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APPARATUS FOR PUMPING VOLATILE LIQUIDS

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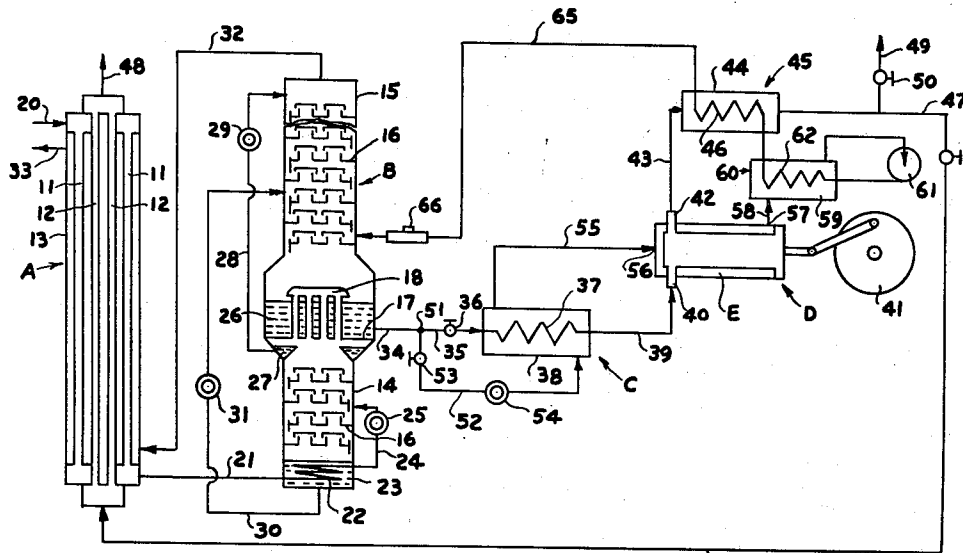


Fig. 1

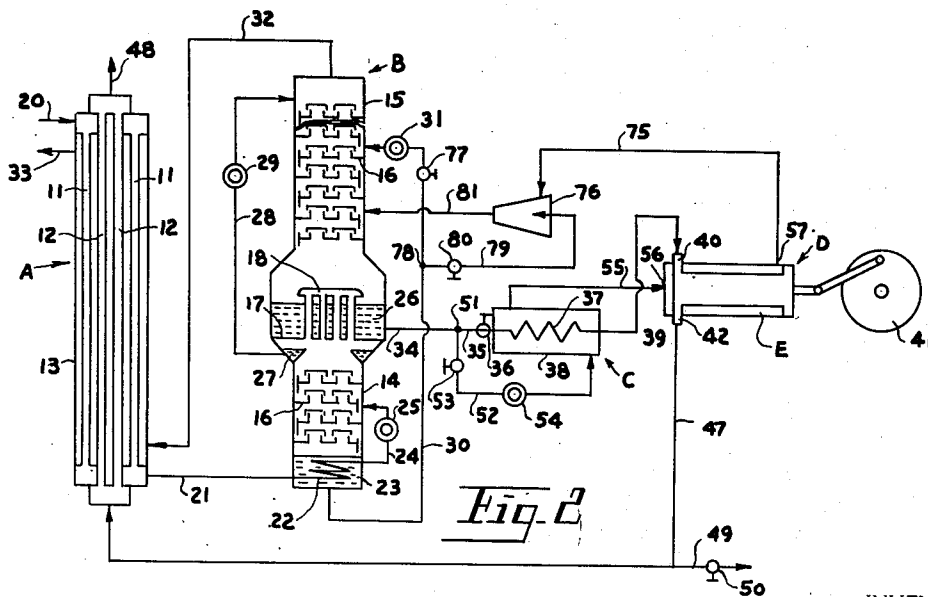


Fig. 2

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APPARATUS FOR PUMPING VOLATILE LIQUIDS

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1 Claim. (Cl. 62—123)

This invention relates to improvements in the pumping in liquid phase of liquefied gases or volatile liquids as for example liquid oxygen, liquid nitrogen, liquid air, liquefied petroleum gases, natural gasoline or any like normally gaseous product, or any liquid volatile under the pumping conditions.

While the invention is applicable to all systems involving the separation of mixtures of low boiling gases, it is found most useful in connection with the pumping of liquid oxygen or nitrogen from an air separation system because of the very low atmospheric pressure boiling points of these liquids. The invention will, therefore be described in connection with the handling of oxygen and nitrogen, it being understood that such description is illustrative and not limiting.

If the oxygen or nitrogen product obtained in air fractionation were to be recovered as a gas at atmospheric temperature and pressure, it would merely be removed from the fractionation column in gaseous form and conducted to a heat interchanger in gaseous form, the pressure in the column being sufficient to discharge the gaseous product against frictional resistance and atmospheric pressure. It is, however, very desirable in many cases to conduct the product directly to the cylinder or pipe lines in which it is stored or transported as a compressed gas at pressures ranging up to 2500 or more pounds per square inch, or to transport the product directly as a liquid under pressure. Although it is common practice to bring the gaseous product at column pressure to substantially atmospheric temperature and thereafter to compress it, it is much more desirable to pump the product as a liquid, and if desired, to vaporize it while subjected to the raised pressure, prior to entering the storage vessel or pipe line.

The compression of gaseous products to high pressure is in several respects a wasteful and undesirable process. Besides the necessity for gas holders and associated equipment, it requires multistage compressors which, if oil-lubricated contaminate the compressed gas with hydrocarbons, while if water is used for lubrication it is usually necessary to redry the compressed gas by passage through an absorbent such as silica gel. For these reasons and others the total plant required for gas compression is costly, occupies considerable valuable space, and has an unduly high power consumption.

The step of pumping oxygen or nitrogen in liquid phase has proven in practice to be one of great difficulty. The liquid is, in the nature of the case, at its boiling point at the existing pressure. From this, it follows that any reduction in pressure, such as is occasioned by fluid friction in the pump suction, or any increase in enthalpy due to leakage into the pump body or to frictional heat transmitted into the liquid, will cause the evolution of gas which breaks the suction and puts the pump out of commission. A further cause of vapor lock is back leakage through the discharge valve, the high pressure leakage liquid partially flashing to the gaseous state. My previously granted Patents Nos. 2,480,093

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and 2,480,094 cover systems for successfully pumping these gases in liquid form using colder products from the fractionating column producing the gas to lower the temperature of the liquefied gas below its boiling point prior to the pumping step.

The present invention has solved this problem by providing a novel method and means whereby a small portion of the liquid to be pumped is expanded and utilized for cooling the main stream to be pumped and for cooling the liquid conveying end of the pump during the pumping step, after which the small portion is reliquefied by heat exchange with the pumped stream, the pressure of the small portion is increased and it is returned to the system.

An important object of the present invention is the provision of a method and apparatus for efficiently subcooling a stream of liquid volatile under the conditions present to prevent the formation of vapor during pumping of the liquid. A further important object of the present invention is the provision of a method and apparatus for recovering refrigerant used for the foregoing purpose where the refrigerant is an expanded portion of the liquid being pumped.

In the attached drawings, the invention is illustrated schematically in four modifications, to wit:

Figure 1 illustrates a form of the invention in which a portion of a stream of oxygen to be pumped is expanded and used to subcool the stream to be pumped as well as the liquid conveying end of the pump, after which the expanded portion, vaporized during the cooling steps, is subjected to increased pressure by means of a mechanical blower, is liquefied and returned to the column;

Figure 2 illustrates a form of the invention similar to Figure 1 wherein the expanded vaporized portion is increased in pressure by means of an injector using crude oxygen from the high pressure section of the column as the propellant, the mixture being discharged from the injector into the column;

Figure 3 illustrates a form of the invention similar to Figure 1 wherein the product to be pumped is liquid nitrogen from the high pressure section of the column; and

Figure 4 illustrates a form of the invention similar to Figure 2 wherein the product to be pumped is liquid nitrogen from the high pressure section of the column.

Referring to the drawings, the system shown in Figure 1 includes a heat interchanger A, a fractionating column B, subcooling heat exchanger C, and a liquid pump D provided with a cooling passageway E in heat exchange relation with the liquid conveying end thereof. The heat interchanger A may be any conventional multi-passageway interchanger shown here as having two banks of tubes 11, 11 and 12, 12 within an outer shell 13 to provide three passageways therethrough in heat exchange relationship with one another. The fractionating column B is shown in the drawing as a two-stage fractionating column although any conventional single or double-stage column may be used. As illustrated, the column B consists of a high pressure section 14 and a low pressure section 15, each supplied with a stack of bubbling plates 16, and separated by a partition 17 which includes the conventional downwardly draining condenser 18, the condensate from which drains into the high pressure section of the column.

Compressed air enters the interchanger through feed pipe 20, passes through tubes 11, 11 and then through conduit 21 to boiling coil 22 submerged in a pool of boiling crude oxygen 23 in the base of the high pressure section. The air flows from the coil 22 through conduit 24 and expansion valve 25 into the high pressure section of the column at a medial height. In this section of the column, the feed air is fractionated into a substantially

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pure gaseous nitrogen rising into the condenser 18 which is immersed in a pool of boiling pure oxygen product 26 collecting in the base of the low pressure section of the column. As the upper section of the column is maintained at a materially lower pressure than the lower section, the condenser acts as a reboiler for the pure oxygen surrounding it. As a result, the nitrogen rich gas rising in the condenser is liquefied, part falling into the pool 27 and part falling onto the top plate of the lower section 14 where it acts as reflux for the lower section. Liquefied nitrogen from pool 27 is transferred through conduit 28 and expansion valve 29 to the top of the upper section in which it acts as reflux. The crude oxygen product formed in the high pressure section of the column collects in the pool 23 in the base of the column from which it is transferred through conduit 30 and expansion valve 31 to the low pressure section of the column at a medial point therein.

The high pressure nitrogen stream and the high pressure oxygen stream flowing into the low pressure section of the column are fractionated in the well-known manner to substantially pure oxygen and a slightly impure nitrogen product. The nitrogen product in gaseous form is withdrawn through conduit 32 at the top of the low pressure section of the column and is conducted to the shell of the interchanger A where it gives up its cold to the feed air, leaving the interchanger A through conduit 33.

The pure oxygen product formed in the low pressure section of the column collects in the pool 26 at the lower end thereof and is removed in liquid form through conduit 34. The main portion of the stream of oxygen product is conducted via conduit 35 and control valve 36 to the coil 37 of heat exchanger C. The stream flowing in coil 37 is in heat exchange relation with colder fluid, to be described hereinafter, flowing in the shell 38 of the exchanger surrounding the coil 37 so that the stream in coil 37 is subcooled during its passage therethrough. From coil 37, the subcooled stream of oxygen product flows through conduit 39 to the intake 40 of the liquid pump D wherein the stream is pumped to the desired pressure. The pump D may be any pump capable of handling a liquid at high pressure but is here illustrated as a single acting plunger pump. Preferably, the pump D is similar to that described in Patent No. 2,439,957, dated April 20, 1948, to C. R. Anderson. The prime mover by which power is applied to the pump to reciprocate the plunger is indicated at 41. The subcooled stream of oxygen flows through conduit 39 and pump intake 40 into the pump cylinder on the suction stroke of the pump plunger. During its flow into and from the pump cylinder, the stream of pure liquid oxygen is further cooled by a colder fluid, to be described hereunder, flowing through the cooling passageway E, shown in the form of a jacket surrounding the pump cylinder. On the compression stroke of the pump plunger the liquid oxygen passes through the pump discharge 42 and conduit 43 to the shell 44 of heat exchanger 45 wherein it flows in heat exchange relation with a warmer fluid in the liquefying coil 46, to be described hereafter. From the heat exchanger 45 the pure oxygen product stream at the desired pressure flows through conduit 47 to the tubes 12, 12 of interchanger A in which the stream is brought to atmospheric temperature and gaseous condition and is discharged at desired pressure through conduit 48. If desired, the stream in conduit 47 may be directed to a storage vessel or pipe line in liquid condition through conduit 49 and control valve 50. Usually, however, it will be passed through the interchanger A and delivered by conduit 48 to pressure cylinders or other pressure vessels (not shown) or to pipe lines in which it is transported under pressure in a gaseous state.

A portion of the oxygen product withdrawn from the column through conduit 34 is diverted at point 51 to conduit 52, control valve 53 and expansion valve 54 where this portion is expanded to a lower pressure and conse-

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quently cooled to the saturation temperature corresponding to the lower pressure. This expanded portion is then passed through the shell 38 of exchanger C in heat exchange with the main stream flowing through coil 37. In passing through the coil 37, the main stream of liquid oxygen product is cooled by heat exchange with the colder expanded portion to a temperature sufficiently low so that there will be substantially no flashing of the oxygen into vapor during the subsequent pumping operation. The expanded portion is thence conducted through conduit 55 to the inlet 56 of the cooling passageway E surrounding the pump D. In the cooling action of the two heat exchange steps, vapor is evolved from the expanded portion. This vapor leaves the passageway E through outlet 57, flows through conduit 58 and passageway 59 of heat exchanger 60, where it is warmed up and from where it passes to the blower 61 in which the pressure of this gaseous oxygen is raised. Heat is removed from the compressed gas by passing the gas through passageway 62 of heat exchanger 60 where it flows in heat exchange relation with the gaseous stream going to the blower. The gaseous stream is next liquefied while flowing through coil 46 of heat exchanger 45 by heat exchange against the stream of pumped oxygen flowing through the shell 44 of the exchanger. The liquefied stream is returned to the low pressure section of the column through conduit 65 and pressure regulator 66. Pressure regulator 66 reduces the pressure of the returning stream to that corresponding to the pressure in the low pressure section of the column.

Since the liquid oxygen is pumped while at a temperature below the equilibrium boiling point temperature of the liquid for that pressure, the liquid as a result may be pumped continuously without vaporization of the liquid within the pump and thus without the pump becoming gas bound.

In the modification of the invention shown in Figure 2, operation of the interchanger A, two stage fractionating column B, subcooling heat exchanger C, liquid pump D, and pump cooling passageway E are similar to that described in connection with Figure 1 and the same reference numerals refer to corresponding parts. Again a portion of the oxygen stream is diverted from the main stream to be pumped, is expanded and utilized for cooling the main stream and the liquid conveying end of the pump. In this modification, the pumped main stream is passed directly from the pump discharge 42 through conduit 47 to the interchanger A wherein it is vaporized and brought to atmospheric temperature, discharging through conduit 48. The expanded portion of oxygen which has been vaporized during the two heat exchange steps, in exchanger C and pump cooling passageway D, flows from the outlet 57 of passageway E through conduit 75 to an ejector 76 in which the pressure of this portion is increased. The propellant stream utilized to increase the pressure of the gaseous portion is a stream of the crude oxygen flowing from the high pressure to the low pressure section of the column. The crude oxygen stream is transferred from the pool 23 at the base of the high pressure section of the column through conduit 30, control valve 77, and expansion valve 31 to a medial point in the low pressure section of the column. A portion of this stream of crude oxygen prior to expansion is diverted at point 78 through conduit 79 and control valve 80 to the nozzle of the ejector 76. The mixture discharged from the ejector is introduced via conduit 81 into the low pressure section of the column on the tray in which the liquid reflux corresponds to the composition of the mixture.

Referring to Figures 3 and 4, systems are shown in which the liquid nitrogen from the high pressure section of the column is the product to be pumped to the relatively high pressure. In these figures, operation of the interchanger A, two stage fractionating column B, subcooling heat exchanger C, liquid pump D and pump cooling passageway E are similar to that described in connection with

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Figure 1 and the same reference numerals refer to corresponding parts. A portion of the stream of nitrogen to be pumped is diverted, expanded and utilized for cooling the main stream and the liquid conveying end of the pump.

Referring to Figure 3, the nitrogen rich product from the high pressure section of the column is transferred through conduit 28, and expansion valve 29 to the upper portion of the low pressure section. A portion of the nitrogen flowing in conduit 28 is diverted at point 101 into conduit 102, through control valve 103 to coil 37 in the subcooling heat exchanger C where it flows in heat exchange with a colder fluid, to be described, flowing through the shell 38 surrounding the coil 37. From coil 37, the cooled stream flows through conduit 104 to the pump intake 40 and is pumped in the liquid pump D to the desired pressure. The liquid nitrogen at the desired pressure leaves the pump discharge 42 through conduit 105 to the shell 106 of heat exchanger 107 wherein it flows in heat exchange relation with a warmer fluid in the liquefying coil 108. From the heat exchanger 107 the product is discharged in liquid form through conduit 109 at the desired pressure. If desired, the product can be gasified and heated to atmospheric temperature in conventional manner in the main heat interchanger by providing a fourth passageway therein, not shown. A small portion of the stream flowing in conduit 102 is diverted at point 110 through conduit 111, control valve 112 and expansion valve 113, to the shell 38 of the heat exchanger C. In passing through the exchanger C, the diverted small portion boils and cools the main stream of nitrogen to be pumped flowing within the coil 37 to a temperature sufficiently low so that there will be substantially no flashing of the nitrogen into vapor during the subsequent pumping operation. The expanded portion is thence conducted via conduit 114 to the inlet 56 of the pump cooling passageway E. Nitrogen is vaporized from the expanded portion while passing through the two heat exchange steps, and the gas leaves the passageway E through outlet 57 and conduit 115, passing to passageway 116 of heat exchanger 117 in which it is warmed up, and thence passes to the blower 61 where the pressure of the expanded nitrogen is raised. Heat is removed from the compressed gas by passing it through passageway 118 of exchanger 117 where it flows in heat exchange relation with the gaseous stream flowing to the blower. The gaseous stream is next liquefied while flowing through coil 108 of heat exchanger 107 in heat exchange with the stream of pumped nitrogen flowing through the shell 106 of the exchanger. The liquefied stream is returned to the top of the low pressure section of the column through conduit 119 and pressure regulator 66. Pressure regulator 66 reduces the pressure of the returning stream to that corresponding with the pressure in the low pressure section of the column.

Referring to Figure 4, the expanded portion of nitrogen which has been vaporized during the subcooling in exchanger C and the pump cooling step, flows from the outlet 57 of cooling passageway E through conduit 126 to an ejector 76 wherein the pressure of the stream is increased. The propellant stream utilized to increase the pressure of the gaseous portion is a stream of gaseous nitrogen from the high pressure section of the column withdrawn from the top of the condenser 18 through conduit 127 and control valve 128 and fed to the nozzle of the ejector 76. The mixture discharged from the ejector is introduced via conduit 129 into the top of the low pressure section of the column.

It should be noted that in the systems disclosed in Figures 1 and 2, where liquid oxygen is the product being pumped, instead of diverting a portion of the oxygen for use as the coolant, as an obvious variant, a portion of the nitrogen rich product from the high pressure section of the column could be used as the coolant as in the embodiments of Figures 3 and 4. In like manner, in the systems of Figures 3 and 4, where the liquid nitrogen product is

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pumped, the oxygen product could be utilized as the coolant as in Figures 1 and 2.

In the normal operation of all the schemes, the subcooling heat exchanger C and the pump cooling passageway E are maintained with the parts to be cooled submerged in boiling liquid coolant medium, the vapors passing off from the boiling liquid being withdrawn through the passageway outlet 57 for recovery treatment. The level of the boiling liquid is maintained by control of the amount of fluid passing through valve 54 in Figures 1 and 2 and expansion valve 113 in Figures 3 and 4. Obviously, any manual control or suitable automatic control of the expansion valve could be used, a float control being the simplest example.

It will be obvious that fluid to be returned to the column in all the described modifications may include some liquid where the amount of liquid expanded is more than sufficient to accomplish the desired cooling effect by vaporization alone. This does not alter the fact that the stream returned to the column in such cases is predominantly vaporous and the appended claims are intended to include such cases within the scope of the terminology "stream of vapor."

I claim:

In combination, a fractionating apparatus for producing a liquid product including a high pressure stage and a low pressure stage and a product collecting space in the low pressure stage for the liquid product, a pump for handling liquids including an intake, a first conduit for connecting the intake of the pump with the product collecting space of the low pressure stage for withdrawing liquid product and passing a major stream of liquid product to the intake of the pump, means for providing a minor stream of liquid product withdrawn from the fractionating apparatus, means for expanding the minor stream, means for heat exchanging the expanded minor stream against the major stream to remove sufficient heat from the major stream to prevent evolution of vapor from the major stream in the pump, pump cooling means having an inlet and an outlet in heat exchange relation with the liquid conveying end of the pump, conduit means for passing the expanded minor stream to the input of the pump cooling means whereby the expanded minor stream removes heat from the pump, a compressor, conduit means for conducting to the compressor the expanded minor stream from the outlet of the pump cooling means, means for liquefying the compressed stream, conduit means between the last-named means and the fractionating apparatus for returning liquefied compressed minor stream to the low pressure stage of the apparatus above the liquid product collecting space, and means for maintaining the pressure of the compressed minor stream in the neighborhood of the pressure of the low pressure stage of the apparatus.

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