LOW ENERGY DISTILLATION SYSTEMS

R. Katzen, W.R. Ackley, G.D. Moon, Jr., J.R. Messick, B.F. Brush, K.F. Kaupisch

Raphael Katzen Associates International, Inc.
1050 Delta Avenue, Cincinnati, Ohio 45208

ABSTRACT

Much work, aimed at improvements in the manufacture and recovery of ethyl alcohol, is currently being conducted in connection with the production of substitute liquid fuels; e.g., Gasohol. A primary consideration in all schemes for producing substitute liquid fuels lies in the energy consumed to produce the fuels. By energy re-use, pressure cascading and waste heat recovery, the expenditure of energy in distillation (alcohol recovery) can be greatly reduced. Such energy savings have been industrially demonstrated in three systems described in this paper. For high grade industrial ethanol production, a steam consumption of 3.0-4.2 Kg/liter (25-35 lb/U.S. gallon) of 100° G.L. alcohol is realized. For motor fuel grade anhydrous alcohol, the steam consumption is 1.8 to 2.5 Kg/liter (15-20 lb/U.S. gallon) of 99.5° G.L. alcohol, and for hydrous motor fuel grade alcohol, the steam consumption is 1.2 to 1.4 Kg/liter (10-12 lb/U.S. gallon) of 96° G.L. alcohol.

ALCOHOL DISTILLATION

Over the past two decades, Raphael Katzen Associates International, Inc. has developed a series of highly efficient alcohol distillation systems for recovery of various grades of ethyl alcohol from synthetic and fermentation feedstocks. For each of these systems, the prime goal is minimization of energy consumption.

The RKAII distillation system for production of high quality spirits or industrial grade alcohol, uses a four tower distillation train. The product is first quality neutral spirits at 96° G.L. (192° U.S. proof) ethanol. When the crude ethanol feed is obtained by the synthetic process, e.g., direct hydration of ethylene, only 3 towers are required. For motor fuel grade alcohol, where a high quality product is not necessary, simpler abbreviated systems are used to reduce investment and operating costs.

PRODUCTION OF 96° G.L. HYDROUS INDUSTRIAL ALCOHOL

The distillation system is shown in Figure 1 (1, 2). The process has been successfully operated commercially with four different fermentation feedstocks, namely, molasses, grain (corn or milo), corn wet milling middlings, and sulfite waste liquor. In addition, it has been operated with an ethylene-based synthetic crude.

Beer from the fermenters, containing approximately 6-8 wt % alcohol and 8-10% total solids (suspended and dissolved) is preheated to near saturation temperature and fed to the beer still. An overhead condensed product, at 75-85° G.L. (150°-170° U.S. proof) is taken to the high wines drum, and the bottoms liquid (stillage), containing not more than 0.02 wt % alcohol, is treated further for animal feed production.

The high wines distillate from the beer still is mixed with recycled alcohol from the concentrating tower and the combined stream is fed to the extractive distillation tower.

The extractive tower is designed to separate substantially all impurities; aldehydes, esters, and higher alcohols from the ethanol. The extraction technique relies on the volatility inversion of the higher alcohols with respect to ethanol in solutions containing high concentrations of water. The net result is that a substantially pure ethanol/water mixture is removed from the bottom of the extractive tower while the impurities are taken overhead.

Dilute alcohol from the base of the extractive tower is stripped and concentrated to product strength in the rectifying tower. A heads purge is taken from the overhead condensate. Product ethanol at 96° G.L. (192° U.S. proof) is withdrawn near the top of the rectifying tower, and a water stream, containing trace amounts of alcohol, is discharged from the base. Heads and side draw fusel oil purges are fed to the concentrating tower to prevent any buildup of impurities in the rectifying tower. The overhead stream from the extractive tower also is fed to the concentrating tower. Heads and fusel oil are concentrated in this tower and removed from the system, with the recovered alcohol being recycled to the extractive tower.

Steam economy is achieved by multi-stage preheating of beer feed, and by operating the extractive and concentrating towers at higher pressures. The overheads from these pressure towers supply thermal energy to the reboilers of the rectifying tower. Such pressure cascading results in a 30 to 50% reduction in virgin steam.

The key features of the RKAII high quality alcohol distillation system are:

1. Extractive distillation accomplishes a higher degree of impurity removal than is possible in more conventional systems. Product ethanol contains only 20-30 ppm of total impurities.

2. The use of pressure cascading permits substantial heat recovery and re-use. In the system described above and in figure 1, the extraction tower and concentrating tower are operated at a pressure higher than the rectifying tower. The overhead vapors

from these pressure towers supply thermal energy to the rectifying tower reboilers. By operating in this manner, the steam usage is kept to a minimum. Commercial facilities using this pressure cascading technique, show steam usages of only 3.0 to 4.2 Kg of steam per liter (25 to 35 lb/gal) of 96° G.L. (192° U.S. proof) ethanol compared to 6.0 Kg/liter in earlier conventional systems.

3. Substantially all (95 to 98%) of the ethanol in the crude feed is recovered as first grade product.

4. Design of highly efficient tower trays permits high turndown capability. These trays are designed to be self-descaling in the stripping section of the beer towers.

5. A highly advanced control system, developed through years of experience, provides for sustained stable operation, with only part-time attention of an operation required. Product quality is maintained with less than 30 parts per million of total impurities. Permanganate time is in excess of 60 minutes.

PRODUCTION OF ANHYDROUS (99.5°-99.98° G.L.) ALCOHOL

Anhydrous alcohol is produced by azeotropic distillation. A high grade product of 99.98° G.L. (199.96° U.S. proof) concentration is produced for use in food and pharmaceutical aerosol preparations. A product of 99.5° G.L. (199° U.S. proof) concentration is produced for blending with gasoline for motor fuel.

The Katzen two-tower dehydrating system design (see Figure 2) has been installed and successfully operated in seven different alcohol plants in North America and the Carribean.

The 96° G.L. (192° U.S. proof) product is withdrawn from the side of the rectifier in the hydrous distillation process. The hydrous alcohol is fed to an atmospheric dehydrating tower. Removal of water from the feed is achieved by the use of benzene, heptane, cyclohexane, or other suitable entraining agent. A ternary azeotrope is taken overhead from the dehydrating tower. The overhead vapors are condensed and the two liquid phases are separated in a decanter.

The entrainer-rich phase is refluxed to the dehydrating tower. A reboiler is used to supply vapor to this tower with heat supplied by either low pressure steam, recovered flash vapor, or hot effluent and condensate streams from the hydrous alcohol unit.

The aqueous phase from the decanter is fed to a stripper. The entraining agent is recovered, along with alcohol, in the overhead vapor. Water is removed from the bottom of the stripper. Direct steam may be used in this stripper.

The bottoms stream from the azeotropic dehydrating tower is the anhydrous alcohol product.

Design know-how consists of optimizing the balance between capital costs and utility consumption, with stable control. Specific features which contribute to overall process efficiency and reliability ot the RKAII anhydrous alcohol distillation system are:

1. Use of a common condenser and decanter for the dehydration and stripping towers to reduce capital costs.

2. Design of highly efficient tower trays for high turndown capability.

3. Low consumption of entraining agent (less than 0.1 Kg per 1,000 liters of anhydrous alcohol).

4. Low consumption of steam (1 to 1.5 Kg/liter or 8.3 to 12.5 lb/gallon of anhydrous alcohol), or equivalent hot condensate or waste streams.

PRODUCTION OF ANHYDROUS MOTOR FUEL GRADE ALCOHOL

For motor fuel grade alcohol, the beer feed is preheated in a multistage heat exchange sequence. A pressure stripper-rectifier (see Figure 3) is used to separate the beer feed into an overhead fraction of about 95° G.L. (190° U.S. proof) alcohol and a bottoms stream containing less than 0.02 wt % alcohol. Side draws are made to remove fusel oils. These oils are recovered by water washing, and reblended as a component of the motor fuel grade alcohol. In addition, a pasteurizing section is used to concentrate low boiling impurities. These are removed by taking a small heads draw which is burned in the plant reboiler. Dehydration of the hydrous product is accomplished in two additional towers. Energy is supplied to the reboilers of the two towers in the dehydration step by condensing the overhead vapors from the pressure stripper-rectifier. By operating the beer stripper-rectifier at a higher pressure (3) than the two-tower dehydration system, very low total steam consumption can be achieved. The steam usage is 1.8 to 2.4 Kg/liter (15 to 20 lb/gallon) of 99.5° G.L. (199° U.S. proof) motor fuel grade alcohol product (5).

PRODUCTION OF HYDROUS MOTOR FUEL GRADE ALCOHOL

For a product to be utilized in NEAT alcohol engines (no gasoline in the blend), further steam economy can be achieved when only 85-95° G.L. (170°-190° U.S. proof) alcohol product is desired. This is accomplished by splitting the stripping-rectifying duties between two towers (see Figure 4, Ref. 4). The first stripper-rectifier tower is operated at a pressure higher than the second tower and receives 50 to 60% of the beer feed. The overhead vapors from the first tower are used to boil up vapor in the second tower.

The steam usage is 1.2 to 1.5 Kg/liter (10 to 12 lb/gallon) of 85°-96° G.L. (170°-192° U.S. proof) motor fuel grade alcohol (on a 100% ethanol basis). Along with steam economy, cooling water requirements are reduced proportionately.

SUMMARY

A summary of investment for typical low energy distillation systems (shown in Figures 1 through 4) for production of 190 MM liter/year (50 MM USGPY) alcohols is given in Table 1. Also, shown are the steam, cooling water and electric energy requirements for each system.

REFERENCES

1. U.S. Patent 3,445,345, Extractive Distillation of C-1 to C-3 Alcohols and Subsequent Distillation of Purge Streams, May 20, 1969.

2. U.S. Patent 3,990,952, Improvement in Alcohol Distillation Process, November 9, 1976.

3. U.S. Patent Application No. 958,533, Distillation Method and Apparatus for Making Motor Fuel Grade Anhydrous Alcohol, November 7, 1978.

4. U.S. Patent Application, Novel Energy Efficient Process for Production of 170 to 190° Proof Alcohol.

5. Raphael Katzen Associates, Grain Motor Fuel Alcohol, Technical and Economic Assessment Study, U.S. DOE Contract No. EJ-78-C-6639, June, 1979.

TABLE 1

LOW ENERGY DISTILLATION SYSTEMS

SUMMARY OF INVESTMENT AND UTILITIES

190 MM liters/yr (50 MM gallons/yr)

	High Grade (96° G.L.) Industrial Alcohol	Anhydrous (100° G.L.) Industrial Alcohol	Anhydrous (99.5° G.L.) Motor Fuel Alcohol	Hydrous Motor Fuel Grade Alcohol
Figure	1	2	3	4
Alcohol Product, U.S. Proof	190	200	199	190
Distillation Unit Investment $MM U.S.	7.3	2.8	6.1	3.4
Steam Usage Kg/liter (lb/gallon)	4.1 (34)	1.4 (11.7)	2.2 (18)	1.2 (10)
Cooling Water MT/hr	1866	934	1311	182
Electric Power kw	289	31	133	177

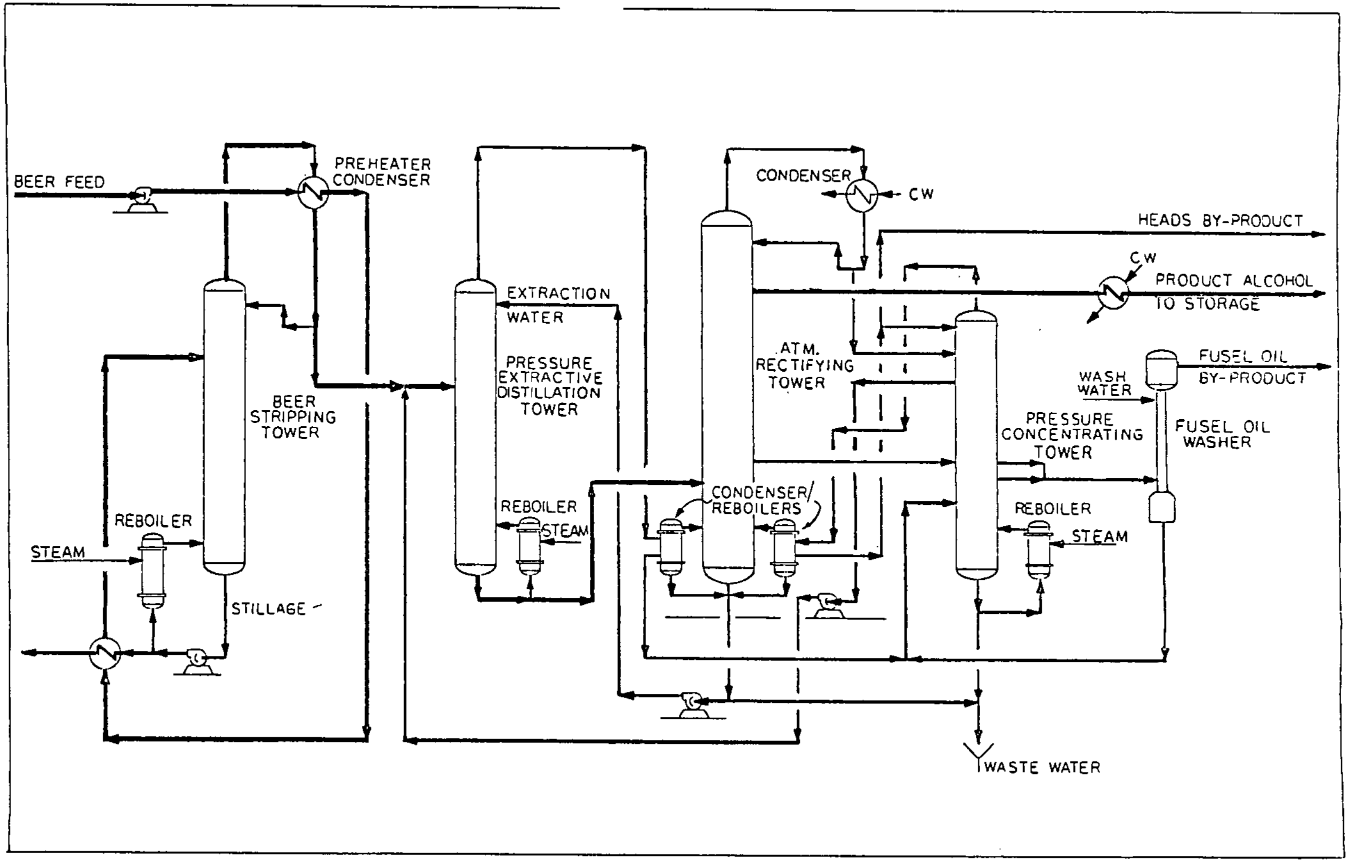

FIGURE 1. HIGH-GRADE HYDROUS ALCOHOL SYSTEM

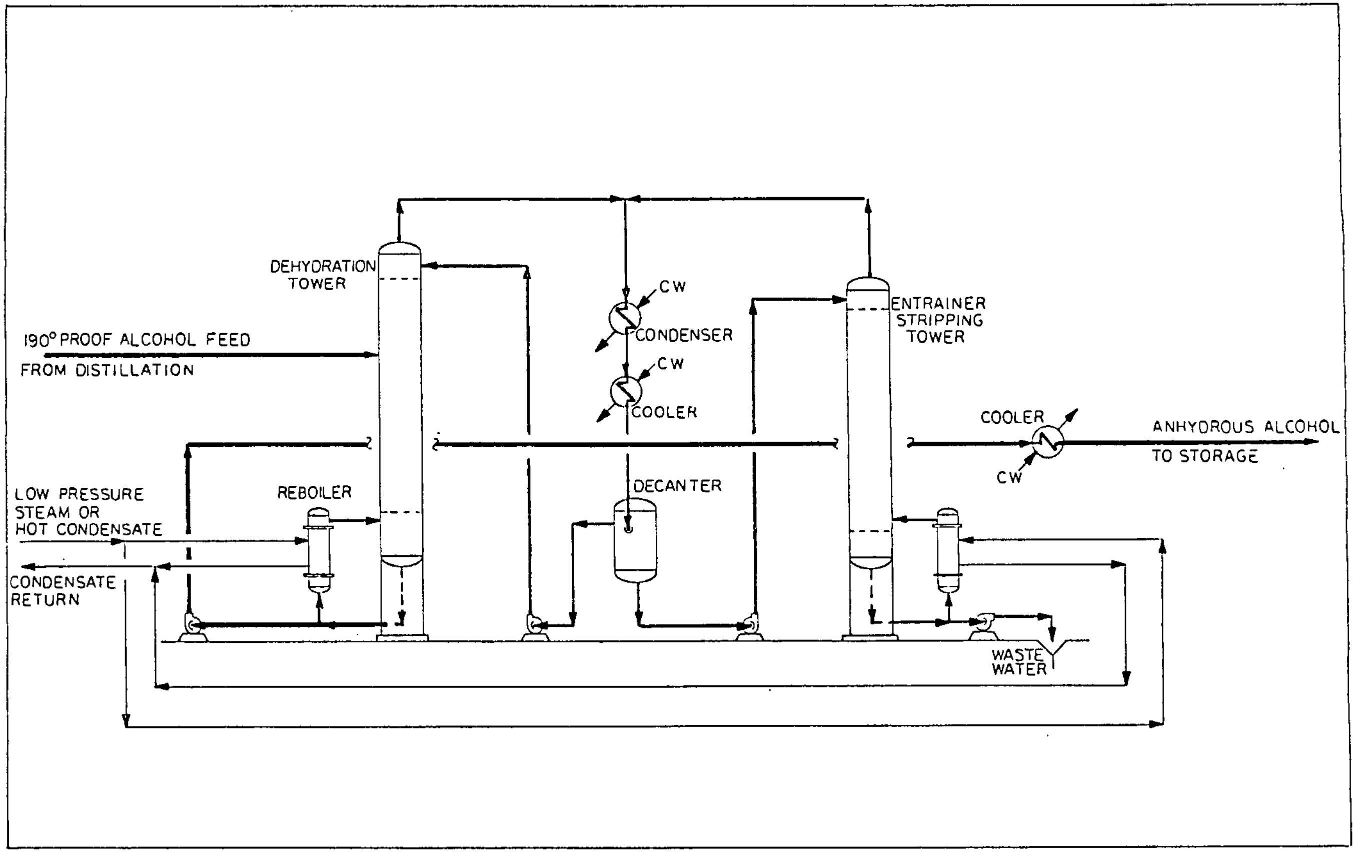

FIGURE 2. HIGH-GRADE ANHYDROUS ALCOHOL SYSTEM

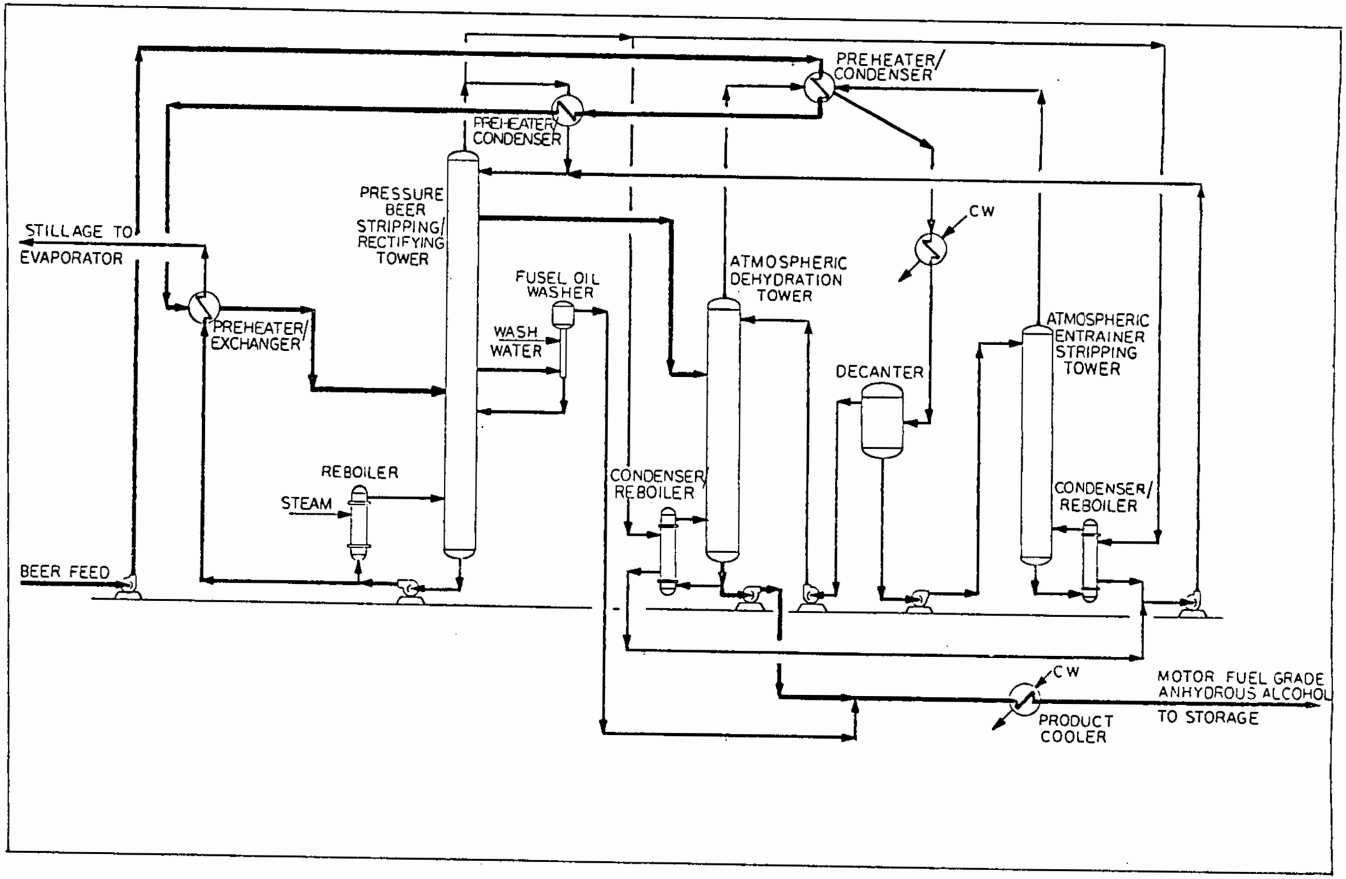

FIGURE 3. MOTOR FUEL GRADE ANHYDROUS ALCOHOL SYSTEM

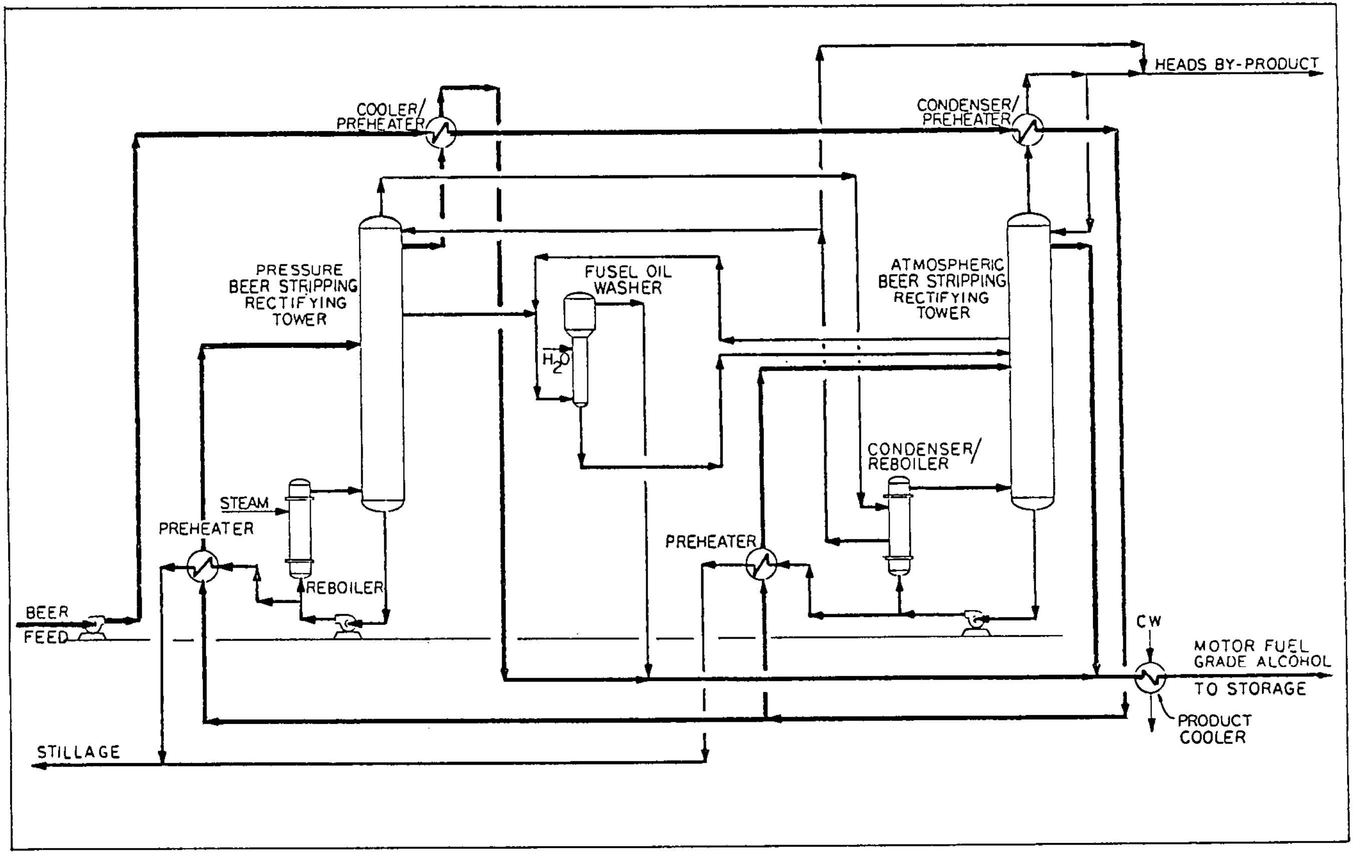

FIGURE 4. MOTOR FUEL GRADE HYDROUS ALCOHOL SYSTEM