(12) STANDARD PATENT (11) Application No. AU 2012270148 B2
(19) AUSTRALIAN PATENT OFFICE

(54) Title
Process for liquefaction of natural gas

(51) International Patent Classification(s)
F25J 1/00 (2006.01)

(21) Application No: **2012270148** (22) Date of Filing: **2012.06.11**

(87) WIPO No: **WO12/172281**

(30) Priority Data

(31) Number	(32) Date	(33) Country
1110096.3	**2011.06.15**	**GB**

(43) Publication Date: **2012.12.20**
(44) Accepted Journal Date: **2017.12.07**

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(56) Related Art
WO 0144735 A1

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
20 December 2012 (20.12.2012)

WIPO | PCT

(10) International Publication Number
WO 2012/172281 A2

(51) International Patent Classification:
F25J 1/02 (2006.01)

(21) International Application Number:
PCT/GB2012/000502

(22) International Filing Date:
11 June 2012 (11.06.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1110096.3 15 June 2011 (15.06.2011) GB

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

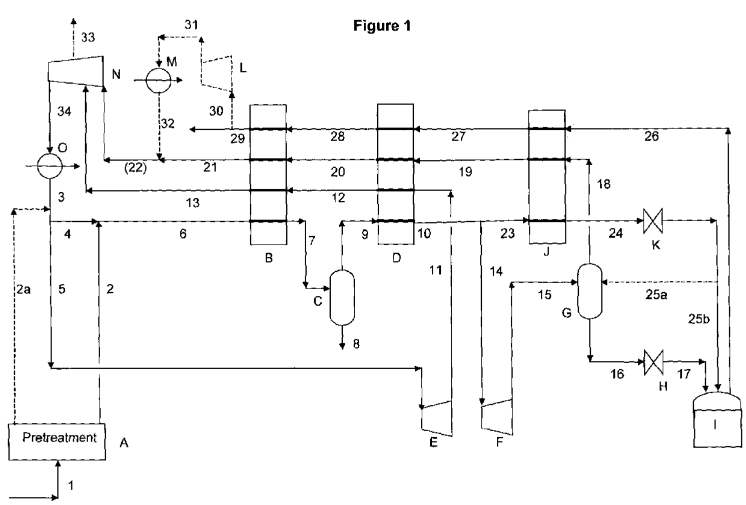
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *of inventorship (Rule 4.17(iv))*

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) Title: PROCESS FOR LIQUEFACTION OF NATURAL GAS



(57) Abstract: A process comprising: cooling natural gas with a heat exchanger and a first expander. The heat exchanger cools the feed natural gas to temperature higher than the outlet temperature of the expander, reheating the expander outlet stream in a first cold passage of the heat exchanger to slightly below the temperature of the feed natural gas to the heat exchanger, passing the cold outlet stream from the heat exchanger into a second expander wherein it is partly liquefied, separating the outlet stream of second expander into liquid and vapour fractions, collecting the liquid fraction for use as LNG product, reheating the vapour fraction in a second cold side passage of the heat exchanger to substantially the same temperature as the temperature of the feed natural gas to the heat exchanger, recycling the reheated vapour fraction partly as feed to the first expander and partly as feed to the heat exchanger.

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Process for Liquefaction of Natural Gas

Field of the Invention

The present invention relates to a method for liquefying methane-rich gas and, more particularly but not exclusively, relates to a method for producing liquefied natural gas (LNG).

Background to the Invention

Liquefaction of natural gas can practically be achieved by:

- evaporation of liquid refrigerants
- work expansion of gases in expansion machines (expanders).

Evaporation of liquid refrigerants gives the lowest power requirement and is the basis of the widely used Cascade and Mixed Refrigerant LNG processes.

Expander-based LNG installations are simple, compact, low in weight and can avoid the importation/preparation/storage of liquid refrigerants. These characteristics are attractive for smaller scale applications, particularly offshore, where low hydrocarbon inventory is desirable from safety considerations. However expander processes have certain drawbacks:

- until recently, limited capacity and experience with expanders
- higher power requirement
- higher internal gas flowrates, requiring larger line diameters, etc.

With most expander-based processes the working fluid (typically nitrogen) remains in the vapour phase at the expander outlet.

Partially liquefying the feed gas itself in an expander, having a two-phase discharge flow, can reduce internal (recycle) gas flows and reduce power requirement.

LNG production in a liquefying expander is not a new idea (USP 2,903, 858 – Bocquet).

The present inventors previously disclosed a process (GB Patent 2393504B, USP 7,234,321) with potentially lower power requirements, wherein a liquefying expander is combined with a precooling circuit which contains a simple mixed refrigerant generated from the feed natural gas.

Other recent disclosures comprise precooling by a parallel/recycle gas expander followed by a liquefying expander:

- WO 01/44735 (Minta et al) describing production of pressurised liquid natural gas (PLNG) at -112^{0}C from feed gas compressed to a high pressure of "above 1600 psia".
- US 2006/0213222 (Whitesell) describing production of LNG from a feed gas entering the process at, or compressed within, the process to a pressure of "between about 1500 psig to about 3500 psig".

Summary of the Invention

Relative to the two above-mentioned patents, an inventive step in the present application consists of identifying operating conditions for the two expanders (the precooling expander and the liquefying expander) which allow for practical production of atmospheric pressure LNG at about -161^{0}C. Moreover a very high pressure feed gas, which is a feature of the above-mentioned patents, is no longer required.

This results in a simplified process with improved thermal efficiency having a wide range of potential applications where the raw feed gas has a pressure as low as 40 bar (4 MPa) .

The present invention facilitates production of LNG from smaller gas fields, particularly offshore, due to its simple flow scheme, low power consumption and non-reliance on storage and use of liquid refrigerants. The liquefaction process itself generally does not require process columns, for instance for refrigerant preparation, which may be less easy to operate under such operating conditions.

Description of the Invention

According to the invention, there is provided a process for liquefying natural gas or other methane-rich gases. The feed gas, generally at a pressure of from 40 (4 MPa) to 100 bar (10 MPa), is liquefied to give LNG product at approx 1 bar (0.1 MPa) / -161°C by the expander-based plant configuration described above and comprising:

cooling feed gas and recycle gas (mentioned below) in a first step by means of a first heat exchanger and in a first work expander; the heat exchanger having an outlet temperature in the range of -50° to -80°C, preferably -60° to -70°C; the expander having a lower outlet temperature than that of the heat exchanger; the expander having its outlet stream reheated in a cold passage of the said heat exchanger and then recompressed to form part of the above mentioned recycle gas.

passing the cooled outlet stream from the said first heat exchanger partly into a hot passage in a second heat exchanger, wherein it is essentially condensed, and partly into a second work expander, the said second expander having a lower outlet temperature than the cold outlet of the second heat exchanger, the second expander outlet stream containing a significant amount of liquid (typically 10-15% wt); the expander outlet being separated into a vapour fraction and a liquid fraction; the vapour fraction being reheated in cold passages in said second and first heat exchangers; then recompressed and returned to the inlet to the process as part of the above mentioned recycle gas.

- reducing the pressure of the above mentioned separated liquid and of the condensed liquid from the hot passage from second heat exchanger (both typically around -120°C) to around to atmospheric pressure; reheating the flashed gas evolved in further cold passages in the above heat exchangers; removing the liquid for use as LNG product.

It has been found that the lowest requirement for recycle gas compression power results from concentrating the extraction of mechanical work into the pressure range above 10 bar (1 MPa) approx at the outlet of the second expander. An advantage of this is that the outlet pressures from the two expanders can be equalized at around 10 bar (1MPa) , reducing the first heat exchanger to a three-passage configuration.

Whereas most existing LNG production relies on evaporation of liquid refrigerants to cool and condense the natural gas so as to form LNG product in a heat exchanger, this invention comprises a liquefaction process with moderate power requirement in which the necessary refrigeration is largely supplied by work expansion of the feed gas itself. Cryogenic liquid refrigerants or other secondary working fluids such as nitrogen are therefore not required. In this way energy is extracted at a low temperature level which results in improved thermodynamic efficiency. As a result, a significant proportion of the LNG is formed directly in a work extracting expander, in addition to that formed by condensation in an exchanger which is cooled by the reheating of the cold gas from the said work expander.

Description of Preferred Embodiments

The invention will be described with reference to the accompanying drawings in which Figures 1 and 2 represent flow diagrams illustrating processes in accordance with the invention.

Figure 1 shows the operating features of the invention. The exact flow sheet will depend upon the feed gas specification, but will generally contain these basic elements. Where pressures are stated anywhere in this application as "bar" these are bar absolute.

The feed natural gas (Stream 1) is passed through a pretreatment stage A in which components that would solidify or otherwise interfere with the downstream liquefaction process, such CO_2, H_2S, water vapour and mercury vapour, are removed to the extent necessary to give appropriate and conventional maximum concentrations in the pretreated gas (Stream 2).

Stream 2 is mixed with part (Stream 4) of the recycle gas (Stream 3) to form Stream 6, which is passed through a passage in heat exchanger B, leaving as Stream 7 at a temperature typically in the range -20° to -60°C, preferably -30° to -50°C. This temperature is typically low enough to condense sufficient NGL to meet the specification for the final LNG product. Any condensed hydrocarbons in separator C are removed as Stream 8. The outlet vapour from C (Stream 9) is further cooled in a passage in heat exchanger D, exiting as Stream 10 at a temperature in the range -50° to -80°C, preferably -60° to -70°C. The remaining part of the recycle gas (Stream 5) is cooled in gas expander E having an outlet Stream 11 with a temperature lower than the temperature of Stream 10.

Optionally part or all of the pretreated feed gas may exit pretreatment stage A via Stream 2a to join the recycle gas Stream 3 upstream of the point at which it is divided into Streams 4 & 5. This option may be convenient when the natural gas feed Stream 1 has only a small content of heavy hydrocarbon. In such a case the pretreated feed gas may be mixed with the whole of the recycle gas and then the resulting mixture divided to supply heat exchanger B through Stream 6 and gas expander E through Stream 5.

The pressure of Stream 11 will typically be around 15 bar (1.5 MPa). Stream 11 enters a first cold passage in heat exchanger D, leaving as Stream 12, which then passes through a first cold passage in heat exchanger B, emerging (Stream 13) at a temperature just below the temperature of Stream 6. The ratio of the flow rate of Stream 4 to the flow rate of Stream 5 is controlled so that the temperature approach between the composite hot and cold sides of heat exchangers B and D are substantially uniform throughout their lengths.

A large part of Stream 10 is then passed (Stream 14) through a second gas expander F from which it emerges as Stream 15 at a pressure between 3 bar (0.3 MPa) and 20 bar (2 MPa) , preferably between 5 bar (0.5 MPa) and 15 bar (1.5 MPa) and in a partly liquefied state. Stream 15 then enters vapour-liquid separator G. The liquid phase from Separator G (Stream 16) is then typically let down in a pressure reduction device H such as a valve or a turbine. The outlet from H (Stream 17), which is typically at or close to atmospheric pressure, is delivered into the LNG Tank I. If it is desired to reduce the nitrogen content of the product LNG, a conventional nitrogen stripping column (not shown) may be used, typically employing the sensible heat of Stream 16 for reboiling.

Optionally and preferably a part of Stream 10 flows as Stream 23 through a hot side passage in heat exchanger J, wherein it is liquefied by indirect heat exchange with the vapour from separator G (Stream 18), emerging as Stream 24. This is then typically let down in pressure through pressure reduction device K, such as a valve or a turbine. The outlet from K is routed either to vapour-liquid separator G, shown in broken line as Stream 25a, or preferably as Stream 25b to the LNG tank I. This second option helps to reduce accumulation of nitrogen in the recycle gas. Stream 18, having been heated in a first cold passage in heat exchanger J, emerges as Stream 19. It is then further heated in a second cold passage in heat exchanger D, emerging as

Stream 20, which is then further heated in a second cold passage in heat exchanger B, emerging as Stream 21 at a temperature slightly below the temperature of Stream 6.

Streams 13 and 21 are compressed in recycle compressor N, from which the outlet Stream 34 is cooled typically with cooling water in cooler O. Compressor N may consist of more than one stage with intercoolers. Streams 13 and 21 will not have the same pressure and may enter at different compressor stages. The outlet stream from O forms the above-mentioned recycle gas Stream 3.

The flashing of Stream 16 across H and the flashing of Stream 24 across K will result in the evolution of vapour comprising mainly methane together with most of the nitrogen content of the feed gas. Typically this vapour (Stream 26), optionally combined with boil-off vapour resulting from heat leak into tank I, is heated in a second cold passage in heat exchanger J to form Stream 27, then in a third cold passage in heat exchanger D to give Stream 28 and finally in a third cold passage in heat exchanger B, emerging as Stream 29 at a temperature slightly below the temperature of Stream 6. A conventional booster blower (also not shown) may be provided in Stream 26 to ensure that the pressure of Stream 29 does not fall below atmospheric pressure. Stream 29 may typically be used as fuel gas.

Part or all of Stream 29 (Stream 30) optionally may be compressed for return to the recycle gas in a low pressure compressor L, leaving as Stream 31. This stream is cooled in cooler M, from which the outlet (Stream 32) joins Stream 21 to form Stream 22, which then enters the suction of recycle compressor N instead of Stream 21 alone if this option is not used. A further option is to withdraw recycle gas (Stream 33) at a convenient point from compressor N typically for use as gas turbine fuel. It may be convenient to use Stream 29 or Stream 33 as stripping gas for regeneration of adsorbents in the pretreatment stage A, prior to their ultimate combustion as fuels.

Figure 2 shows a preferred embodiment of the invention in which expanders E and F have essentially the same outlet pressure of between 3 bar (0.3 MPa) and 20 bar (2 MPa), preferably between 5 bar (0.5 MPa) and 15 bar (1.5 MPa). The outlet stream from expander E (Stream 11) is then combined with Stream 19 to form Stream 19a, which enters heat exchanger D in place of Stream 19 in Fig.1. The heat exchangers B and D then have only three passages, simplifying the construction of the exchanger and the operation of the plant.

Although in most applications it is expected that the Streams 2 and 3 will have temperatures close to ambient temperature, cooling below this level may be advantageous. It is feasible to cool those streams, and optionally the outlet streams from compressor intercoolers and aftercoolers, by means of a mechanical refrigeration cycle or by means of an absorption refrigeration system, typically using lithium bromide (LiBr), which could receive its heat supply from the exhaust of a gas turbine, gas engine or combined cycle or anything else suitable.

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In this specification, the word “comprising” is to be understood in its “open” sense, that is, in the sense of “including”, and thus not limited to its “closed” sense, that is the sense of “consisting only of”. A corresponding meaning is to be attributed to the corresponding words “comprise", "comprised" and "comprises" where they appear.

The preceding description is provided in relation to several embodiments which may share common characteristics and features. It is to be understood that one or more features of any one embodiment may be combinable with one or more features of the other embodiments. In addition, any single feature or combination of features in any of the embodiments may constitute additional embodiments.

In addition, the foregoing describes only some embodiments of the inventions, and alterations, modifications, additions and/or changes can be made thereto without departing from the scope and spirit of the disclosed embodiments, the embodiments being illustrative and not restrictive.

Furthermore, the inventions have been described in connection with what are presently considered to be the most practical and preferred embodiments, it is to be understood that the invention is not to be limited to the disclosed embodiments, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the inventions. Also, the various embodiments described above may be implemented in conjunction with other embodiments, e.g., aspects of one embodiment may be combined with aspects of another embodiment to realize yet other embodiments. Further, each independent feature or component of any given assembly may constitute an additional embodiment.

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Claims

1. A process for liquefying natural gas or other methane-rich gases comprising:
   - cooling feed natural gas at a pressure of from 40 to 100 bar (4 to 10 MPa) to a temperature of -50^0 to -80^0C by means of a heat exchanger having at least one cold passage and a first gas expander, the heat exchanger receiving the feed natural gas and having an outlet temperature higher than the outlet temperature of the first gas expander;
   - reheating the first gas expander outlet stream in one of the at least one cold passages of said heat exchanger to just below the inlet temperature of the feed natural gas to said heat exchanger, compressing and recycling;
   - passing part or all of the cold outlet stream from said heat exchanger into a second gas expander in which it is partly liquefied;
   - separating the outlet stream of said second gas expander into vapour and liquid fractions;
   - collecting the liquid fraction for use as LNG product;
   - reheating the vapour fraction in one of the at least one cold passages of said heat exchanger to just below the inlet temperature of the feed natural gas to said heat exchanger;
   - recycling the said reheated vapour fraction after compression in part to the said first expander and in to the said heat exchanger; and

   CHARACTERISED IN THAT

   the outlet stream of the second expander is at a pressure between 5 and 15 bar (0.5 and 1.5 MPa).

2. A process as claimed in Claim 1 in which the heat exchanger receives all the feed natural gas.

3. A process as claimed in Claim 1 in which the heat exchanger receives a large part, at least 30%, of the feed natural gas.

4. A process as claimed in any preceding claim in which the feed natural gas is cooled to a temperature of -60^0 to -70^0C.

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5. A process as claimed in any preceding claim further comprising combining the outlet stream and the vapor fraction when the first and second gas expanders have essentially the same outlet pressure of between 5 bar and 15 bar (0.5 and 1.5 MPa), prior to final reheating, compression and recycle.

6. A process as claimed in any preceding claim in which any part or all of the feed and/or compressor discharge and/or recycle streams are cooled, typically by use of an absorption refrigeration cycles such as lithium bromide (LiBr).

7. A process as claimed in any preceding claim in which the heat requirement for an absorption refrigeration system is supplied by gas engine or gas turbine exhaust heat, such gas engines or turbines which may be used for supplying power to the process compressors.

8. A process as claimed in any preceding claim wherein such cooling of either feed and/or recycle streams is combined with removal of carbon dioxide and/or other impurities from the feed gas.

Figure 1

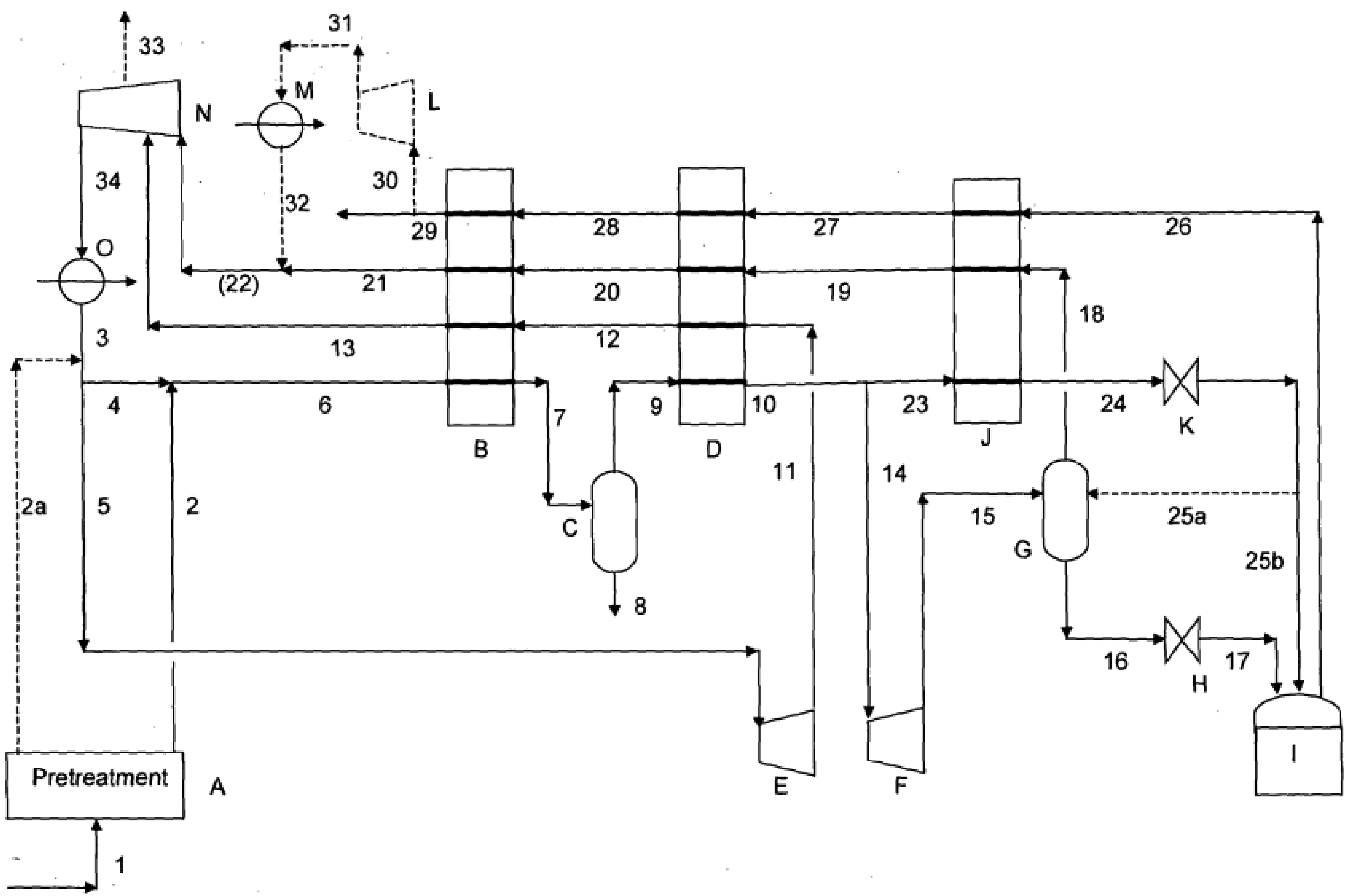
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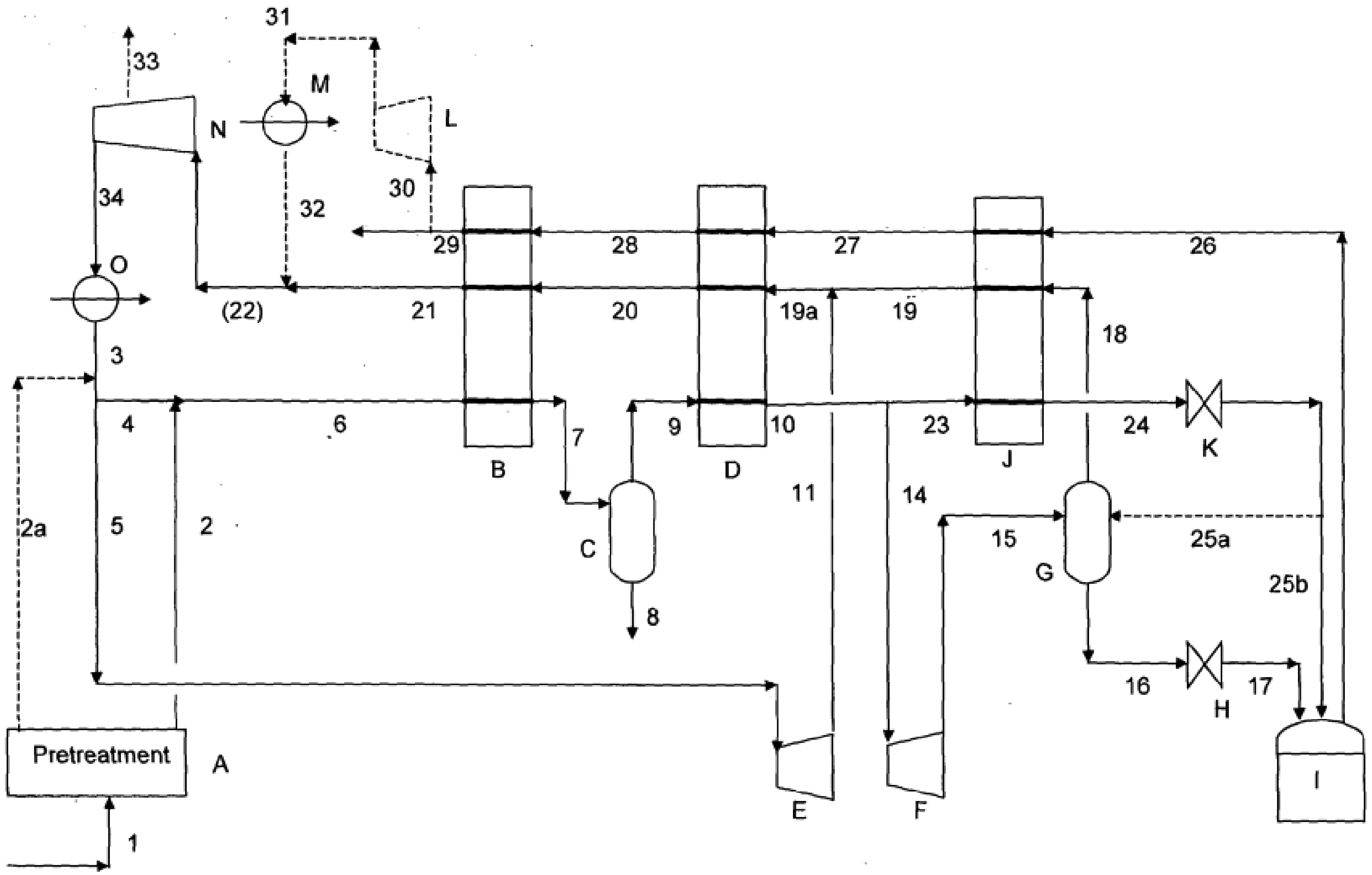
Figure 2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