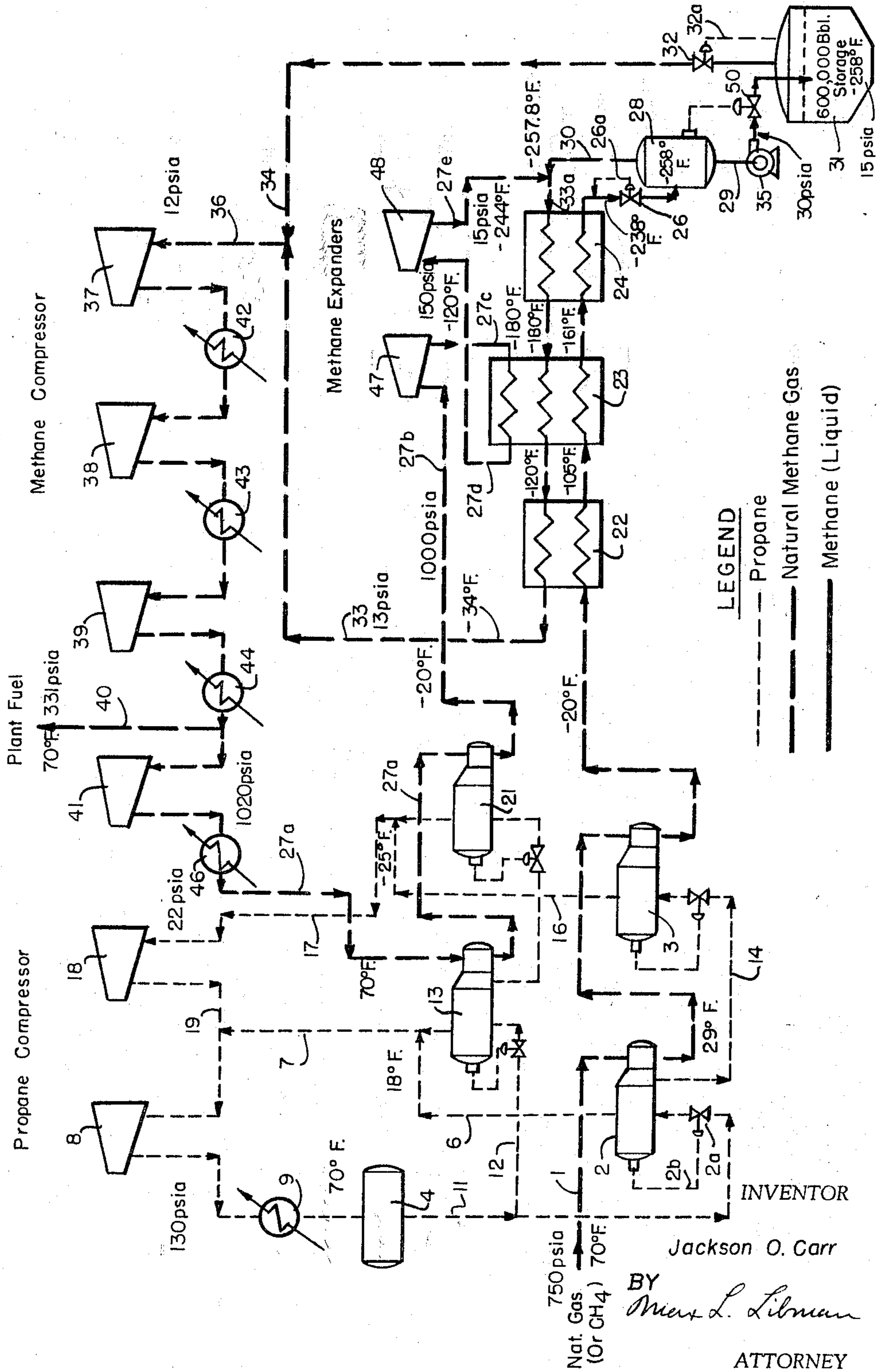


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J. O. CARR

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GAS LIQUEFACTION EMPLOYING AN EVAPORATING AND  
GAS EXPANSION REFRIGERANT CYCLES  
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**GAS LIQUEFACTION EMPLOYING AN EVAPORATING AND GAS EXPANSION REFRIGERANT CYCLES**

Jackson O. Carr, Shawnee Mission, Kans., assignor to Conch International Methane Limited, Nassau, Bahamas, a Bahamian company

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9 Claims. (Cl. 62-9)

This invention relates to an improved method and apparatus for the liquefaction of gas, particularly natural gas, and has for its principal object considerably simplifying the equipment and ease of operation and lowering the cost in comparison with known methods.

Cascade refrigeration techniques for liquefying natural or other gases on a large scale are well known, for example as shown in U.S. Patent No. 3,020,723 to De Lury et al. Known systems, in order to operate at reasonable efficiencies, require a relatively large number of cascade stages, generally using several different refrigerants having successfully lower boiling temperatures, in order to achieve the desired efficiency. The present invention achieves a high degree of efficiency by first cooling the natural gas under high pressure with a vapor compression refrigeration cycle in which the natural gas is heat exchanged against an evaporating liquid (e.g., propane) and then, at the same high pressure, is heat exchanged against cold gas in a gas expansion cycle with no liquefaction of the refrigerant gas. It is a feature of the invention that the gas in the gas expansion cycle is itself cooled against evaporating liquid in the vapor compression cycle to efficiently utilize the refrigeration potential thereof; another feature of the invention is that the refrigerant gas in the gas expansion cycle is the same type of gas as is being liquefied, typically methane, and that flash methane from the pressure let down of the liquefied main stream is put directly into the gas expansion cycle, preferably at more than one stage.

Another feature is that the expansion in the gas expansion cycle takes place in two stages, and the cold gas is put into heat exchange with the main stream between these two expansion stages, as well as after the second stage.

As mentioned above, among the main advantages of the invention is the relatively simple equipment required; however, a further advantage of the system is that it can handle gas with a relatively high content of impurities of higher volatility than the main constituent, e.g., nitrogen, without special precautions being taken to remove such impurities.

The specific nature of my invention, as well as other objects and advantages thereof, will clearly appear from a description of a preferred embodiment as shown in the accompanying drawing, in which FIG. 1 is a flow chart of a typical embodiment of the invention.

Referring to the figure, the invention will be described with reference to the liquefaction of a typical natural gas, the principal ingredient which is methane, typically over 90%, with some other hydrocarbons of less volatility such as propane, butane, etc., and containing nitrogen typically in amounts ranging from 0.65% to about 4.5%. Other impurities, such as water, H<sub>2</sub>S, CO<sub>2</sub>, and so forth, are removed prior to entering the liquefaction process by standard procedures, which are not a part of the present invention. The incoming natural gas in line 1 is initially at a pressure of about 750 p.s.i.a. and a tem-

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perature of about 70° F. The natural gas is initially subjected to two successive stages of heat exchange in a propane cycle, in heat exchangers 2 and 3.

In heat exchanger 2, the propane from storage tank 4 at 130 p.s.i.a. is let down sufficiently to cool the feed gas in line 1 down to 29° F. Throttle 2a is used with a conventional level-control device 2b to control the liquid level in heat exchanger 3, and similar control means are provided for heat exchangers 3, 13 and 21. The vapor which is flashed off upon expansion in the heat exchanger is conducted in line 6 to line 7, and thence to propane compressor 8 which raises its pressure to 130 p.s.i.a., and after cooling down 70° F. in a heat sink 9, it is returned to the storage tank 4, from which it is taken in line 11 to heat exchanger 2. Some of this propane is also diverted in line 12 to heat exchanger 13, where it is used to cool refrigerating gas in the gas expansion cycle as will be explained later.

Liquid propane from heat exchanger 2 is also taken in line 14 for use in heat exchanger 3, in which the feed gas is further cooled to minus 20° F. without reduction in pressure. Flash vapor from heat exchanger 3 is taken in line 16 at minus 25° F., and in line 17 at 22 p.s.i.a. to propane compressor 18, in which it is compressed and delivered to line 19 in a condition similar to the propane in line 7, which it joins as input to propane compressor 8. Propane from heat exchanger 13 is similarly passed through a second heat exchanger 21 to further re-cool refrigerant gas in line 27a which was previously cooled in heat exchanger 13.

Feed gas in line 1, now at minus 20° F., is passed successively through heat exchangers 22, 23, and 24, where the feed gas is successively cooled to the typical temperatures indicated in the drawing, by heat exchange with cold gas in the expansion refrigeration cycle. The feed gas emerges from heat exchanger 24 at a temperature of minus 238° F., and still at high pressure. It will be noted that the temperature of the feed gas was reduced, after passing heat exchanger 22 to minus 105° F.; the feed gas is condensed into liquid form in heat exchanger 23. The liquid feed gas emerging from heat exchanger 24 is now throttled down at 26, under control of pressure control device 26a, into flash tank 28, where its pressure is reduced to slightly above atmospheric. The resulting vaporization of some of the feed gas lowers the temperature of the liquid gas in 28 to minus 258° F., at which temperature it is taken in line 29, raised in pressure by compressor 35 to approximately 30 p.s.i.a., and throttled in throttle 50 down into final storage tank 31 at 15 p.s.i.a. The liquid methane in final storage tank 31 is at minus 258° F. and 15 p.s.i.a.

The gas expansion cycle which is employed in heat exchangers 22, 23 and 24 will now be described. This cycle uses methane (and light components) entirely in the gaseous condition, without liquefaction. Methane from heat exchanger 22 previously described, emerges in line 33 in spent condition at 13 p.s.i.a. and minus 34° F. It is joined by methane vapor from the final storage facility in line 34 under control of throttle 32 and pressure control device 32a at about the same pressure, but at a much lower temperature; these commingled streams join in line 36 and are compressed in methane compressor stages 37, 38, 39, and 41, all of which may be combined in a single multi-stage compressor if desired. Between the successive stages, the methane stream is cooled by heat sinks 42, 43, 44 and 46, which may be water coolers. Part of the output from compressor stage 39 is diverted

in line 40 at 331 p.s.i.a. and 70° F. for use as plant fuel, or any other purpose. At the operating conditions indicated, this output may amount to approximately 10% of the input feed gas. The rest of the output from compressor 39 is further compressed in the final stage compressor 41 and delivered to line 27a at 1020 p.s.i.a., and a final temperature (after passing through heat sink 46) of 70° F. This stream is then precooled in heat exchangers 13 and 21 as previously described, by heat exchange with propane from the propane cycle. After passing through heat exchanger 21, methane in line 27b is at minus 20° F. and 1,000 p.s.i.a.; this gas is now expanded in methane expander 47 (with the production of some useful work) to a temperature of minus 180° F., and then is passed in line 27c into heat exchanger 23, in conjunction with a separate gas feed stream to be later described. It assists in cooling the feed stream in line 1 from a temperature of minus 105° F. to a temperature of minus 161° F., as shown in the flow chart. The methane in line 27d after passing through heat exchanger 23, is at a temperature of minus 120° F. and 150 p.s.i.a.; in this condition, it is passed through second methane expander 48, and emerges in line 27e at 15 p.s.i.a. and minus 244° F. It is joined in line 33a by flash vapor from flash tank 28 previously described; and the commingled streams pass successively through heat exchangers 24, 23, and 22, in that order, to produce the cooling of the main feed stream previously described. Methane gas emerges in line 33 from heat exchanger 22 at a temperature of minus 34° F. as previously described. It will thus be noted that the gas expansion cooling cycle flows in an essentially closed circuit including the methane compressors, methane expanders, and heat exchangers 22, 23 and 24, with flash vapor from the feed gas added in lines 30 and 34, and a corresponding amount of methane gas removed in line 40.

A typical liquefaction plant using the invention may have an input flow of over 500,000 pounds per hour, a final storage capacity of 600,000 barrels for receiving liquefied gas at the rate of over 400,000 pounds per hour, and a plant fuel output on line 47 of nearly 50,000 pounds per hour. In large-scale operations of this type, it will be apparent that the need for both efficiency of operation and economy of capital investment are prime considerations in determining the practical success or failure of a given system. The present invention is directed toward improving both of these factors.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made in construction and arrangement within the scope of my invention as defined in the appended claims.

I claim:

1. Method of liquefying a gas comprising
  - (a) supplying the gas in a main feed stream at high pressure exceeding 300 p.s.i.a. and substantially ambient temperature,
  - (b) providing a separate liquid propane evaporating refrigerant in a vapor compression cycle,
  - (c) dividing the liquid refrigerant in parallel paths,
  - (d) cooling the feed gas by heat exchange with a throttled separate evaporating refrigerant from one of the paths while maintaining the feed gas at its high pressure,
  - (e) further cooling and condensing the feed gas at said high pressure by heat exchange with a second refrigerant in a recirculating gas expansion cycle wherein said second refrigerant is compressed as a gas, cooled to substantially ambient temperature as a gas, expanded to a low temperature as a gas, and heat exchanged with the feed gas,
  - (f) pre-cooling said second refrigerant after its compression and prior to its expansion by heat exchange with the other portion of said separate throttled liquid refrigerant, and
  - (g) throttling down said main feed stream in a flash

drum, to liquid form at a still lower temperature and reduced pressure, with the formation of flash vapor.

2. Method as claimed in claim 1, wherein said second refrigerant is the same type of gas as the feed stream, including

- (a) passing said flash vapor into the circulation stream of said second refrigerant to cool said refrigerant at a point where the pressure of said circulation stream is substantially at atmospheric pressure, and
- (b) taking off gas from said circulation stream as product gas at ambient temperature after at least partial compression.

3. Method as claimed in claim 2, including the steps of
  - (a) expanding said second refrigerant in step (e) of claim 1 in two stages,

- (b) putting said second refrigerant between said two stages in heat-exchange relationship with the main stream, and

- (c) further putting said second refrigerant, after the second expansion stage, in heat-exchange relationship with the main stream.

4. Method as claimed in claim 3, wherein step (c) of claim 3 is performed in several heat exchange steps in series, while the heat exchange of step (b) of claim 3 is performed in conjunction with only one of said series steps.

5. Method as claimed in claim 4, wherein the feed gas is natural gas consisting mainly of methane.

6. Method of liquefying a gas comprising

- (a) supplying the gas in a main feed stream at high pressure and substantially ambient temperature,

- (b) providing a separate liquid propane evaporating refrigerant in a vapor compression cycle,

- (c) dividing the liquid refrigerant in parallel paths,

- (d) cooling the feed gas by heat exchange with a throttled separate evaporating refrigerant from one of the paths while maintaining the feed gas at its high pressure,

- (e) further cooling the feed gas to below its critical temperature at said high pressure by heat exchange with a second refrigerant comprising a circulating stream of gas of the same type as the feed gas, wherein said second refrigerant is compressed as a gas, cooled to substantially ambient temperature as a gas, expanded to a low temperature as a gas, and heat exchanged with the feed gas,

- (f) throttling down said main feed stream in an evaporative cooler to liquid form at a still lower temperature and reduced pressure, with the formation of flash vapor,

- (g) passing said flash vapor into the circulation stream of said second refrigerant to cool said refrigerant at a point where the pressure of said circulating stream is substantially atmospheric pressure, and

- (h) taking off gas from said circulation stream as product gas at ambient temperature after at least partial compression.

7. Method as claimed in claim 6, including the steps of

- (a) expanding said second refrigerant in two stages,

- (b) putting said second refrigerant, between said two stages, in heat-exchange relationship with the main stream, and

- (c) further putting said second refrigerant, after the second expansion stage, in heat-exchange relationship with the main stream.

8. Method of liquefying a gas comprising

- (a) supplying the gas in a main feed stream at high pressure and substantially ambient temperature,

- (b) providing a separate liquid propane evaporating refrigerant in a vapor compression cycle,

- (c) dividing the liquid refrigerant in parallel paths,

- (d) cooling the feed gas by heat exchange with a throttled separate evaporating refrigerant from one of the

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paths while maintaining the feed gas at its high pressure,

- (e) further cooling the feed gas to below its critical temperature and said high pressure by heat exchange with a second refrigerant in a recirculating gas expansion cycle wherein said second refrigerant is compressed as a gas, cooled to substantially ambient temperature as a gas, expanded to a low temperature as a gas, and heat exchanged with the feed gas, 5
- (f) expanding said second refrigerant in two stages, 10
- (g) putting said second refrigerant, between said two stages, in heat exchange with the main stream and
- (h) further putting said second refrigerant, after the second expansion stage, in heat exchange with the main stream.
9. Method according to claim 8, wherein step (h) of claim 8 is performed in several heat exchange steps in

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series, while the heat exchange of step (g) is performed in conjunction with only one of said series steps.

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15 NORMAN YUDKOFF, *Primary Examiner.*

V. W. PRETKA, *Assistant Examiner.*