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METHOD FOR THE LIQUEFACTION AND SEPARATION  
OF GASES WITH THE AID OF EXTERNAL WORK  
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Fig. 1

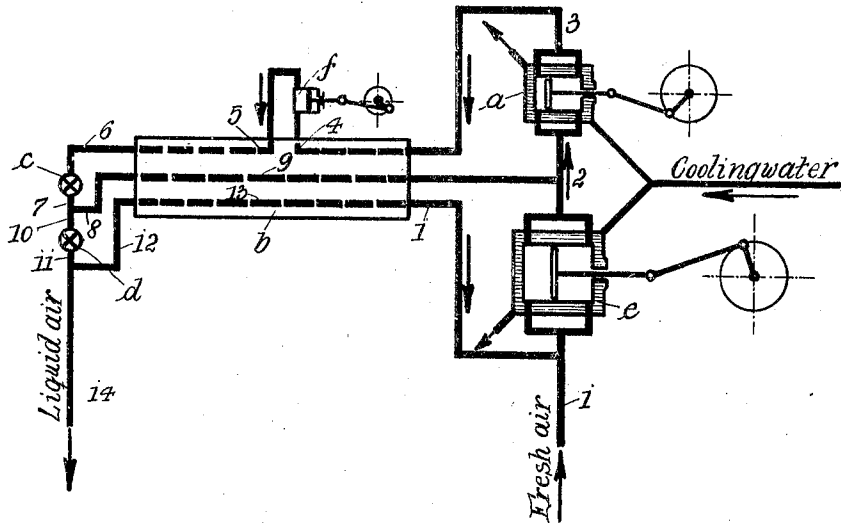
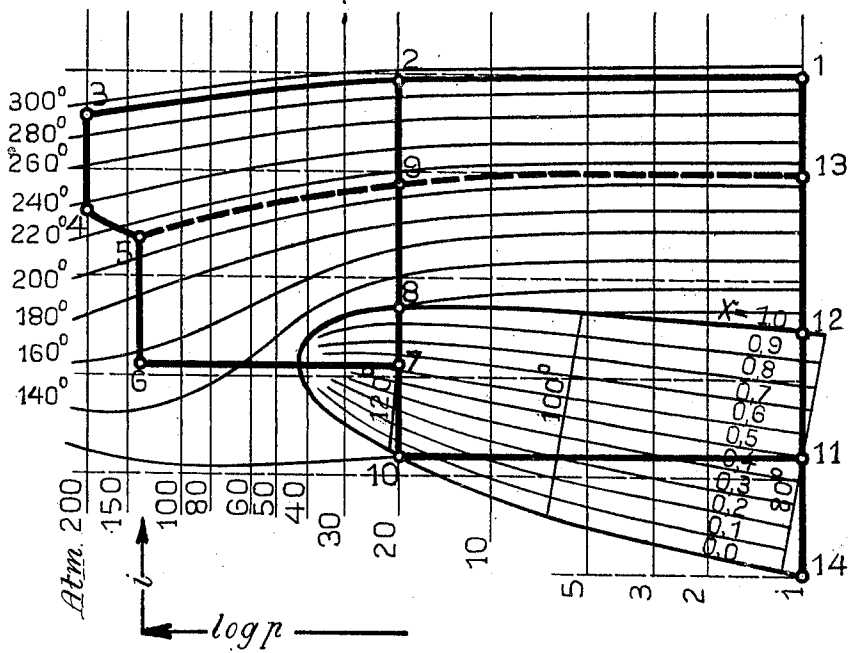


Fig. 2



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## UNITED STATES PATENT OFFICE.

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## METHOD FOR THE LIQUEFACTION AND SEPARATION OF GASES WITH THE AID OF EXTERNAL WORK.

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*To all whom it may concern:*

Be it known that I, ARTHUR SELIGMANN, a citizen of the Germany, residing at Bremen, Germany, have invented certain  
5 new and useful Improvements in a Method for the Liquefaction and Separation of Gases with the Aid of External Work (for which I have filed application in Germany May 26, 1922); and I do hereby declare the following to be a full, clear, and  
10 exact description of the invention, such as will enable others skilled in the art to which it appertains to make and use the same.

My invention relates to an improved  
15 method for the liquefaction and separation of gases with the aid of external work. It would be theoretically possible per se to completely liquefy liquefiable gases merely by expansion in doing outer work. Only  
20 in this manner the minimum of energy consumption can be realized. Practically it is however impossible to work a power engine perfectly, for instance at the temperature of the liquid air being under atmospheric  
25 pressure (80° abs.). The first technical air liquefaction (Linde) was carried through in abandoning the outer work, merely with the aid of the internal work by throttling or  
30 by a method which is extremely unfavorable from a heat-theoretical point of view. Subsequently experiments have been made to use expansion machines again for diminishing the energy consumption. The methods  
35 which has been mainly applied in practice, that by Claude and that by Heylandt, must be satisfied with producing only a part of the refrigerating duty by outer work, for the remainder the throttling must be used. According to both these methods one  
40 proceeds in such a manner that the air is divided and only the one part-current is sent through the power engines.

According to my improved method only a  
45 part of the refrigerating duty takes place in an expansion machine and the method differs from the known methods essentially in that the decrease of pressure but not the quantity of the gas are divided.

The accompanying drawing illustrates the  
50 idea of the invention.

Fig. 1 is a diagram and Fig. 2 illustrates the process in a diagram which has coordinates as the specific heat contents  $i$  and the logarithm of the pressure  $p$ , which  
55 is especially adapted for the comparison of

methods of this kind. The numerals relate to air. The curves drawn in full lines are isotherms for the inscribed absolute temperatures, the horizontal curves drawn in dash lines are throttle curves and their distances from each other correspond to 20 kcal/kg.; the vertical lines are isobars. The border curve and further lines of constant vapour quality are also shown. Corresponding points are designated in both figures by the same numerals. Although as  
60 example an air liquefying process with double circuit has been chosen, my invention is not limited to such a process. A simple circuit may also be used. The temperatures  
65 and pressures are indicated in absolute measure.

In the high pressure compressor  $a$  the air is isothermically compressed at 290° abs. from 20-200 atm. abs., forced through the first  
75 part of the counter current apparatus  $b$ , in being cooled isobarically to 238°, then adiabatically expanded to 142 atm. in the expansion cylinder  $f$ , at which occasion it cools down to 213° and produces a working efficiency equal to 7 kcal/kg. The air is further isobarically cooled in the second part of the counter current apparatus  $b$  and  
80 throttled in the throttle valve  $c$  to 20 atm. in being cooled from 155° to 119° and liquefied to 37%. The remaining vapour transmits in  $b$  again its cold and is sucked in again by  $a$ , the liquid however is throttled  
85 a second time in the valve  $d$  to 1 atm. in cooling down to 80° and in being evaporated again for 49%. The liquid which now remains is the desired final product. The cold vapour is conducted under equal pressure and heat absorption through  $b$  and forced  
90 back isothermically from the low pressure-compressor  $e$  together with the required quantity of fresh air into the suction tube of  $a$ .

Owing to the fact that part of the refrigerating efficiency is produced by throttling  
100 at lowest temperature it is possible to make the other part work at considerably higher temperature, whereby the difficulties connected with the working of the power engine are considerably reduced. The adiabatic  
105 refrigerating duty could theoretically be placed at a higher or lower temperature than stated in the example and in this case it ought amount to a lesser or greater fraction of the total refrigerating duty. The  
110

entire expansion may be considered as a kind of preliminary cooling of the high-pressure air and the advantage, in comparison with the well known preliminary cooling  
 5 by means of cold vapour machines, consists, besides the suppression of the total special plant required for this purpose, in that not only no power has to be expended but that power is even produced.

10 If the state 5 at the end of the expansion is definite the state 4 at the admission into the cylinder can evidently no longer be freely selected on the adiabat but the required refrigerating duty is clearly determined owing  
 15 to the heat transmission in the counter current apparatus. It seems unnecessary to discuss the manner of calculation. In practical application the temperature at the end of the expansion will be of such a low degree that  
 20 the working and lubricating of the machine can just be effected without any difficulty.

Although it is theoretically better if a greater percentage of the total refrigerating duty is produced by performing outer work,  
 25 so that in this respect the commonly used methods appear to be superior, it must not be overlooked that, according to my method the adiabatic expansion which theoretically is considered to be right can be much better  
 30 converted into practice than according to the commonly used methods. The insulating of the cylinder against access of heat from the outside is to be carried through in a much better manner as the cylinder does by far  
 35 not get so cold as that of Heylandt or as that of Claude, and it is further of considerably smaller size, as its dimensions are evidently determined by the volume of the air at the end of the expansion, the air being, according to my method at this moment under higher pressure. In all piston  
 40 machines the wall losses (which means the irreversible transmission of heat between the inflowing and outflowing gases) are especially disturbing, these losses are however directly proportional to the temperature difference which occurs in the cylinder. This temperature difference is also considerably  
 45 smaller than according to Claude's method and scarcely to be compared with the enormous drop of temperature which characterizes the Heylandt method. In my method the losses due to clearance are further much  
 50 smaller as the pressure ratio is considerably smaller than according to the two methods  
 55

mentioned above. Evidently a turbine might be used for doing the work instead of the piston machine.

The outer work may be further done in two or more steps not directly continuous, 60 a portion of a counter-current apparatus being inserted between every two steps.

The method is further adapted for the liquefaction of hydrogen or helium. With this object in view it is merely necessary 65 to work an expansion machine in such a manner that the final temperature of the expansion is slightly below the integral inversion temperature for the corresponding pressure, this being somewhat difficult but 70 not impossible.

In the case that the liquefaction of the gas is not the final object but only the means for separating it into its constituents, which in this case have to be delivered hot and at 75 gaseous state, the method can be applied. In the counter current apparatus quantitatively other conditions will then prevail but qualitatively the same conditions. The quantity of back-flowing gases is equal to 80 the quantity of the advancing gases but their specific heat is lower at the expanded state. Consequently a part of the refrigeration duty can be performed also in this case at moderate temperature. 85

What I claim is:

1. A method for liquefaction and separation of gases with the aid of external work performance in which the total quantity of gas circulating in the apparatus is at first 90 preliminarily cooled in counter current, then partly expanded in a machine in performing work, cooled further in counter current and finally completely expanded by simple throttling. 95

2. A method for the liquefaction and separation of gaseous mixtures containing helium with the aid of external work performance in which the total quantity of gas circulating in the apparatus is at first preliminarily 100 cooled in counter current, then partly expanded in a machine in performing work, cooled further in counter current and finally completely expanded by simple throttling the state at the end of the last work- 105 performing expansion being situated with in the integral inversion curve of the throttling action.

In testimony whereof, I affix my signature.  
 ARTHUR SELIGMANN.