better controls in the plants, we decided that computer controlling is a must for the purpose of obtaining the stable quality we need. The best way to get improved quality is to combine all the possibilities for better process control. Those advantages include reducing the amount of utilities such as steam, electricity, water and so on in variable expenses, as well as labor saving by reduction of manpower. We have 5 series of large scale facilities, which are operated continuously for 24 hr in three shifts. Since installing this electronic controlling system using operation know-how accumulated from long experience, all processing equipment has been controlled by this system through instruments, various sensors, controllers and so on. All an operator now has to do is watch the controlled status mainly by patrolling. Thus, switching the oil variety can be accomplished in the best operation procedure without loss. For example, even when the operators change shifts, fluctuation of the operation can be avoided completely. Furthermore, as another excellent characteristic of this system, accumulated data in the past several hours can be confirmed visually as a graph on the display for review whenever any question arises in the process. When something abnormal has happened, the source of trouble can be traced easily. This contributes greatly to the uniform quality of the products. Conventional automatic facilities are very useful in producing uniform quality products. However, they are not good enough when a change of operational conditions is required by automatically interlocking to other controllers organically due to different oil qualities or other external factors. These defects can be covered adequately by the computer controlling system. Operational conditions will have to be changed in various ways for production of a uniform quality from variable raw materials, and if such change is made erroneously, the quality of the final products fluctuates as a result.

These changes in our plants required approximately 5 years to implement, and most difficulties have been overcome by the efforts of the technical operators, who are the operators, and at the same time the electronic technicians and technical analysts. The highest level of production quality is obtained by their prompt action and their wide knowledge in processing, electronics and technical analysis.

Energy Considerations

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ABSTRACT

A general survey is given on possibilities for energy conservation in an oil refinery with special consideration given to palm oils and coconut oil. Some selected areas are discussed more in detail: heat conservation by means of regenerative heat exchangers, optimization of vacuum equipment for deodorization etc. and use of heat pumps. Some examples are given to illustrate possible savings and payback time for installation of energy saving equipment.

INTRODUCTION

The rising energy costs experienced throughout the world over the last 10-15 years have made energy the major single processing cost for a number of refiners. In some cases investments in energy-saving equipment can have payback times calculated in months or even weeks.

However, there is no single set of measures that can be taken, as these will vary from country to country and even from plant to plant. What can be done is to give broad outlines of measures that can be applied within the oil refining industry, although these will have to be related to specific situations.

SOME THEORETICAL VIEWS ON ENERGY TRANSFORMATIONS

It is well known that according to the first law of thermodynamics energy can be transformed from one form into another, but it cannot be created or destroyed. It is therefore somewhat contradictory to talk about energy savings. By using the concepts of enthalpy, free energy, entropy, etc. it is possible to get quantitative measures of energy transformation and quality of different kinds of energy, but in practice it is not so easy to use this for engineering calculations. An easier way to understand what happens when energy transformation and transportation occurs is to utilize the concept of exergy and anergy, which was introduced about 20 years ago. This alternative to conventional thermodynamics has been further developed by Kaiser, Grassmann and others (1,2).

According to this theory all kinds of energy can be considered as being composed of two complementary parts, which are called exergy and anergy. Exergy is the fraction which can be used for work while the other part, the anergy, is of inferior quality and of little interest in engineering except in special cases (e.g., for heat pumps). In all processes energy is not consumed, but exergy is to a larger and smaller extent transformed into anergy, and it is desirable to minimize this transformation as far as possible.

COSTS OF DIFFERENT KINDS OF ENERGY

Only two kinds of energy are considered here – heat energy (in the form of steam) and electrical energy. Electrical energy is one of the more noble forms of energy (high exergy and low anergy) and is also often (but not always) more expensive than heat energy. The cost of electrical power in some European countries is shown in Figure 1. The big difference in costs is due to the method of production. In Norway practically all electricity comes from hydroelectric power stations, in Sweden, from hydroelectric and nuclear plants, and in Germany and Holland mainly from plants powered by fossil fuels such as coal, oil or gas.

In most cases steam is produced in boilers fueled either by fossil fuels or by locally available fuels such as sunflower husks or waste from palm-oil mills. The relative cost of steam compared to electrical energy is of great interest when designing a system to optimize plant energy costs.

Figure 2 shows this relationship for a number of countries and clearly demonstrates that the optimal solution will vary from land to land. It will even vary from area to area as shown by the two figures from India, one based on steam generated from oil and the other on steam from coal. Such considerations now determine whether vacuum should be raised by steam ejectors or vacuum pumps.

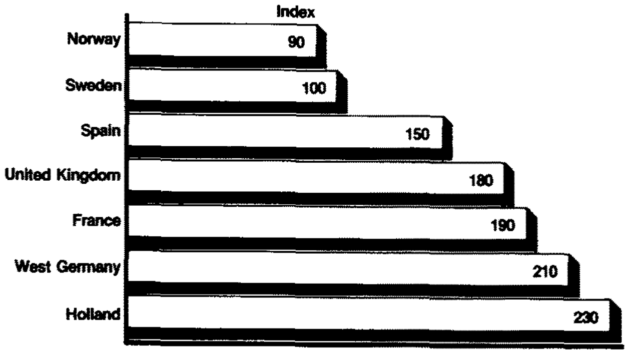

FIG. 1. *Relative costs of electricity in some European countries.*

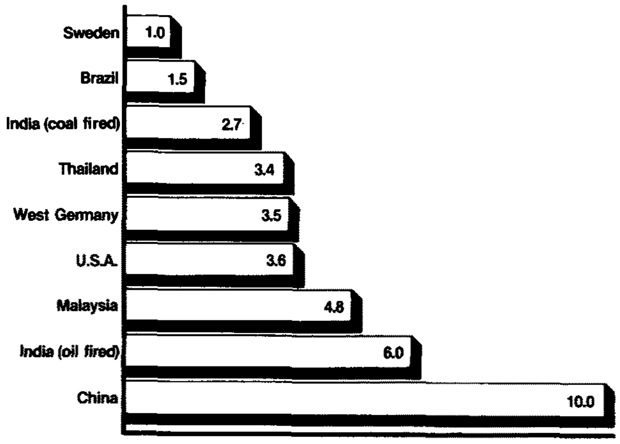

FIG. 2. The cost of steam compared with the cost of electricity.

1. By design of plants

- **1.1 Reducing the unit production cost of steam and electricity**
- **1.2 Heat regeneration *within* a single process or external heat regeneration (storage of heat energy).**
- **1.3 Optimization of vacuum units (heat pumps)**
- **1.4 Extraction of heat from effluents**
- **1.5 Optimization of transport and regulation of fluids.**
- **1.6 Minimizing of heat losses by good insulation**
- **1.7 Design of continuous processes**

2. By optimal operation of plants

- **2.1 Running at optimal (design) capacity**
- **2.2 Effective energy management**

FIG. 3. Selected means of minimizing energy consumption.

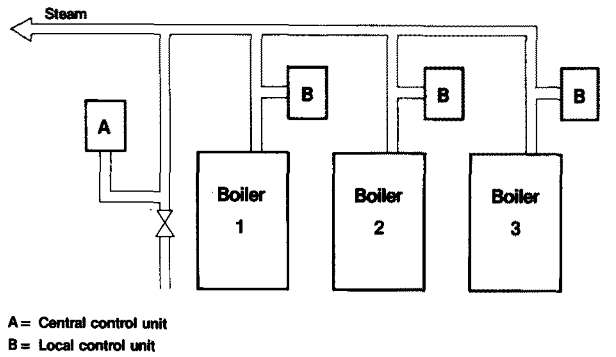

FIG. 4. A modular system for steam production. A = central control unit; B = local control unit.

SURVEY OF ENERGY-SAVING MEASURES

Some important methods of energy conservation are summarized in Figure 3. Most of the measures are connected to the design of the plants (1.1-1.7) and the rest (2.1-2.2) on how the plants are to be operated. Each of these measures is discussed below, some with numerical examples.

Reducing Production Cost of Steam and Electricity

In most cases, steam is produced within the refinery in a boiler fired by a fuel which is determined by the local conditions. Normally, the boiler (one or two) has a large overcapacity compared to normal operating conditions in order to cover peakloads. This means that during long periods, the boiler is running below its optimal load, which means low efficiency and a higher unit cost for the steam. This can be overcome by installing smaller boilers (normally three or four) working in parallel as an automated modular system controlled by a microprocessor according to Figure 4 (3). The difference in efficiency between one big boiler and several small boilers is illustrated in Figure 5. At low steam demand, only one boiler is in operation and the others are on standby. When the load goes above the maximal production of one boiler the next is automatically started and so on. The system just described produces steam at a lower unit cost and is also said to have advantages from a maintenance point of view.

The maximal steam pressure needed in a refinery is normally limited to 12-15 bar, which pressure is adequate as motive steam for vacuum units and for heating oil up to about 180 C. When a new boiler is to be installed, it might be appropriate to investigate the installation of a combined heat/power generation system such as that shown schematically in Figure 6. In this case one ton of superheated steam at 33 bar is used to generate 27 kWh of electricity while reducing its pressure to 15 bar. In most cases the cost differential between generating 33 bar and 15 bar steam is far less than the cost of 27 kWh of electrical energy.

Energy Conservation by Simple Heat Exchange

One of the easiest ways to reduce the energy consumption in many installations is to install heat exchangers for heat

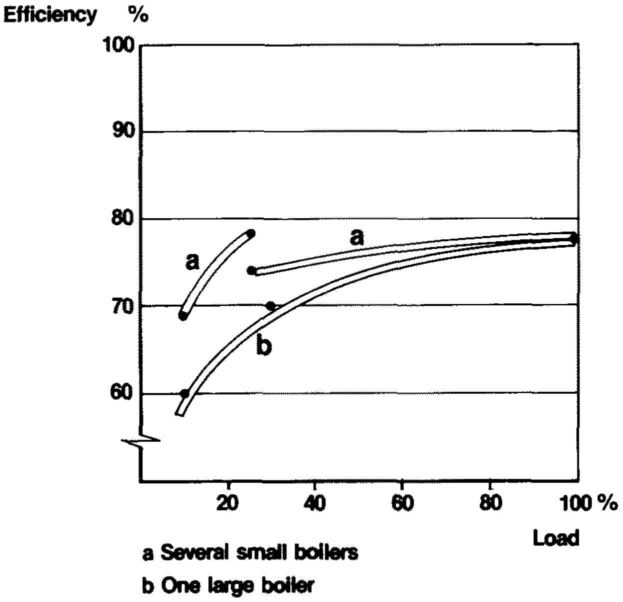

FIG. 5. The efficiency of steam boilers. Line a represents several small boilers; line b represents one large boiler.

recovery. This can be done either within a single process stage or over a complete process line from crude oil to the end product.

Figure 7 shows a simple example of heat recovery in a process in which the oil has to be heated during processing and cooled down again after processing. The incoming oil is first heated regeneratively by hot processed oil in a PHE (I) and then further heated in PHE (II) to the desired processing temperature using steam, hot water, etc. The temperature program given in the figure is typical for palm or coconut oils. It is possible to reduce the heat load further in the heater II by increasing the heat transfer surface in the regenerative heat exchanger I. By doing so the heat exchanger I will cost more, the heater II will cost less and the total pressure drop (and therefore also the pumping cost) through the system will increase. With actual prices for steam, power and capital depreciation available, it is easy to design the system to minimize total costs.

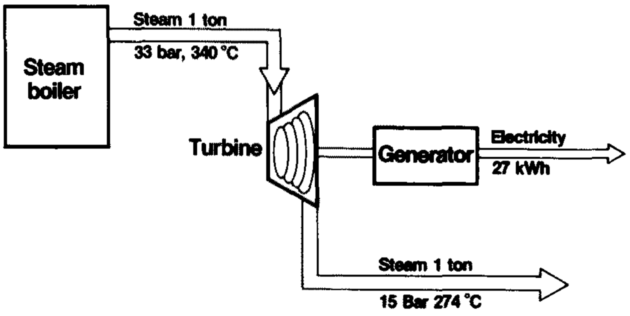

FIG. 6. Combined heat and power production.

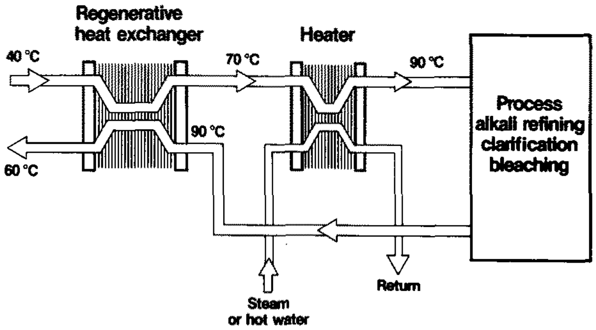

FIG. 7. Heat recovery in a palm oil processing plant.

Heat Recovery in a Fractionation Plant

Figure 8 shows an example of heat recovery within a plant for fractionation of fats and oils. In the wet fractionation process an aqueous solution is used to improve olein/stearin separation, and this solution is recirculated in a closed loop in the plant. As the aqueous solution in one part of the process has to be at a lower temperature (+5 to +30 C, depending on the nature of the oil or fat) and in another part of the process at a higher temperature (about 90 C), it is obvious that a regenerative heat exchange will very much reduce the energy costs for this process.

For the applications just described plate heat exchangers are used. These units are characterized by a high heat transfer coefficient in combination with a low pressure drop, and they can also be easily enlarged by addition of more plates if the plant capacity is to be increased.

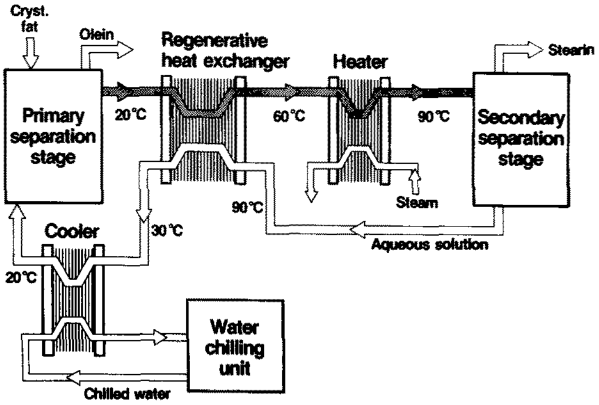

FIG. 8. Heat recovery in a plant for wet fractionation of fats and oils.

Heat Recovery in Deodorization

Considerable amounts of heat energy are stored in a deodorized oil at a temperature of about 220-250 C, and in order to get overall low energy consumption it is necessary to utilize this energy, which can be done in many ways. The simplest way is to transfer part of the heat energy to the ingoing oil by means of a heat exchanger as previously described. It is also possible to cool the oil in a suitable heat exchanger by means of vaporizing water to produce low-pressure steam, which can be used as motive steam for vacuum production.

Final cooling of deodorized oil from about 100-120 C down to storage temperature (40-50 C for palm oil) is often carried out in a heat exchanger using cooling water, but the heat energy is then not normally recovered. However, by correct sizing of the heat exchanger it is possible to produce hot water, which can then be further used as a heating medium. These two alternatives are shown in Figure 9.

Another alternative is to use a heat pump as shown in Figure 10. There are now available on the market heat pumps of special design and utilizing R 114 as refrigerant for upgrading heat from 40 C to low pressure steam of 105 C with a coefficient of performance of 2.5. It is easier to recover heat in continuous processes, but it is also possible to recover heat in semicontinuous deodorizers as discussed by Weber (4).

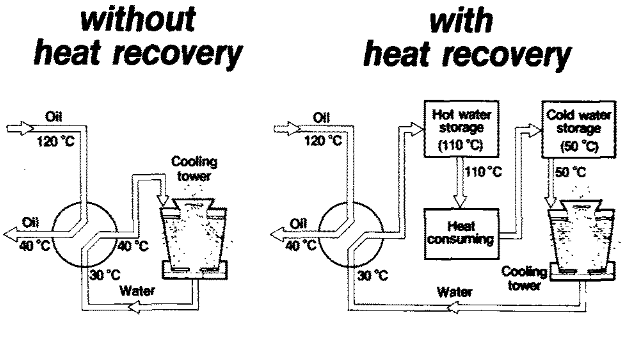

FIG. 9. Oil cooling, with (right) and without (left) heat recovery.

Heat Recovery at Hydrogenation

Hydrogenation is done at 150-200 C. To reach this temperature it is natural to make a heat exchange between the ingoing cooled oil and the outgoing hot hydrogenated fat.

A suitable arrangement for this heat recovery is shown in

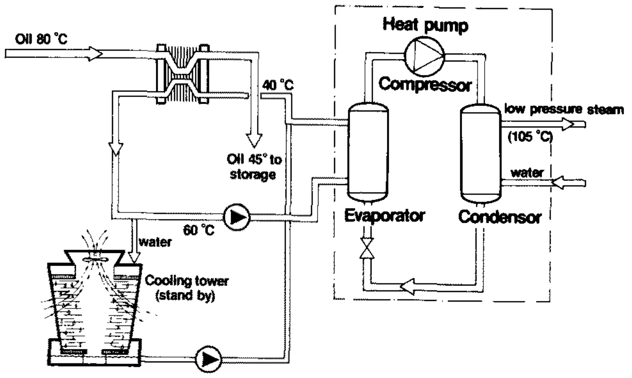

FIG. 10. Heat recovery by means of a heat pump.

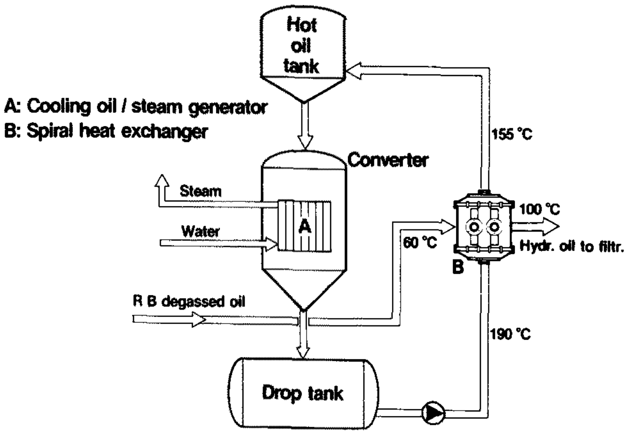

FIG. 11. Heat recovery in a hydrogenation plant.

Figure 11. Refined, bleached and deaerated oil at 60 C is pumped at a fixed throughput via the heat exchanger SHE where it is heated to 155 C and into the hot oil tank. The heat energy is delivered from the hot (190 C) hydrogenated fat, which is pumped at the same fixed throughput in the other channel of the heat exchanger and cooled to 100 C on its way to the catalyst filter. If the massflow is the same on both sides in the heat exchanger, the temperature increase on the ingoing oil side is somewhat larger than the temperature decrease on the hydrogenated oil. This is because the specific heat of the hydrogenated fat is somewhat higher than that of the oil.

The heating and cooling just described is often done batchwise at the same time as another batch is being hydrogenated. If the hot oil tank and the drop tank each have a volume about twice that of the converter volume, then the cooling and heating can be made continuously, which has several advantages: the pumps and the heat exchanger can be smaller in size and it is easier to regulate the oil/fat flow to get maximum heat exchange.

When choosing the type of heat exchanger the following requirements should be observed:

- It must be easy to empty,
- It must be easy to clean, and
- Clogging by catalyst should not occur.

The above requirements are best fulfilled by spiral heat exchangers (Figure 12), which are characterized by having only one channel for each liquid. This permits a perfect counter-current flow and minimizes the risk for stagnant zones, which is important to prevent clogging by catalyst in the hydrogenated unfiltered fat.

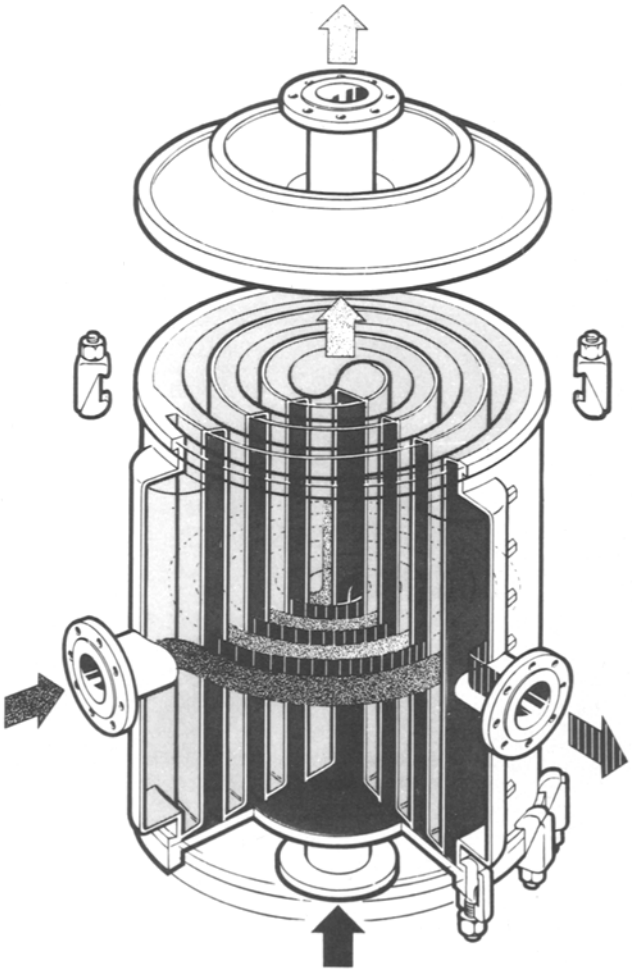

FIG. 12. A spiral heat exchanger.

Hydrogenation is an exothermic reaction, the heat generated raising the fat temperature approximately 1.6 C for each unit drop in iodine value (I.V.). When hydrogenating for large I.V. drops such as hydrogenating palm oil down to I.V. 2, the heat rise can be up to about 90 C and it is necessary to remove this heat during the course of the reaction. As the temperature is above 150 C it is possible, as indicated in Figure 11, to produce low-pressure steam, which can be used elsewhere in the refinery.

Energy Conservation at Vacuum Production

In many stages of fats and oil processing vacuum has to be used, such as drying of oils, in bleaching and naturally in both deodorization and physical refining. The operating cost for vacuum production is a major part of the total processing costs, and substantial savings can be accomplished by good design.

A multistage steam ejector system has, when once designed, a fixed suction capacity, which cannot be varied with changing load. It is therefore important that the size of the equipment is neither over- nor underdimensioned for the intended plant capacity. In cases where there will be large changes of suction load in a specific plant, it is possible to install a vacuum system consisting of several parallel working units or parts of units, which can then be operated or not, depending on the momentary suction load.

The temperature of the cooling water to the condensers has a large influence on the steam consumption of the

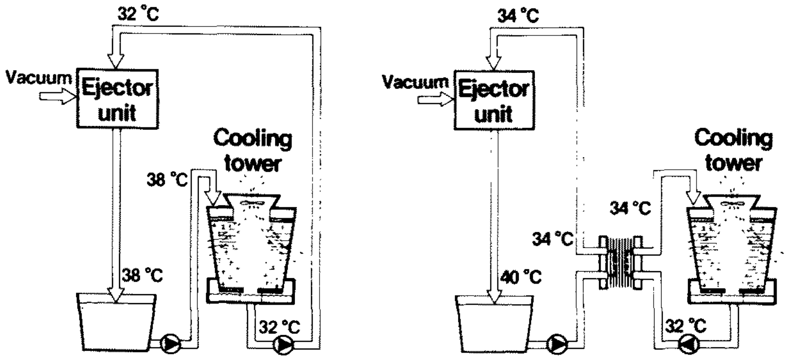

FIG. 13. Direct (left) and indirect (right) cooling of barometric water.

Suction load: Steam 102 kg/h Vacuum: 2.5 torr
Air 10 kg/h Steam press: 3 bar G

Cooling water temp	26 °C	16 °C
Cooling water flow	76 m^3/h	47 m^3/h
Steam consumption	630 kg/h	360 kg/h
Power consumption for pumps	17 kW	12 kW

FIG. 14. Relationship of cooling water temperature and energy consumption for vacuum production.

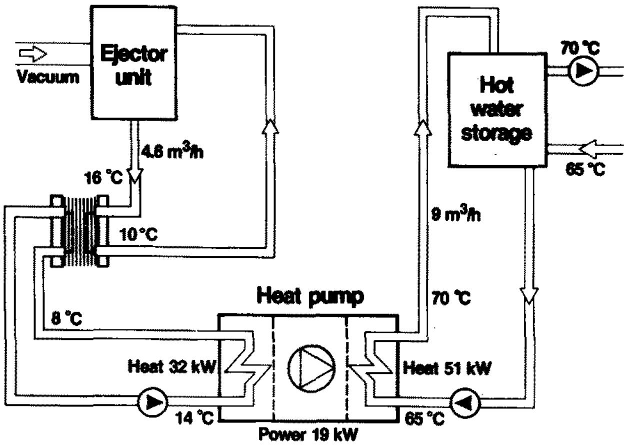

FIG. 15. Heat pump for cooling of barometric condensor water. Figures correspond to $1\ m^3$/hr oil.

steam ejectors. In tropical countries the cooling water (from a cooling tower) often has a temperature of 30-35 C when entering the condenser, in which the temperature is then raised 5-7 C before the water is once again cooled in a cooling tower and recirculated either directly or indirectly according to Figure 13.

It is, however, possible to cool the recirculated water with a conventional refrigerating unit down to any temperature even as low as 2 C. The lower the cooling water temperature, the lower is the steam consumption of the ejectors, but at the same time the energy consumption for cooling the water increases (5).

This is illustrated by the data in Figure 14, where at a certain load the amount of motive steam for the vacuum unit, as well as the water and power consumption, is decreased considerably when the temperature of the cooling water is decreased from 26 C to 16 C. In the last stage of the vacuum unit the steam ejector has been replaced by a water ring pump. The lower power consumption at the lower water temperature is due to the lower volume of cooling water.

In order to get the desired suction pressure of 2.5 torr it is necessary to use a double booster for the 26 C water, but for the 16 C water a single booster is sufficient. The difference in design and size of some items in the two units compared is the reason for the approximately 20% lower price for the unit using 16 C cooling water. For a total economic evaluation one must, of course, also consider the costs for producing the 16 C water.

The total minimal costs (operation and capital costs) are normally obtained around a temperature of 10-15 C of the outgoing water from the refrigerator. In order to get a good economy it may be essential to utilize the heat released from the refrigerating unit, e.g., it is working as a heat pump. Figure 15 shows how such a heat pump can be integrated into a deodorizer unit. The data given correspond to deodorization of one ton of oil. In this case chilled water at 10 C is fed to the main condenser, and is raised to 16 C in the condenser, and then recooled to 10 C in a plate heat exchanger using chilled water at 8 C as the cooling water. This 8 C water is produced in a refrigeration unit (= heat pump), which releases the transferred heat to hot water storage at 70 C. In many cases the energy in this hot water can be used to replace low-pressure steam, for heating oils in storage tanks, or heating boiler feed water. The heat energy transferred per one ton of deodorized oil is 32 kWh from the chilled water with a compressor work of 19 kWh and consequently 51 kWh of heat energy is produced, e.g., the coefficient of performance (C.O.P.) of the heat pump is in this case 51 ./. 19≈2.6-2.7.

In cases where there is a large difference in cooling water temperature between day/night or summer/winter, substantial savings of steam to the ejectors can be made by installing a device which throttles the steam flow when the water temperature decreases (5).

OPTIMIZING OF TRANSPORT AND REGULATIONS OF LIQUIDS

A large part of the power used in an oil refinery is used for operating pumps for moving oil, water and other liquids. It is common practice to feed liquids by centrifugal pumps, giving a higher pressure than needed and then regulating the flow by means of a throttling valve, either manually or by a closed loop controller. The pressure drop in the regulating valve represents an energy loss (high-quality mechanical energy is transformed into low-quality thermal energy). A more energy-saving system is to use positive pumps like screw pumps or piston pumps, where the flow is regulated by changing the pump speed or length of stroke.

FURTHER ENERGY-SAVING MEASURES

A number of measures to save energy are so obvious that they are mentioned without further comments:

- Insulate equipment to minimize heat loss with the surroundings,
- Stop all leakage of steam, water etc.,
- Regulate speeds of fans etc. to requirements,
- Utilize released heat from air conditioning for production of hot water.

Energy consumption can also be influenced by the way of operating the plants. The ideal case is to run a plant continuously at design capacity. Continuous processes as such are normally less energy-consuming compared to semicontinuous or batch processes, since starting and stopping of a processing plant involves some additional energy consumption. Further, larger plants normally have a somewhat better "energy efficiency" (e.g., a lower energy consumption per unit of oil processed) than smaller plants.

REFERENCES

1. Grassmann, Verfahrenstechnik, 13:28 (1979).
2. Kraiser, V., Chemical Engineering, 23 Febr:61 (1981).
3. Krug, H.J., Fette, Seifen, Anstrichmittel, 86:162 (1984).
4. Weber, K., Ibid. 86:1. Sonderheft, 547 (1984).
5. Gehring, Ibid. 83:519 (1981).

Session IV Discussion

The following questions, answers and comments were presented during the informal discussion held at the end of the day's plenary presentations.

Q: There are literally several hundred carotenoids classified separately as hydrocarbon carotenes (hydrophobic carotenoids) and hydroxylated carotenes (xanthophylls). When you talked about "β-carotene" or "carotene" analysis, what exactly do you mean?

Swoboda: Reference to carotene or β-carotene in CPO is by convention an analytical definition based on the spectrophotometric measurement of light absorption at 446 nm. The experimentally determined absorbance calculated for a 1% by weight solution of the oil in hydrocarbon solvent is then multiplied by 383 parts per million (ppm) of carotene. This procedure therefore does not give any information about the chemical structures of the carotenoids present, nor does it measure colorless phytoenes.

Q: Regarding palm oil pre-treatment for physical refining, please comment on: the necessity of use of calcium carbonate to neutralize excess mineral acidity, and the advantages in "wet degumming" using water hydration of gums and centrifugal separation, over the normal phosphoric acid degumming. (Our palm oil is of low quality: 10% FFA, 70 ppm phosphorus, 20 ppm iron.)

Swoboda: During pre-treatment both calcium carbonate and "wet" degumming have been recommended. My own investigations suggest that the former is useless and variations of the latter have tremendous potential. Investigations at PORIM show that calcium carbonate has very little activity either in the removal of phosphoric acid or in the adsorptive cleansing of the impurities from the CPO. Maybe the surface of the insoluble calcium carbonate becomes coated with insoluble calcium phosphate. In the factory calcium carbonate may have some function as a filter aid. Wet degumming or water washing after phosphoric acid conditioning is, by contrast, extremely efficient at removing the acid. Results on the removal of impurities depend on conditions used, but always enhance the effectiveness of the further treatment with bleaching earth. Much effort currently is being directed to the improvement of the degumming process.

Q: Can you explain why with liquid-liquid extraction the final extracted oil gives a blue tint in color measurement?

Swoboda: This question is based on a misunderstanding of my presentation maybe because I was not lucid enough. The table in question shows the Lovibond colors after a thermal bleach "break" test of CPO which has been subjected to a variety of liquid extraction treatments. The results show three effects: that when using alcohol; that when an aqueous solution is used, and the additional benefit of caustic soda. It is only with the CPO and with the raffinate from extraction with alcohol that a brownish color is formed that requires the use of blue as well as red and yellow for color matching in the Lovibond. When the SCOPA bleachability test is used, alcohol extraction alone is sufficient to improve the bleachability of good quality CPO. However, with deteriorated oils an alkaline washing also is required. The latter also most efficiently reduces the phosphorus and iron levels.

Q: Could the speaker expand on the discussion of the "refinery of the future" referred to in his paper? Specifically, please indicate likely process conditions for the steps of raffination, alkali washing and deodorization? What oil color could be expected to result from such an installation? Please specify the chemical types of impurities removed at each of the three steps.

The process of liquid extraction of color components which are finally removed by alkali in the processing of palm oil is very interesting, considering the possible avoidance of earth bleaching. Could you elaborate on the possible application to tallow bleaching of liquid extraction processing?

Would not the factors "involving" selection of solvent, i.e. inertness to increasing impurities; safety, and condensibility to avoid pollution, render the process economically nonviable?

Swoboda: In discussing the possible future development of the refining process it is not possible to give precise specifications or costings. With the limited experience available it also is not possible to predict exactly how efficient a particular process will be with poor quality or alternative feedstock such as tallow. With average CPO it should be possible to achieve a processed palm oil of maximum color 1 red 10 yellow in a 5.25 inch Lovibond cell. Improvements in physical and alkali refining of palm oil will occur as well as the possible adoption of new processing based on liquid extraction. The operations which need to be optimized for palm oil are "degumming" and bleaching earth performance. For extraction processes, the azeotropes of either ethyl or isopropyl alcohol are the most suitable solvents from the point of view of safety and convenience in an industrial environment and also least likely to give problems with the quality of the product.

Q: Can you specify the starting quality parameters of the crude palm oil and stearin used in tests with various clays? How does effectiveness vary with crude oil qualities? What is the difference in a "more highly activated clay" that makes it suitable for poor quality crude? Can you comment on the formation of conjugated double bonds during bleaching?

Shaw: The characteristics of the crude palm oil and stearin are given in the paper. If we can consider there is an "active" center in a bleaching earth which is capable of absorbing either a pigment or metal soap, we can increase the number of available active sites in two ways. By using larger quantities of bleaching earth or by using an earth having a higher frequency of sites in a more highly activated clay. For poor quality crude oils where we have higher levels of impurities to remove, again we can imagine an increase in the concentration as required by using larger quantities of more active bleaching earths. The reactions occurring on the bleaching earth are a combination of absorption and catalytic processes such as isomerization. By choice of correct bleaching temperature and bleaching earth activity, absorption will occur preferentially.

SESSION IV DISCUSSION

Q: Can bleaching earths of different levels of acid activation influence the color stability of refined bleaching deodorized palm oil? If so can you briefly describe the color reversion mechanism?

Shaw: We have found using our products that color stability does not deteriorate when the products are used under standard conditions of temperature and bleaching earth contact time. Color reversion is possibly caused by polymerization of low molecular weight pigments occurring at a faster rate than their removal by absorption.

Q: Can you bleach crude palm oil under atmospheric condition and get a color of 3.0R max? What are the potential disadvantages of atmospheric bleaching of palm oil?

Shaw: By increasing bleaching earth dosage level under atmosphere conditions a color of 3 red can be obtained. However, under atmospheric conditions there is danger of damaging oil by oxidation.

Comment: Regeneration of bleaching earth first is an uneconomical proposition and would produce a bleaching earth of poor performance. Processes are required to remove residual oil, carbonized pigments, copper, iron and phosphorus.

Q: Is there a difference in eliminating flavors (real deodorization) and deacidification? Are they going together or separately and which first?

Stage: Flavor compounds are more volatile than fatty acids. Therefore, they distill off together with fatty acids during deodorization.

Q: For deodorization, do you think there is a need for a holding time to complete chemical changes in the oil (not associated) to strip of volatile compounds?

Stage: Practically no retention time is needed with our system of deodorization.