**(Reprint from "Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns" — Vol. 4, No. 1, Pages 14—23, Oberhausen (Rhld) — August 1935.)**

# The Linde-Fränkl Process For The Separation Of Gas Mixtures.

By

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Utilization of regenerators in the liquefaction and separation of gases; method of operating regenerators; their advantages over recuperators; utilization in connection with power-saving processes; expansion with production of external work; expansion turbines; blowing uncompressed gas mixture into the rectification column; description of an oxygen plant with regenerators; co-current evaporator; power consumption figures.

Up to a short time ago the excessive cost of oxygen stood in the path of the utilization of oxygen or oxygen-enriched air for chemical and metallurgical processes of many different kinds; because the costs of its production according to the heretofore known processes were too high to permit gaining the advantages of its application for such purposes.

This has been changed in recent years wherein it has become possible for the *Gesellschaft für Linde's Eismaschinen A.-G.* to develop a process first proposed by *Matthias Fränkl* (D.R.P. 490878), namely, the utilization of cold accumulators in the liquefaction and separation of gas mixtures, to such an extent that it is now possible to produce oxygen in oxygen plants operating in accordance with this method at a price appreciably lower than that of oxygen produced in accordance with the previously customary methods of operation so that the price factor to a great extent no longer stands in the path of its utilization. The new process can only be utilized when the required purity of the finished product is not too high; oxygen for welding and cutting, therefore, cannot be produced by means of the new process. Furthermore, it is suitable only for large plants, for example, for oxygen production in units having an hourly capacity of approximately 200 m³ oxygen and up; however, in the utilization of oxygen in the metallurgical and chemical industries only very large plants — of a totally different order of magnitude than that to which we have been heretofore accustomed — will in general enter consideration.

Various large chemical works already some time ago erected plants with the best of success in accordance with the Linde-Fränkl Process. As an example, at the beginning of 1935 one of these plants (with three units) produced over 6500 m³ oxygen of a purity of 98.5% per hour. The capacity of this plant will be increased in the near future to an hourly production of more than 12 000 m³ (five units).

The new process will be more fully described below. Its great advantages, through which are obtained an appreciable reduction in the production costs, are based above all, as mentioned above, on the utilization of alternately operated cold accumulators ("Regenerators") in place of the previously solely customary, continuously operating tubular exchangers ("Recuperators").

The exchangers heretofore employed consist as is known of tube-bundles through which on the one hand the gas mixture, still warm, which is to be separated, is conducted into the separation apparatus, and on the other hand the cold separation products are led out counter-currently, whereby the heat is exchanged more or less efficiently between these gases through the tube walls. The greater this efficiency is desired to be, thus reducing the cold and thereby power losses, the greater must be the transfer surfaces, the longer the gas paths, or the higher the gas velocities. However, transfer surfaces consisting of tubes are expensive due both to the necessarily high tube wall strength required and to the high cost of the working material — in most instances only copper can be processed — as well as due to the high labor cost involved. Simultaneously the longer gas paths and greater gas velocities cause an increase in the pressure drop of the gas. This, however, increases the pressure in the separation apparatus and likewise the minimum pressure to which the gas mixture to be separated must be compressed prior to entering the apparatus. This again, however, brings with it an increase in the power consumption of the plant, so that in determining the dimensions of a tubular exchanger it is difficult to find a balance between the various requirements. It is particularly difficult to construct good heat exchangers in the form of continuously operating counter-current coils when there is only a slight pressure difference between the gases flowing inside and outside the tubes. With equal volumes of the gases flowing in the two directions, due to the low difference between the specific heats, the temperature differences at all points in the counter-current coils are very low. A good exchange could, therefore, only be attained through extraordinary great heating surfaces and an impermissibly high pressure drop which, however, would be particularly troublesome at low pressures. For this same reason also, certain other processes yet to be discussed, by means of which the separation could be effected at low pressures and therewith lower power consumption, could not be used at all or with only slight efficacy in plants employing continuously operating counter-current coils. Therefore, regardless of the manner of constructing the tubular exchangers, they will always have an appreciable effect on the production cost of the separation products, whether caused by a high power consumption of the plant for which they are responsible or by the paying off of their high original cost.

The *Fränkl* invention herein introduces a change. The cold accumulators proposed by him in place of tubular exchangers are of the same type as those frequently employed heretofore in the metallurgical industry (for example, in Siemens-Martin furnaces). There, however, they attained an efficiency of approximately 80% at the highest, while in the separation of gases tubular exchangers have already been constructed with efficiencies of approximately 98%. Fränkl, however, has now shown the way to produce cold accumulators having an efficiency of more than 99%. In the process discussed herein they are cylindrical vessels 4—5 m in height of suitable diameter which are filled with a filler-mass having the greatest possible surface *(Fig. 1)*. For the purpose of regulating the direction of flow of the gases, regulating equipment is provided at the top of the vessels which is actuated, for example, by means of compressed air, while automatically operating valves or flaps are provided at the lower end. Two cold accumulators always operate together. For this reason four accumulators must be provided for the separation of air: one pair for the heat exchange between the air and the produced oxygen and one pair for the exchange between the air and the nitrogen; because the method of operation of the cold accumulators is as follows: while the air flows downwards through the first accumulator into the separation apparatus, warming this first accumulator and thereby cooling itself, the separation product leaves the apparatus and flows upwards through the second accumulator, cooling this second accumulator and itself taking up heat from same. After a certain period (1—4 min) the reversing equipment is operated through which the gas directions are reversed, so that now the air is cooled in the second accumulator which became cold in the preceding time interval, and the separation product gives up its cold to the first accumulator which had previously been warmed. After the same period reversal is again effected and the operation is thus regularly repeated. From the fact that air and cold gases flow through the cold accumulators in opposite directions, it is apparent that the cold accumulators are also counter-current exchangers. The reversal periods are so measured, in consideration of the volume of heat that the accumulator mass can take up, that the temperature fluctuations at the upper and lower ends of the accumulators do not become too great. The filler mass which has proved best — likewise

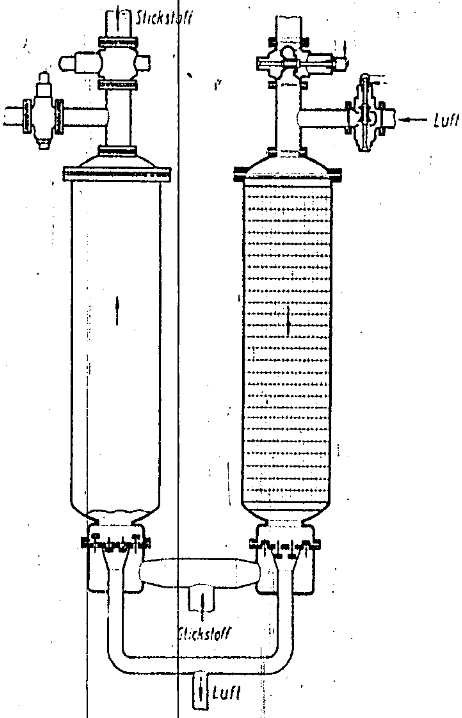

Fig. 1.
Couple of cold accumulators.
(Luft = air, Stickstoff = Nitrogen)

proposed by Fränkl — consists of tightly wound spiral layers made up of thin corrugated metal bands approximately 25 mm wide *(Fig. 2).*

Such cold accumulators have the following advantages over the tubular exchangers: It is possible to locate exceedingly large heating surfaces in them in a comparatively small space. In the described method for instance, more than 1000 m² heating surface is contained in a total space of only 1 m³. One thereby obtains cross-sections for the gases which have only a very small hydraulic diameter, through which the heat transfer conditions become very favorable even with low gas velocities. The pressure losses therefore also become low, in fact so low that they could not be attained at all with tubular exchangers and low pressures. It has been determined in already erected oxygen plants, for example, that it is possible to attain, at the warm ends of the accumulators, a temperature difference of less than 0.5° between low pressure air (4.3 atm.) and oxygen and nitrogen (0.02 atm.) with a pressure drop of the low pressure air of less than 0.1 atm. and the expanded gas of approximately 0.15 atm. in the accumulators including the regulating equipment installed on them at the top and the bottom.

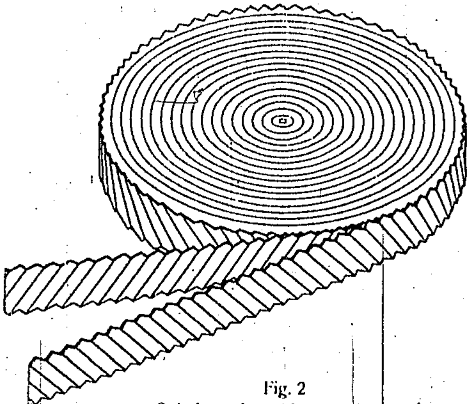

Fig. 2
Spiral tray for cold accumulator.

Besides the cost of manufacturing one of these cold accumulators which is so efficient from a heat technique standpoint is low. In comparison with the cost of tubular exchangers, both the labor and raw material costs are considerably lower. Here the expensive copper is not the sole possible material, but rather the accumulator casings can be made of iron and the spiral discs of aluminum or also of galvanized or aluminum-covered iron. Above all, the sheet metal utilized may be very thin inasmuch as no consideration need be given to strength or tightness.

To this, however, must still be added a further large advantage of the cold accumulators, namely, that a preliminary purification of the gas mixture to be separated is no longer necessary. In utilizing the older processes all moisture and carbon dioxide contained in the gases must be carefully removed prior to their entrance into the separation apparatus; because ice and carbon dioxide frost would very rapidly obstruct the apparatus cross-sections, so that operation would become impossible already after a brief period. Thus, in the separation of air, the carbon dioxide is removed, for example, through washing the air with a solution of caustic soda and the moisture through chemical drying or by forecooling to approximately —40° C. If, however, cold accumulators are employed, then all this equipment can be eliminated (provided a slight moisture and carbon dioxide content in the oxygen is not harmful, which will probably always be the case). When passing through the cold accumulator water vapor and carbon dioxide are precipitated from the air to the cold surfaces of the discs and are again evaporated (sublimed) following the reversal by the separation products which come, absolutely dry and free from carbon dioxide, from the inner apparatus and thus take them along out of the cold accumulators. These steps are effected the more certainly the greater the ratio of the volume of the outgoing gas to that of the incoming air; in practice it has been found that a ratio of 1.5:1 which due to the difference in gas pressures is usually present in all instances or at least is easily produced, is sufficient. The elimination of the equipment for drying and for carbon dioxide purification, however, not only reduces the original cost of the plant, but rather also appreciably reduces its operating costs through the thus effected savings in power, chemicals and operating labor.

It is true, however, that opposed to these great advantages of the cold accumulators, there are also several disadvantages: As mentioned above, they bring with them the peculiarity of their operation, namely, that the raw gas and the separation products flow consecutively through the same chambers. When utilizing cold accumulators, therefore, it is practically impossible to produce absolutely pure gas; because at each reversal the volume of raw gas which happens to be in the one accumulator enters into the exit-line of the pure gas and contaminates the latter. This disadvantage can be appreciably eliminated in that a preliminary outlet is provided for the gas to be produced at the warm ends of the accumulators which is so regulated that for a period following the reversal the accumulator in question blows to the atmosphere and then is also slightly washed out prior to being connected with the outlet line of the pure gas. However, even if this washing at the beginning of each reversal interval were extended for a longer period — which naturally would mean a loss in produced gas — it would still be impossible to obtain gas purities of 99.7—99.9% which purities are possible to attain with the standard separation processes and to which many industries have become accustomed. This is due to the fact that in practice it is not possible to continuously prevent every small leak in the reversal equipment even with the best construction and most careful operation; this applies particularly to the check valves which operate at low temperature at the lower ends of the accumulators. In plants employing cold accumulators, therefore, it is for instance impossible to produce nitrogen of such extremely high purity (0.02% $O_2$) as that required for the synthesis of ammonia. Even the now general customary high purity of the oxygen for gas welding and cutting is difficult to attain. Still it is possible in air separation plants employing cold accumulators, as has been proved by actual operations, to produce nitrogen having an $O_2$ content of at least 1% and oxygen having an $O_2$-content up to 99%; the real field of application is the production of oxygen of 40—98% purity. If, however, a higher purity is demanded, it will be possible to conduct the produced oxygen through tubular exchangers of the customary type and to retain the cold accumulators at least for the nitrogen resulting thereby as a by-product; the advantages of the cold accumulators are thus still retained for fourfifths of the air. Furthermore, a smaller portion, approximately 4%, of the nitrogen resulting during the oxygen production can, if required, be recovered in pure form also in plants utilizing cold accumulators.

There is a further disadvantage connected with the reversal of the cold accumulators. It was mentioned above that the raw gas volumes still remaining in the cold accumulators at the time of reversal entered the separation products. These raw gas volumes, therefore, are lost to the separation process itself and the yield of pure gas is thus reduced. The greater the pressure of the raw gas, the greater these losses become; for high pressures, therefore, continuously operating exchangers are to be preferred. With pressures up to approximately 8 atm., however, it is possible to keep the reversal losses very low — through suitable reversal precautions; in air separation plants with an air pressure of approximately 4.4 atm. these losses amount to only 3—4%.

The above described favorable characteristics of the cold accumulator: very low cold losses and very low resistances result, as mentioned, in a considerable reduction of the power consumption of a separation plant. To this must still be added, however, that power saving processes which, as was mentioned briefly above, previously could be utilized not at all or only with insufficient efficacy because operated with low pressures, now can be employed for further reducing the power consumption by means of utilizing cold accumulators as heat exchangers.

This applies above all to the method of operation employed by Claude in which the cold required for carrying out a separation process is produced through the expansion of compressed gases in an expansion engine with production of external work instead of only through a purely throttling-action *(Thomson-Joule-Effect)*. In plants using expansion engines it has heretofore been necessary to operate with pressures appreciably higher than those theoretically required, particularly because it was impossible to construct countercurrent coils which, as shown above, would have given low losses with low pressures of the compressed gases. This thus results in the partial loss again of the advantage of the greater cold production of an expansion engine per $m^3$ expanded gas as compared to that of an expansion by means of throttling. For this reason and because expansion engines operating at a low temperature always make the operation somewhat more difficult, there has heretofore been no incentive for utilising them to a considerable extent in place of the simple throttling. However, the fact that it is possible through the utilization of cold accumulators to attain excellent heat transfer conditions already at comparatively low pressures and to reduce the unavoidable losses to a minimum, makes it possible to produce all or by far the major portion of the cold through expansion engines already with those low pressures which are required anyway for the gas separation.

Inasmuch as in most cases plants employing cold accumulators have large units of high hourly capacity and therefore the gas volumes to be conducted through the expansion engine are quite considerable, it is possible to profitably utilize expansion turbines in place of piston-engines. All losses and inconveniences are thereby absolutely eliminated which could result through regulators, stuffing boxes, lubrication or piston seals in piston-engines operating at a low temperature. The cold-gas turbines specially developed by the *Gesellschaft Linde* represent an expansion engine which can operate with practically no supervision or operating interruption and which has an excellent thermodynamic efficiency.

Furthermore, only the use of cold accumulators makes possible the full utilization of a process proposed by Lachmann. This process consists therein that air, only slightly compressed, cooled to liquefaction temperature but still in gaseous state, is blown into the upper (2nd) column of a double-column air separation apparatus at that point in the column at which the rising vapors have the approximate composition of air. With an ordinary double-column apparatus wherein the entire air to be separated is introduced into the pressure column (1st column) under the pressure of this column, more vapors rise upwards in the lower portion of the upper column than would be required for a sufficient rectification effect; the volume of the liquid trickling downwards through the upper column is also thereby unnecessarily large. Although this appreciably facilitates the rectification in the upper column, nevertheless the rectification process proceeds with a power loss due to the fact that the heat exchange between the down-trickling liquid and the rising vapors is accomplished with unnecessarily large temperature differences. These differences, however, are appreciably smaller in the *Lachmann* method of operation. Inasmuch as more than 40% of the entire air volume could theoretically be blown into the upper column, that is, would not have to be compressed, a corresponding saving in power could be effected. Heretofore, however, it has been impossible to make use of this process inasmuch as the losses that would result during the cooling of the blower air in continuously operating counter-current coils through pressure drop and poor exchange would again cancel the intended advantage. The described favorable characteristics of the cold accumulators, however, make the utilization of the *Lachmann* Process possible. The thereby somewhat difficult rectification can still be practically carried out with very good results through the new construction of the rectification trays (circular trays, patented by the *Gesellschaft Linde*).

With this process the required cold can now be produced in a very simple manner. The entire air volume is again compressed to the pressure column pressure and cooled in cold accumulators. However, the portion to be blown into the upper column is expanded at suitable temperature in an expansion turbine to the pressure and temperature of the upper column and is then introduced into the upper column. If the volume of the air to be blown in is approximately 30% and the pressure column pressure is about 4 atm., then the cold production of the turbine will suffice for covering the entire losses.

The *Gesellschaft Linde* has recently constructed several large air separation plants whose method of operation is a variation of this process, a variation which was chosen because of several practical advantages (for example, the certain evaporation of the carbon dioxide in the cold accumulators), but which does not follow the described method of operation. This method of construction will be explained by means of Figure 3. In the plant selected as an example oxygen containing 98 to 99% $O_2$ is to be produced. The pressure required for the separation, that is the pressure of the first column — it is dependent upon the purity of the oxygen — amounts then to 4.3 to 4.4 atm. It is now entirely sufficient to compress by far the greater portion of the air only to this pressure; the most inexpensive method of accomplishing this in large plants generally being by means of turbo-compressors. The compressed air is cooled through cold accumulators; thereby freed from water and carbon dioxide, and is then conducted to the pressure column (1). The cold required for carrying out the process is produced by means of withdrawing a portion of the nitrogen produced in the pressure column — 15—20% of the total air volume — at the top of this column, heating it several degrees and then conducting it to an expansion turbine wherein it is expanded with production of work to the pressure of the nitrogen coming from the upper column — approximately 0.15 atm. The nitrogen must be heated prior to entering the turbine in order that liquefaction of the nitrogen will not occur during the expansion and thus impair the thermodynamic efficiency. The nitrogen is heated in a counter-current coil (6) by means of a small quantity of high pressure air of approximately 120 atm. which is thereby liquefied in heat exchange with the nitrogen and then expanded through a throttle-valve into the upper column. This volume of high pressure air at the most amounts to 4% of the total air volume, which means, therefore, that 96% of the entire air must be compressed to the above mentioned low pressure of only approximately 4.4 atm. However, the small quantity of high pressure air, due to the fact that it is conducted through continuously operating counter-current coils (5 and 6) to the separation apparatus, must be freed from carbon dioxide and dried prior to entering the counter-current coils — cold accumulators would not be suitable for this purpose owing to the small volume involved and to the comparatively large reversal losses caused by the high pressure ÷; the costs of this step are very low in comparison to the volume. The nitrogen withdrawn from the pressure column is naturally lost for the trickling of the upper column; as a whole, however, as has been shown, a saving in power results inasmuch as the favorable relation between liquid and vapor strived for by Lachmann is attained, and the rectification in the upper column can still be conducted in such a manner that the entire withdrawn oxygen does not contain much more than 2% $O_2$. The high pressure air is cooled in the last named counter-current coil (5) by means of nitrogen which comes from the turbine. The volume of this nitrogen is only approximately one-fourth that of the high pressure air. Through this inversely the volume of the gases, oxygen and nitrogen, passing out through the cold accumulators is greater than that of the air entering through the accumulators. As a result of this mode of action the complete removal of the impurities deposited in the accumulators through the outgoing gases is assured.

Another method of cold production consists in expanding the high pressure air with production of work in a *Heylandt* expansion engine which operates starting with high pressures and room temperature. This method of operation will find advantageous utilization above all in those instances where oxygen of lower purity is to be produced and where as a result the separation pressure would be lower and the cold to be produced per m³ low pressure air would also be less. Such an expansion engine is naturally always a piston-engine inasmuch as the pressure of the air to be handled is high and for that reason its specific volume is very small; however, inasmuch as the engine operates starting at room temperature, the major portion of the above mentioned difficulties of the piston engines can be prevented.

A further process which particularly with the utilization of cold accumulators likewise favorably from a power consumption standpoint, consists in the use of so-called co-current evaporators. They serve for the purpose of producing oxygen of lower purity with a lower power consumption corresponding to the lower purity. Fundamentally a co-current evaporator operates in the following manner */Fig. 4/:* For example, a liquid oxygen-nitrogen mixture is permitted to flow from the top to the bottom over trays which are arranged around a tube-bundle and is thereby totally evaporated, whereby the resulting oxygen vapors pass downwards co-currently with the liquid and the oxygen-enrichment of the liquid increases steadily towards the bottom and thus it becomes warmer. The heat required for evaporating the oxygen is led in through the low pressure air which is lique-

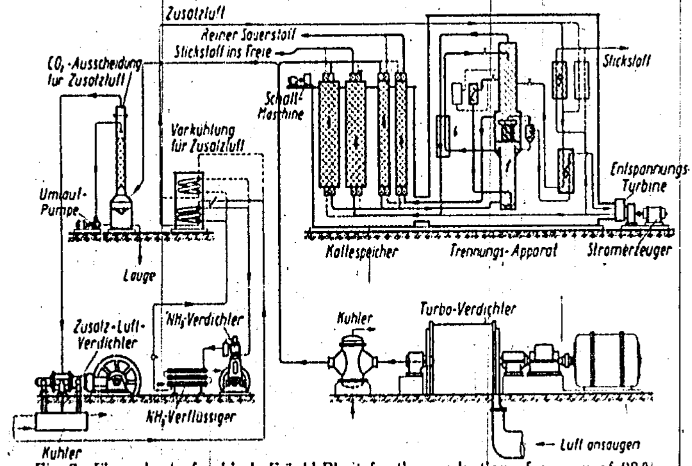

Fig. 3: Flow sheet of a Linde-Fränkl Plant for the production of oxygen of 98%.
1 = Rectification columns / 2 = Filtre for purification of the liquid oxygen coming from the 1st column
3 = Separating vessel / 4, 5 and 6 = Counter-current interchanger.

| | | | | | |
|---|---|---|---|---|---|
| Zusatzluft | Additional-Air | Lauge | Caustic Soda Lye | Entspannungs- | Expansion |
| Reiner Sauerstoff | Pure Oxygen | Schaltmaschine | Reversing Engine | Turbine | Turbine |
| Stickstoff ins Freie | Nitrogen in the open | Kältespeicher | Cold Accumulator | Zusatz-Luft- | Additional- |
| $CO_2$-Ausscheidung | $CO_2$-Absorption | Trennungs- | Separating | Verdichter | Air Compressor |
| für Zusatzluft | for additional-air | Apparat | Apparatus | $NH_3$-Verdichter | $NH_3$-Compressor |
| Vorkühlung für | Precooling for | Stromerzeuger | Electric Current | $NH_3$-Verflüssiger | $NH_3$-Liquefyer |
| Zusatzluft | additional-air | | Generator | Turbo-Verdichter | Turbo-Compressor |
| Umlaufpumpe | Circulating Pump | Kühler | Cooler | Luft-Ansaugung | Air Intake |

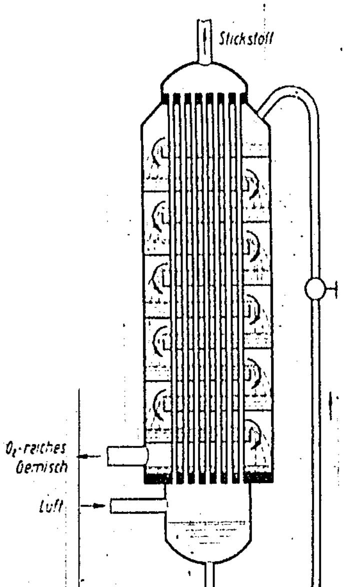

Fig. 4
Flow sheet of a Co-current evaporator.
(Luft = Air, Stickstoff = Nitrogen
$O_2$-reiches Gemisch = $O_2$-enriched Mixture)

fied to a considerable extent inside the tubes. The there occurring liquid becomes enriched with oxygen while trickling downwards, while the vapors reaching the top become more or less pure nitrogen (reflux liquefaction, fractional condensation, according to *Claude:* condensation avec retour en arrière). Here again the advantage consists in the reduction of the pressure; because the vapors rising in the pressure chamber of the co-current evaporator, in accordance with their upwards diminishing oxygen content and their thus upwards decreasing temperature, are in heat exchange with evaporating liquid which is likewise colder at the top than at the bottom, in contrast to the condensator in an ordinary pressure column wherein the coldest portion of the air, the nitrogen, must be precipitated through the evaporation of the warmest liquid, the more or less pure oxygen. If the oxygen is permitted to boil on the trays at a sub-pressure of approximately 0.5 atm, it will suffice to compress the air to be separated practically to only about 0.2 atm. While the nitrogen leaves the top of the tube bundle practically pure, it is possible to produce the oxygen with an $O_2$-content of approximately 50%. The necessary cold must hereby be produced by means of a separately erected air liquefaction plant. A still simpler method consists in compressing the air to slightly more than 1 atm. and permitting the oxygen to boil at approximately atmospheric pressure; the required cold production can then be obtained through expansion of the produced nitrogen in an expansion engine. Hereby, however, the oxygen attains a purity of only about 42%, corresponding to the state of equilibrium between vapor and liquid at the higher pressure at the bottom in the co-current evaporator.

If a co-current evaporator is further combined with a rectification column, it is possible to obtain oxygen with an $O_2$-content of from 60 to 80% in an advantageous manner.

There are still other possibilities of constructing plants with cold accumulators in a cost-saving

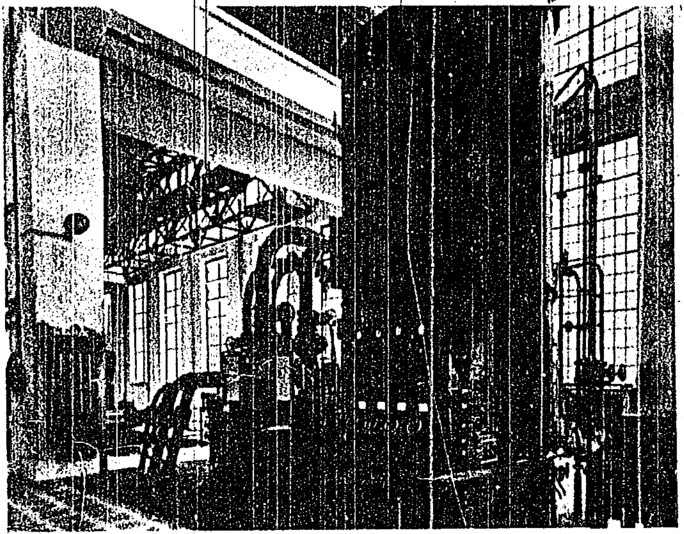

Fig. 5
Linde-Fränkl Plant for 600 m$^3$ h Oxygen (98%)
Left: Upper part of cold accumulators
Right: Upper part of the separating apparatus.

### TABLE I.

Power Consumption Figures for the Production of Oxygen of Various Purities.

| Purity of the produced Oxygen Mixture | Power Consumption per m³ Oxygen Mixture | Power Consumption per m³ pure Oxygen (100 %) in Oxygen Mixture | Volume of Nitrogen to be removed from the air per m³ Oxygen Mixture | Power Consumption per m³ Removed Nitrogen |
|---|---|---|---|---|
| % $O_2$ | KWH/m³ | KWH/m³ | m³/m³ | KWH/m³ |
| 40 | 0,09 | 0.22 | 0.92 | 0.095 |
| 60 | 0.19 | 0.315 | 1.87 | 0.1 |
| 80 | 0.31 | 0.39 | 2,83 | 0.11 |
| 90 | 0,38 | 0.425 | 3.31 | 0,115 |
| 98 | 0.445 | 0.455 | 3.69 | 0.12 |
| To be compared with the figures for a large plant utilizing tubular exchangers: | | | | |
| 98 | 0.65 | 0.665 | 3.69 | 0.175 |
| 99.7 | 0.73 | 0.73 | 3.77 | 0,195 |

manner, however, it would lead too far afield to attempt to enumerate all these possibilities here. One or another of the processes will be employed from case to case depending upon the purpose for which the gas is to be utilized; naturally the particular degree of purity of the oxygen and the corresponding method of its production will always be selected on the basis of what is best suited for the production of the end products of the total operations and which entail the lowest costs.

From the above description can be seen the great advantages it is possible to obtain wherever the possibility exists of utilizing the *Linde-Fränkl* Process in gas separation plants. The savings are quite considerable, both in plant as well as in power costs, so that the total production costs per m³ oxygen are reduced to a fraction of the costs which can be calculated in the most favorable instance according to the old processes. In order to present a picture of the power costs, figures are given in *Table 1* covering the power consumption of plants with electrically driven compressors (measured at the switchboard), for the production of oxygen of various purities; they apply to large plants. The figures are dependent upon the size of the plant, therefore, somewhat higher values apply for smaller plants. In the utilization of oxygen-enriched air, for example, as blast-furnace

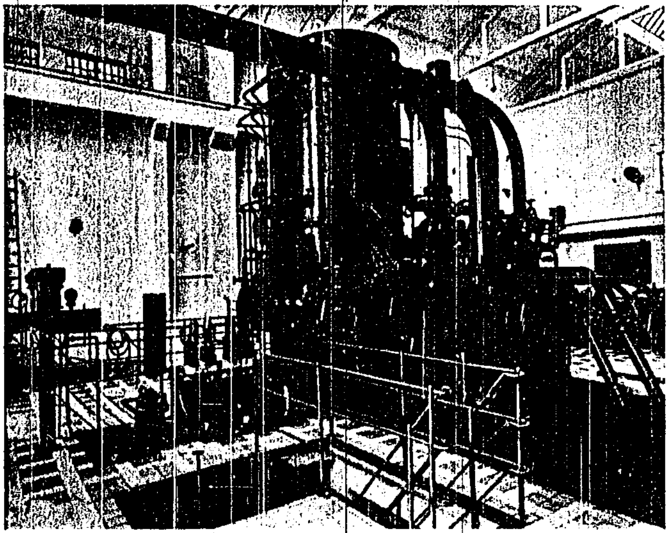

Fig. 6

Back view of the plant Fig. 5. Left: Expansion engine with 2 stages
Middel: Separating apparatus Right: Cold accumulators

93

blast, the matter in question is not really the production of oxygen, but rather the removal of nitrogen from combustion air. For a certain degree of enrichment of the blast, the same quantities of nitrogen are thereby always to be removed irrespective of the purity of the oxygen produced in the oxygen plant. For this reason, in order to judge the various possibilities, the Table also shows the power consumption figures per m³ removed nitrogen. They afford an excellent comparative possibility and show with particular clarity that it is most favorable — judging from a power consumption standpoint — to produce the oxygen with no greater purity than is actually required.

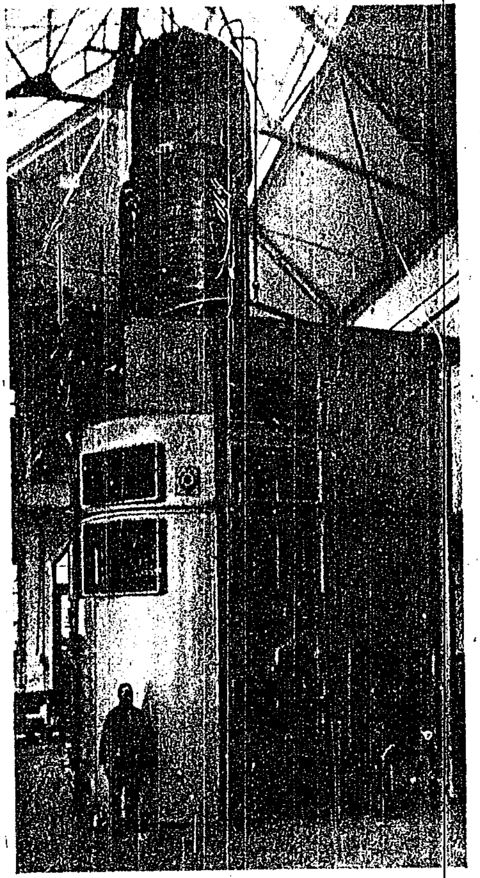

Fig. 7

Linde-Fränkl-Apparatus for 2600 m³/h Oxygen (98 %) at erecting in the work shop.

Finally, in order to present a picture of the appearance and size of recent plants which operate in accordance with the *Linde-Fränkl* Process, *Photographs 5 to 9* are included herewith; they are of plants which were constructed by the *Gesellschaft Linde. Photographs 5 and 6* illustrate a plant having an hourly production of 600 m³ oxygen (98%). *Photographs 7 to 9* were taken in the workshop and show the construction of an apparatus for producing 2600 m³ oxygen (98%) per hour. On the right of *Photograph 9* the main parts, counter-current coil and rectification column, of an air separation apparatus for an hourly production of 5 m³ oxygen are shown for the purpose of comparison; this affords an excellent idea of the magnitude of the dimensions of such recent large plants.

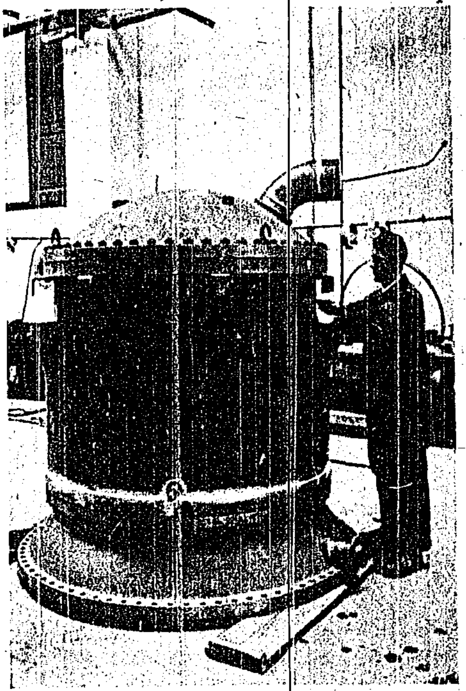

Fig. 8

Nitrogen condenser to separating apparatus Fig. 7

Fig. 9
Upper column to separating apparatus Fig. 7
Right: Counter-current interchanger and rectification column for 5 m$^3$ h oxygen.

## Summary.

The plant and power costs of gas liquefaction and separation plants are appreciably influenced by the construction of the counter-current cold exchangers. The heretofore solely customary continuously operating tubular exchangers (recuperators) have certain disadvantages such as high pressure loss, deficient cold exchange and expensive construction which bring about high costs for the separation products. The *Linde-Fränkl* Process, however, through the utilization of alternately operated cold accumulators (regenerators), eliminates not only these disadvantages, but rather also increases the efficiency of previously known processes for reducing the power consumption or makes possible for the first time their practical utilization. Principally to these processes belong the expansion of the compressed gases in expansion engines for obtaining the required cold production and the blowing in of uncompressed gas mixture into the rectification column for reducing the power consumption. Methods of operation for the production of oxygen are described which have already been tested in practice and which make possible the reduction of the production cost of this gas to such a point that it can now be utilized for the most varied chemical and metallurgical processes.

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Printed in Germany by Mandruck A.O., Munich.