alkylation plant DIB col.

IMPROVED FURNACE EFFICIENCY

Fired process furnaces consume about 70% of the total fuel used in Shell refineries. As a result, much effort has been devoted to improvements in furnace efficiency. Potential improvements in this area are both mechanical and operational in nature. One mechanical possibility, for example, is prevention of heat losses by additional maintenance attention to furnace refractory, insulation, and air leakage into the furnace. Another mechanical possibility is installation of additional heat exchanger tubes in the upper part of the furnace just below the stack (convection section) to remove heat from stack gases into a useful service.

The primary operational opportunity of saving fuel in process furnaces is in improved firing techniques. Of course, all firing procedures must be conducted in such a fashion that smoking is prevented. Environmental regulations govern smoke emissions from furnace stacks. The present regulations for the Wood River Refinery require that a general stack opacity (resistance to light transmission) of 40% maximum be maintained. In May, 1975, this will be reduced to 30% maximum.

A large percentage of the fuel used at the Wood River Refinery is heavy residual oil, which is more difficult to fire optimally without smoking than gas. Regardless of the type fuel used, however, the task of firing a furnace is not simple as there are a large number of variables that must be considered. One step which can be taken to improve furnace efficiency from an operating standpoint is to provide adequate surveillance of the firing variables. Reviewing operating personnel in proper firing techniques and encouraging them to give appropriate attention to all firing conditions is very beneficial. Indications are that fuel savings of at least 3% at our refinery have been attained through closer surveillance of furnace operation.

Proper furnace operation requires an adequate supply of air, which enters the combustion chamber primarily via the furnace inlet air plenum and/or air shutters provided for each burner. Some air in excess of the stoichiometric amount is required in the furnace to achieve complete combustion. However, excess air must be kept at a minimum since the unnecessary air absorbs heat that would otherwise be available for heating the process stream. While operating with minimum excess air uses less fuel, it does increase the potential of smoke emissions because changes in operating conditions can quickly result in an air deficiency. Air flow into the furnace is typically controlled by adjusting a damper located in either the inlet air plenum or the furnace stack.

Closer surveillance by operating personnel, while very beneficial, still falls short of yielding optimum furnace operation. Automatic instrument control of the key firing variables is necessary to accomplish this. Shell has developed a ramp-type furnace combustion optimizer for this task. These optimizers can be used while firing either fuel gas or fuel oil. They also have a smoke constraint feature, which is controlled by furnace stack opacity.

The Shell ramp-type furnace combustion optimizer is essentially an excess air control device which operates by controlling damper position. A plot of fuel flow to the furnace and excess air versus damper position for a distilling plant furnace at the Wood River Refinery is shown in Figure 9. As the damper is closed from wide open, excess air in the furnace decreases and fuel usage falls rapidly. When the damper position reaches 25% open in this particular furnace, insufficient air is available for complete fuel combustion and less heat is thus transferred to the process. To try to make up for this deficit in heat, the process variable which controls fuel flow signals for more fuel and fuel usage increases.

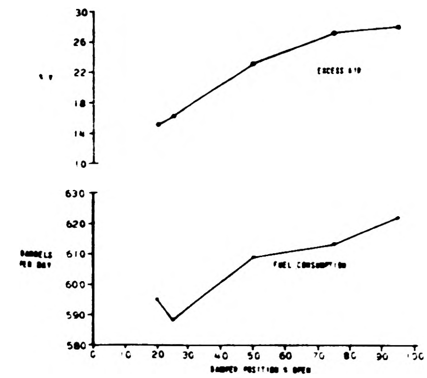

Fig. 9. Dist. furn. - fuel & excess air vs damper pos.

The Shell optimizer operation involves a continual adjustment in damper position with fuel flow as the measured variable. It operates on a change of fuel flow, however, and not on an absolute value of fuel flow. The optimizer strives to close the damper and does so slowly in a linear fashion (ramp) until fuel flow increases as a result of an air deficiency. It detects this increase in fuel flow and ramps open the damper a small amount. Fuel flow then decreases, and the optimizer again moves the damper toward closed. It continues back and forth in this fashion and thus optimizes fuel usage. There is a smoke constraint feature, however, which overrides the fuel flow control signal if necessary and keeps the damper from closing to the point where smoking occurs. The smoke detector is a laser beam opacity monitor, which detects smoke in the stack gas by measuring resistance to light transmission.

A section of the operating record for this optimizer on one of the furnaces at the Wood River Refinery is presented in Figure 10. At Time Zero, the optimizer is put into operation. Before then, the damper was manually set at 47% open with occasional low opacity readings occurring. The damper was quickly brought down to about 25% open, where it was

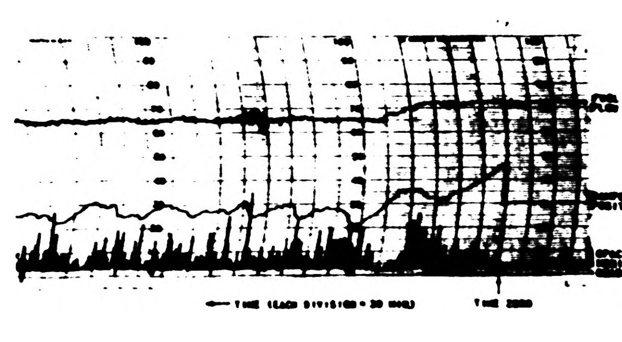

Fig. 10. Shell comb. optimizer record - dist. furn.

controlled over a relatively narrow region. As shown, the opacity readings were higher than for manual control. Since the optimizer continually monitors the stack gas for smoke, it can control the furnace near incipient smoking (minimum excess air) but still effectively prevent undesirable smoke emissions. Fuel usage with the optimizer in service dropped from 72.0 on the operating record to 65.5, or a reduction of about 9%.

It is estimated that this optimizer yields 5-10% fuel savings beyond that realized by closer surveillance alone. Attention by operating personnel is still required, of course, to give attention to aspects of proper firing other than fuel flow, damper position, and smoking. It is important when using this optimizer to insure that uncontrolled air leakage into the combustion chamber has been minimized. If too much air enters the furnace in this fashion, damper control for optimization will not be as effective. Of course, air leakage is never desirable for efficient furnace firing.

One of the distillation plants at the Wood River Refinery has an application in which these optimizers are particularly useful. There are five furnaces in this plant, and the stack gases from each flow into a common stack. If smoke emits from the common stack, it is difficult to tell which furnace is not firing properly. Operating personnel properly tend to be conservative in firing these large furnaces. They would generally operate with more excess air in all the furnaces to insure that smoking doesn't occur, which, of course, leads to reduced firing efficiency. With the Shell optimizer, each furnace can be individually optimized while preventing smoking via a smoke constraint device in its own flue gas.

A Shell optimizer has been installed on one of the furnaces in this plant, and installation on two others is being done. The one which was installed is saving about 7,000 bbl/year fuel oil above that saved by closer surveillance alone. Cost of the optimizer is in the range of $10,000-$15,000.

SUMMARY

This paper has presented three areas in which our refinery is very active in reducing energy consumption. They are not unique to petroleum refining, and the principles can be applied in many process industries. With today's energy shortage, it is essential for industry to conserve energy by the techniques mentioned here or in other fashions. It is also essential that we as citizens do our best in energy conservation at home, in commercial buildings and small businesses, in transportation, and in the general conduct of our everyday living.

REFERENCES

(1) "Nelson Cost Indexes", Oil & Gas Journal, page 78, January 7, 1974.

(2) "Prices", Economic Indicators, page 26, December, 1973.