

Descriptions of Example Process Flowsheets

These examples ask for the construction of flowsheets from the given process descriptions. Necessary auxiliaries such as drums and pumps are to be included even when they are not mentioned. Essential control instrumentation also is to be provided. Chapter 3 has examples. The processes are as follows:

1. visbreaker operation,
2. cracking of gas oil,
3. olefin production from naptha and gas oil,
4. propylene oxide synthesis,
5. phenol by the chlorobenzene process,
6. manufacture of butadiene sulfone,
7. detergent manufacture,
8. natural gas absorption,
9. tall oil distillation,
10. recovery of isoprene,
11. vacuum distillation,
12. air separation.

1. VISBREAKER OPERATION

Visbreaking is a mild thermal pyrolysis of heavy petroleum fractions whose object is to reduce fuel production in a refinery and to make some gasoline.

The oil of 7.2 API and 700°F is supplied from beyond the battery limits to a surge drum F-1. From there it is pumped with J-1A&B to parallel furnaces B-1A&B from which it comes out at 890°F and 200 psig. Each of the split streams enters at the bottom of its own evaporator T-1A&B that has five trays. Overheads from the evaporators combine and enter at the bottom of a 30-tray fractionator T-2. A portion of the bottoms from the fractionator is fed to the top trays of T-1A&B; the remainder goes through exchanger E-5 and is pumped with J-2A&B back to the furnaces B-1A&B. The bottoms of the evaporators are pumped with J-4A&B through exchangers E-5, E-3A (on crude), and E-3B (on cooling water) before proceeding to storage as the fuel product.

A side stream is withdrawn at the tenth tray from the top of T-2 and proceeds to steam stripper T-3 equipped with five trays. Steam is fed below the bottom tray. The combined steam and oil vapors return to T-2 at the eighth tray. Stripper bottoms are pumped with J-6 through E-2A (on crude) and E-2B (on cooling water) and to storage as "heavy gasoline."

Overhead of the fractionator T-2 is partially condensed in E-1A (on crude) and E-1B (on cooling water). A gas product is withdrawn overhead of the reflux drum which operates at 15 psig. The "light gasoline" is pumped with J-5 to storage and as reflux.

Oil feed is 122,480 pph, gas is 3370, light gasoline is 5470, heavy gasoline is 9940, and fuel oil is 103,700 pph.

Include suitable control equipment for the main fractionator T-2.

2. CRACKING OF GAS OIL

A gas oil cracking plant consists of two cracking furnaces, a soaker, a main fractionator, and auxiliary strippers, exchangers, pumps, and drums. The main fractionator (150 psig) consists of four zones, the bottom zone being no. 1.

A light vacuum gas oil (LVGO) is charged to the top plate of zone 3, removed from the bottom tray of this zone and pumped to furnace no. 1 that operates at 1000 psig and 1000°F. A heavy

vacuum gas oil (HVGO) is charged to the top plate of zone 2, removed at the bottom tray and charged to furnace no. 2 that operates at 500 psig and 925°F.

Effluents from both furnaces are combined and enter the soaker; this is a large vertical drum designed to provide additional residence time for conversion under adiabatic conditions. Effluent at 500 psig and 915°F enters the bottom zone of the main fractionator.

Bottoms from zone 1 goes to a stripping column (5 psig). Overhead from that tower is condensed, returned partly as reflux and partly to zone 3 after being cooled in the first condenser of the stripping column. This condensing train consists of the preheater for the stream being returned to the main fractionator and an air cooler. The cracked residuum from the bottom of the stripper is cooled to 170°F in a steam generator and an air cooler in series. Live steam is introduced below the bottom tray for stripping.

All of the oil from the bottom of zone 3 (at 700°F), other than the portion that serves as feed to furnace no. 1, is withdrawn through a cooler (500°F) and pumped partly to the top tray of zone 2 and partly as spray quench to zone 1. Some of the bottoms of zone 1 likewise is pumped through a filter and an exchanger and to the same spray nozzle.

Part of the liquid from the bottom tray of zone 4 (at 590°F) is pumped to a hydrogenation unit beyond the battery limits. Some light material is returned at 400°F from the hydrogenation unit to the middle of zone 4, together with some steam.

Overhead from the top of the column (zone 4) goes to a partial condenser at 400°F. Part of the condensate is returned to the top tray as reflux; the rest of it is product naphtha and proceeds beyond the battery limits. The uncondensed gas also goes beyond the battery limits. Condensed water is sewerage.

3. OLEFIN PRODUCTION

A gaseous product rich in ethylene and propylene is made by pyrolysis of crude oil fractions according to the following description. Construct a flowsheet for the process. Use standard symbols for equipment and operating conditions. Space the symbols and proportion them in such a way that the sketch will have a pleasing appearance.

Crude oil is pumped from storage through a steam heated exchanger and into an electric desalter. Dilute caustic is injected into the line just before the desalting drum. The aqueous phase collects at the bottom of this vessel and is drained away to the sewer. The oil leaves the desalter at 190°F, and goes through heat exchanger E-2 and into a furnace coil. From the furnace, which it leaves at 600°F, the oil proceeds to a distillation tower.

After serving to preheat the feed in exchanger E-2, the bottoms proceeds to storage; no bottoms pump is necessary because the tower operates with 65 psig at the top. A gas oil is taken off as a sidestream some distance above the feed plate, and naphtha is taken off overhead. Part of the overhead is returned as reflux to the tower, and the remainder proceeds to a cracking furnace. The gas oil also is charged to the same cracking furnace but into a separate coil. Superheated steam at 800°F is injected into both cracking coils at their inlets.

Effluents from the naphtha and gas oil cracking coils are at 1300°F and 1200°F, respectively. They are combined in the line just before discharge into a quench tower that operates at 5 psig and 235°F at the top. Water is sprayed into the top of this tower. The

bottoms is pumped to storage. The overhead is cooled in a water exchanger and proceeds to a separating drum. Condensed water and an aromatic oil separate out there. The water is sewered whereas the oil is sent to another part of the plant for further treating.

The uncondensed gas from the separator is compressed to 300 psig in a reciprocating unit of three stages and then cooled to 100°F. Condensed water and more aromatic distillate separate out. Then the gas is dried in a system of two desiccant-filled vessels that are used alternately for drying and regeneration.

Subsequently the gas is precooled in exchanger E-6 and charged to a low temperature fractionator. This tower has a reboiler and a top refluxing system. At the top the conditions are 280 psig and -75°F. Freon refrigerant at -90°F is used in the condenser. The bottoms is recycled to the pyrolysis coil. The uncondensed vapor leaving the reflux accumulator constitutes the product of this plant. It is used to precool the feed to the fractionator in E-6 and then leaves this part of the plant for further purification.

4. PROPYLENE OXIDE SYNTHESIS

Draw a process flowsheet for the manufacture of propylene oxide according to the following description.

Propylene oxide in the amount of 5000 tons/yr will be made by the chlorohydrin process. The basic feed material is a hydrocarbon mixture containing 90% propylene and the balance propane which does not react. This material is diluted with spent gas from the process to provide a net feed to chlorination which contains 40 mol % propylene. Chlorine gas contains 3% each of air and carbon dioxide as contaminants.

Chlorination is accomplished in a packed tower in which the hydrocarbon steam is contacted with a saturated aqueous solution of chlorine. The chlorine solution is made in another packed tower. Because of the limited solubility of chlorine, chlorohydrin solution from the chlorinator is recirculated through the solution tower at a rate high enough to supplement the fresh water needed for the process. Solubility of chlorine in the chlorohydrin solution is approximately the same as in fresh water.

Concentration of the effluent from the chlorinator is 8 lb organics/100 lb of water. The organics have the composition

Propylene chlorohydrin	75 mol %
Propylene dichloride	19
Propionaldehyde	6

Operating pressure of the chlorinator is 30 psig, and the temperature is 125°F. Water and the fresh gas stream are at 80°F. Heat of reaction is 2000 Btu/lb chlorine reacted. Percentage conversion of total propylene fed to the chlorinator is 95% (including the recycled material).

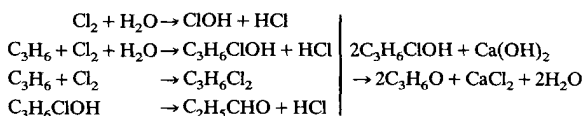
Overhead from the chlorinator is scrubbed to remove excess chlorine in two vessels in succession which employ water and 5% caustic solution, respectively. The water from the first scrubber is used in the chlorine solution tower. The caustic is recirculated in order to provide adequate wetting of the packing in the caustic scrubber; fresh material is charged in at the same rate as spent material is purged. Following the second scrubber, propylene dichloride is recovered from the gas by chilling it. The spent gas is recycled to the chlorinator in the required amount, and the excess is flared.

Chlorohydrin solution is pumped from the chlorinator to the saponifier. It is mixed in the feed line with a 10% lime slurry and preheated by injection of live 25 psig steam to a temperature of 200°F. Stripping steam is injected at the bottom of the saponifier, which has six perforated trays without downcomers. Propylene

oxide and other organic materials go overhead; the bottoms contain unreacted lime, water, and some other reaction products, all of which can be dumped. Operating pressure is substantially atmospheric. Bubblepoint of the overhead is 60°F.

Separation of the oxide and the organic byproducts is accomplished by distillation in two towers. Feed from the saponifier contains oxide, aldehyde, dichloride, and water. In the first tower, oxide and aldehyde go overhead together with only small amounts of the other substances; the dichloride and water go to the bottom and also contain small amounts of contaminants. Two phases will form in the lower section of this tower; this is taken off as a partial side stream and separated into a dichloride phase which is sent to storage and a water phase which is sent to the saponifier as recycle near the top of that vessel. The bottoms are a waste product. Tower pressure is 20 psig. Live steam provides heat at the bottom of this column.

Overhead from the first fractionator is condensed and charged to the second tower. There substantially pure propylene oxide is taken overhead. The bottoms is dumped. Tower pressure is 15 psig, and the overhead bubblepoint is 100°F. Reactions are



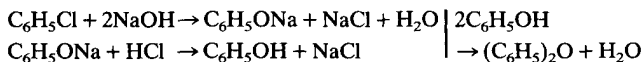
Show all necessary major equipment, pumps, compressors, refrigerant lines. Show the major instrumentation required to make this process continuous and automatic.

5. PHENOL BY THE CHLOROBENZENE PROCESS

A portion of a plant for the manufacture of phenol from monochlorobenzene and NaOH is in accordance with the following description.

- Construct a flowsheet of the process, with operating conditions and the two control instruments mentioned.
- Prepare a material balance showing the compositions of the process streams in the portion of the plant before the brine decanter V-103. The amount of phenol in this stream is 2000 lb/hr. Excess caustic (5%) is fed to the emulsifier.

Process description: The principal reactions in the plant are



From storage, monochlorobenzene and 10% caustic are pumped together with diphenyl ether from decanter V-102 into emulsifier V-101 which is provided with intense agitation. The effluent from that vessel is pumped with a high pressure steam driven reciprocating pump P-103 at 4000 psig through a feed-effluent exchanger E-101 and through the tube side of a direct fired heater R-101. Here the stream is heated to 700°F and reaction 1 occurs.

From the reactor, the effluent is cooled in E-101, cooled further to 110°F in water cooler E-102, and then enters diphenyl ether decanter V-102. The lighter DPE phase is returned with pump P-104 to the emulsifier. The other phase is pumped with P-105 to another stirred vessel R-102 called a Springer to which 5% HCl also is pumped, with P-106; here reaction 2 occurs.

The mixture of two liquid phases is cooled in water cooler E-103 and then separated in brine decanter V-103. From that vessel the lighter phenol phase proceeds (P-108) to a basket type evaporator D-101 that is heated with steam. Overhead vapor from

the evaporator proceeds beyond the battery limit for further purification. Evaporator bottoms proceeds to waste disposal. The aqueous phase from decanter V-103 is pumped with P-109 through a feed-bottoms exchanger E-104 to the top tray of the brine tower D-102. The overhead is condensed in E-105, collected in accumulator V-104 and pumped beyond the battery limits for recovery of the phenol. Tower D-102 is provided with a steam heated reboiler E-106. Bottom product is a weak brine that is pumped with P-110 through the feed-bottoms exchanger and beyond the battery limits for recovery of the salt.

Two important control instruments are to be shown on the flowsheet. These are a back pressure controller in the reactor effluent line beyond exchanger E-101 and a pH controller on the feed line of the 5% HCl that is fed to springer R-102. The pH instrument maintains proper conditions in the springer.

Note: There is a tendency to byproduct diphenyl ether formation in reactor R-101. However, a recycle of 100 pph of DPE in the feed to the reactor prevents any further formation of this substance.

6. MANUFACTURE OF BUTADIENE SULFONE

A plant is to manufacture butadiene sulfone at the rate of 1250 lb/hr from liquid sulfur dioxide and butadiene to be recovered from a crude C₄ mixture as starting materials. Construct a flowsheet for the process according to the following description.

The crude C₄ mixture is charged to a 70 tray extractive distillation column T-1 that employs acetonitrile as solvent. Trays are numbered from the bottom. Feed enters on tray 20, solvent enters on tray 60, and reflux is returned to the top tray. Net overhead product goes beyond the battery limits. Butadiene dissolved in acetonitrile leaves at the bottom. This stream is pumped to a 25-tray solvent recovery column T-2 which it enters on tray 20. Butadiene is recovered overhead as liquid and proceeds to the BDS reactor. Acetonitrile is the bottom product which is cooled to 100°F and returned to T-1. Both columns have the usual condensing and reboiling provisions.

Butadiene from the recovery plant, liquid sulfur dioxide from storage, and a recycle stream (also liquified) are pumped through a preheater to a high temperature reactor R-1 which is of shell-and-tube construction with cooling water on the shell side. Operating conditions are 100°C and 300 psig. The combined feed contains equimolar proportions of the reactants, and 80% conversion is attained in this vessel. The effluent is cooled to 70°C, then enters a low temperature reactor R-2 (maintained at 70°C and 50 psig with cooling water) where the conversion becomes 92%. The effluent is flashed at 70°C and atmospheric pressure in D-1. Vapor product is compressed, condensed and recycled to the reactor R-1. The liquid is pumped to a storage tank where 24 hr holdup at 70°C is provided to ensure chemical equilibrium between sulfur dioxide, butadiene, and butadiene sulfone. Cooling water is available at 32°C.

7. DETERGENT MANUFACTURE

The process of making synthetic detergents consists of several operations that will be described consecutively.

ALKYLATION

Toluene and olefinic stock from storage are pumped (at 80°F) separately through individual driers and filters into the alkylation reactor. The streams combine just before they enter the reactor. The reactor is batch operated 4 hr/cycle; it is equipped with a single impeller agitator and a feed hopper for solid aluminum chloride which is charged manually from small drums. The alkylation

mixture is pumped during the course of the reaction through an external heat exchanger (entering at -10°F and leaving at -15°F) which is cooled with ammonia refrigerant (at -25°F) from an absorption refrigeration system (this may be represented by a block on the FS); the exchanger is of the kettle type. HCl gas is injected into the recirculating stream just beyond the exit from the heat exchanger; it is supplied from a cylinder mounted in a weigh scale. The aluminum chloride forms an alkylation complex with the toluene. When the reaction is complete, this complex is pumped away from the reactor into a storage tank with a complex transfer pump. To a certain extent, this complex is reused; it is injected with its pump into the reactor recirculation line before the suction to the recirculation pump. There is a steam heater in the complex line, between the reactor and the complex pump.

The reaction mixture is pumped away from the reactor with an alkylmer transfer pump, through a steam heater and an orifice mixer into the alkylmer wash and surge tank. Dilute caustic solution is recirculated from the a.w.s. tank through the orifice mixer. Makeup of caustic is from a dilute caustic storage tank. Spent caustic is intermittently drained off to the sewer. The a.w.s. tank has an internal weir. The caustic solution settles and is removed at the left of the weir; the alkylmer overflows the weir and is stored in the right-hand portion of the tank until amount sufficient for charging the still has accumulated.

DISTILLATION

Separation of the reactor product is effected in a ten-plate batch distillation column equipped with a water-cooled condenser and a Dowtherm-heated (650°F, 53 psig) still. During a portion of the distillation cycle, operation is under vacuum, which is produced by a two-stage steam jet ejector equipped with barometric condensers. The Dowtherm heating system may be represented by a block. Product receiver drums are supplied individually for a slop cut, for toluene, light alkylmer, heart alkylmer, and a heavy alkylmer distillate. Tar is drained from the still at the end of the operation through a water cooler into a bottoms receiver drum which is supplied with a steam coil. From this receiver, the tar is loaded at intervals into 50 gal drums, which are trucked away. In addition to the drums which serve to receive the distillation products during the operation of the column, storage tanks are provided for all except the slop cut which is returned to the still by means of the still feed pump; this pump transfers the mixture from the alkylmer wash and surge tank into the still. The recycle toluene is not stored with the fresh toluene but has its own storage tank. The heavy alkylmer distillate tank connects to the olefinic stock feed pump and is recycled to the reactor.

SULFONATION

Heart alkylmer from storage and 100% sulfuric acid from the sulfuric acid system (which can be represented by a block) are pumped by the reactor feed pump through the sulfonation reactor. The feed pump is a positive displacement proportioning device with a single driver but with separate heads for the two fluids. The reactor is operated continuously; it has a single shell with three stages which are partially separated from each other with horizontal doughnut shaped plates. Each zone is agitated with its individual impeller; all three impellers are mounted on a single shaft. On leaving the reactor, the sulfonation mixture goes by gravity through a water cooler (leaving at 130°F) into a centrifuge. Spent acid from the centrifuge goes to storage (in the sulfuric acid system block); the sulfonic acids go to a small surge drum or can bypass this drum and go directly to a large surge tank which is equipped with an agitator and a steam jacket. From the surge drum, the material is sent by an extraction feed pump through a water cooler, then a "flomix," then

another water cooler, then another "flomix" (leaving at 150°F), and then through a centrifuge and into the sulfonic acid surge tank. Fresh water is also fed to each of the "flomixers." Wash acid is rejected by the centrifuge and is sent to the sulfuric acid system. The "flomix" is a small vertical vessel which has two compartments and an agitator with a separate impeller for each compartment.

NEUTRALIZATION

Neutralization of the sulfonic acid and building up with sodium sulfate and tetrasodium pyrophosphate (TSPP) is accomplished in two batch reactors (5 hr cycle) operated alternately. The sodium sulfate is pumped in solution with its transfer pump from the sodium sulfate system (which can be represented by a block). The TSPP is supplied as a solid and is fed by means of a Redler conveyor which discharges into a weigh hopper running on a track above the two reactors. Each reactor is agitated with a propeller and a turbine blade in a single shaft.

Sodium hydroxide of 50% and 1% concentrations is used for neutralization. The 50% solution discharges by gravity into the reactor; the 1% solution is injected gradually into the suction side of the reactor slurry circulating pump. As the caustic is added to the reactor, the contents are recirculated through a water-cooled external heat exchanger (exit at 160°F), which is common to both reactors. When the reaction is completed in one vessel, the product is fed gradually by means of a slurry transfer pump to two double drum dryers which are steam-heated and are supplied with individual vapor hoods. The dry material is carried away from the dryers on a belt conveyor and is taken to a flaker equipped with an air classifier. The fines are returned to the trough between the dryer drums. From the classifier, the material is taken with another belt conveyor to four storage bins. These storage bins in turn discharge onto a belt feeder which discharges into drums which are weighed automatically on a live portion of a roller conveyor. The roller conveyor takes the drums to storage and shipping.

Notes: All water cooled exchangers operate with water in at 75°F and out at 100°F. All pumps are centrifugal except the complex transfer, and the sulfonation reactor feed, which are both piston type; the neutralization reactor recirculation pump and the transfer pumps are gear pumps.

Show all storage tanks mentioned in the text.

8. NATURAL GAS ABSORPTION

A gas mixture has the composition by volume:

Component	N ₂	CH ₄	C ₂ H ₆	C ₃ H ₈
Mol fraction	0.05	0.65	0.20	0.10

It is fed to an absorber where 75% of the propane is recovered. The total amount absorbed is 50 mol/hr. The absorber has four theoretical plates and operates at 135 psig and 100°F. All of the absorbed material is recovered in a steam stripper that has a large number of plates and operates at 25 psig and 230°F.

Water is condensed out of the stripped gas at 100°F. After compression to 50 psig, that gas is combined with a recycle stream. The mixture is diluted with an equal volume of steam and charged to a reactor where pyrolysis of the propane occurs at a temperature of 1300°F. For present purposes the reaction may be assumed to be simply $C_3H_8 \rightarrow C_2H_4 + CH_4$ with a specific rate $k = 0.28/\text{sec}$. Conversion of propane is 60%. Pressure drop in the reactor is 20 psi.

Reactor effluent is cooled to remove the steam, compressed to 285 psig, passed through an activated alumina drying system to remove further amounts of water, and then fed to the first fractionator. In that vessel, 95% of the unconverted propane is recovered as a bottoms product. This stream also contains 3%

ethane as an impurity. It is throttled to 50 psig and recycled to the reactor. In two subsequent towers, ethylene is separated from light and heavy impurities. Those separations may be taken as complete.

Construct a flow diagram of this plant. Show such auxiliary equipment as drums, heat exchangers, pumps, and compressors. Show operating conditions and flow quantities where calculable with the given data.

9. TALL OIL DISTILLATION

Tall oil is a byproduct obtained from the manufacture of paper pulp from pine trees. It is separated by vacuum distillation (50 mm Hg) in the presence of steam into four primary products. In the order of decreasing volatility these are unsaponifiables (US), fatty acid (FA), rosin acids (RA), and pitch (P). Heat exchangers and reboilers are heated with Dowtherm condensing vapors. Some coolers operate with water and others generate steam. Live steam is charged to the inlet of every reboiler along with the process material. Trays are numbered from the bottom of each tower.

Tall oil is pumped from storage through a preheater onto tray 10 of the pitch stripper T-1. Liquid is withdrawn from tray 7 and pumped through a reboiler where partial vaporization occurs in the presence of steam. The bottom 6 trays are smaller in diameter and serve as stripping trays. Steam is fed below tray 1. Pitch is pumped from the bottom through steam generator and to storage. Overhead vapors are condensed in two units E-1 and E-2. From the accumulator, condensate is pumped partly as reflux to tray 15 and partly through condenser E-1 where it is preheated on its way as feed to the next tower T-2. Steam is not condensed in E-2. It flows from the accumulator to a barometric condenser that is connected to a steam jet ejector.

Feed enters T-2 at tray 5. There is a pump-through reboiler. Another pump withdraws material from the bottom and sends it to tower T-3. Liquid is pumped from tray 18 through a cooler and returned in part to the top tray 20 for temperature and reflux control. A portion of this pumparound is withdrawn after cooling as unsaps product. Steam leaves the top of the tower and is condensed in the barometric.

Tray 5 of T-3 is the feed position. This tower has two reboilers. One of them is a pumparound from the bottom, and the other is gravity feed from the bottom tray. Another pump withdraws material from the bottom, and then sends it through a steam generator and to storage as rosin acid product. A slop cut is withdrawn from tray 20 and pumped through a cooler to storage. Fatty acid product is pumped from tray 40 through a cooler to storage. Another stream is pumped around from tray 48 to the top tray 50 through a cooler. A portion of the cooled pumparound is sent to storage as another unsaps product. A portion of the overhead steam proceeds to the barometric condenser. The rest of it is boosted in pressure with high pressure steam in a jet compressor. The boosted steam is fed to the inlets of the two reboilers associated with T-3 and also directly into the column below the bottom tray.

The vapors leaving the primary barometric condenser proceed to a steam ejector that is followed by another barometric. Pressures at the tops of the towers are maintained at 50 mm Hg absolute. Pressure drop is 2 mm Hg per tray. Bottom temperatures of the three towers are 450, 500, and 540°F, respectively. Tower overhead temperatures are 200°F. Pitch and rosin go to storage at 350°F and the other products at 125°F. The steam generated in the pitch and rosin coolers is at 20 psig. Process steam is at 150 psig.

10. RECOVERY OF ISOPRENE

Draw carefully a flowsheet for the recovery of isoprene from a mixture of C₅ hydrocarbons by extractive distillation with aqueous acetonitrile according to the following description.

A hydrocarbon stream containing 60 mol % isoprene is charged at the rate of 10,000 pph to the main fractionator D-1 at tray 40 from the top. The solvent is acetonitrile with 10 wt % water; it is charged at the rate of 70,000 pph on tray 11 of D-1. This column has a total of 70 trays, operates at 10 psig and 100°F at the top and about 220°F at the bottom. It has the usual provisions for reboiling and top reflux.

The extract is pumped from the bottom of D-1 to a stripper D-2 with 35 trays. The stripped solvent is cooled with water and returned to D-1. An isoprene-acetonitrile azeotrope goes overhead, condenses, and is partly returned as top tray reflux. The net overhead proceeds to an extract wash column D-3 with 20 trays where the solvent is recovered by countercurrent washing with water. The overhead from D-3 is the finished product isoprene. The bottoms is combined with the bottoms from the raffinate wash column D-4 (20 trays) and sent to the solvent recovery column D-5 with 15 trays.

Overhead from D-1 is called the raffinate. It is washed countercurrently with water in D-4 for the recovery of the solvent, and then proceeds beyond the battery limits for further conversion to isoprene. Both wash columns operate at substantially atmospheric pressure and 100°F. The product streams are delivered to the battery limits at 100 psig.

Solvent recovery column D-5 is operated at 50 mm Hg absolute, so as to avoid the formation of an azeotrope overhead. The required overhead condensing temperature of about 55°F is provided with a propane compression refrigeration system; suction condition is 40°F and 80 psig, and discharge condition is 200 psig. Vacuum is maintained on the reflux accumulator with a two-stage steam ejector, with a surface interstage condenser and a direct water spray after-condenser. The stripped bottoms of D-5 is cooled to 100°F and returned to the wash columns. Some water makeup is necessary because of leakages and losses to process streams. The solvent recovered overhead in D-5 is returned to the main column D-1. Solvent makeup of about 20 pph is needed because of losses in the system.

Steam is adequate for all reboiling needs in this plant.

11. VACUUM DISTILLATION

This plant is for the distillation of a heavy petroleum oil. The principal equipment is a vacuum tower with 12 trays. The top tray is numbered 1. Trays 1, 2, 10, 11, and 12 are one-half the diameter of the other trays. The tower operates at 50 mm Hg.

Oil is charged with pump J-1 through an exchanger E-1, through a fired heater from which it proceeds at 800°F onto tray 10 of the tower. Live steam is fed below the bottom tray.

Bottoms product is removed with pump J-3 through a steam

generator and a water cooled exchanger E-3 beyond the battery limits. A side stream is taken off tray 6, pumped with J-2 through E-1, and returned onto tray 3 of the tower. Another stream is removed from tray 2 with pump J-4 and cooled in water exchanger E-2; part of this stream is returned to tray 1, and the rest of it leaves the plant as product gas oil.

Uncondensed vapors are removed at the top of the column with a one-stage steam jet ejector equipped with a barometric condenser.

Show the principal controls required to make this plant operate automatically.

12. AIR SEPARATION

Make a flowsheet of an air purification and separation plant that operates according to the following description.

Atmospheric air at the rate of 6.1 million SCFD is compressed to 160 psig in a two-stage compressor JJ-1 that is provided with an intercooler and a knockout drum. Then it proceeds to a packed tower T-1 where it is scrubbed with recirculating caustic soda solution. Overhead from T-1 is cooled to 14°F in a refrigerated exchanger. After removal of the condensate, this stream proceeds to a dryer system that consists principally of two vessels F-1 and F-2 packed with solid desiccant.

After being precooled with product oxygen in exchanger E-1 and with product nitrogen in E-2, the air serves as the heating medium in reboiler E-3 of column T-2. Its pressure then is reduced to 100 psig, and it is fed to the middle of column T-2. Bottoms of T-2 is fed to the middle of column T-3. This stream contains 40% oxygen.

Columns T-3 and T-4 operate at 15 and 30 psig, respectively. Column T-3 is located above T-4. Elevations and pressure differentials are maintained in such a way that no liquid pumps are needed in the distillation section of the plant.

Part of the overhead from T-2 (containing 96% nitrogen) is condensed in E-4 which is the reboiler for column T-3, and the remainder is condensed in E-5 which is the reboiler for T-4. Part of the condensate from E-4 is returned as reflux to T-2 and the rest of the condensates from E-4 and E-5 serve as top reflux to T-3. Overhead from T-3 contains 99.5% nitrogen. After precooling the feed in E-2, this nitrogen proceeds to the battery limits.

Bottoms of T-3 proceeds to the top of stripper T-4. Vapor overhead from T-4 is recycled to the middle of T-3. The bottoms product (containing 99.5% oxygen) is sent partly to liquid storage and the remainder to precooler E-1 where it is vaporized. Then it is compressed to 150 psig in a two-stage compressor JJ-2 and sent to the battery limits. Compressor JJ-2 has inter- and aftercoolers and knockout drums for condensate.