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Study of simulation of Oxygen Production by Cryogenic Method

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Abstract:

Oxygen is most essential for the survival of humans and during the pandemic of Covid-19, has caused the scarcity of oxygen cylinders for Hospitals in India in 2021.Oxygen used for patients has various specifications as the lives of them depend upon that oxygen. The Industrial way of producing oxygen is by various methods. Cryogenic separation is the one that gives the purest oxygen (>99.5%). A cryogenic air separation unit (ASU) is an old process used to produce high purity oxygen or nitrogen at high volumes. The modified process for small scale oxygen production is given as, Air is compressed by isothermal compressor at a pressure of 20 bar with temperature rise upto 90 ℃. After compressore air is received by the cooler where the temperature is dropped to 0 ℃ . The coolant used in cooler is 50% water 50% ethylene glycol mixture. After cooler air is passed through turboexpander. Pressure of air is reduced to 2 bar by increasing the volume of air. By simulation study we obtained 98% purity of oxygen with the approximate flowrate of 77 gm/ sec(2 tons per day)

Keywords: *Turboexpander, Isothermal Compressor, Oxygen Purity*

1. Introduction:

Cryogenic air separation on industrial scale started in the beginning of 20th century fostering the development of metallurgy and other branches of industry highly dependent on the availability of oxygen, nitrogen and finally argon. Cryogenic air separation units (ASU) are characterized by very good quality of the products, big capacities and high reliabilities. In spite of other emerging technologies of air separation (sorption, membrane), cryogenics remains the basic technology for oxygen production. However, cryogenics are restricted for the applications requiring the gases in high quantities – above several hundred tons of the separated gases per day . We have designed and simulated a process which can be established in each hospital to have its own oxygen production . This process is based on some principles of cryogenic oxygen process but using a turboexpander .

Ziyad Salameh, in *Renewable Energy System Design,* 2014 Isothermal Compression is a phenomenon where compression takes place without increasing the temperature of the feed, but in actual practice some temperature rise takes place as the heat transfer from the compressed air to metal wall and piston is not 100% efficient. Isothermal Compressors are designed such that it consists of an internal cooling mechanism which removes the heat from the compressed air without letting the temperature of air to rise greatly.

Tadeh Avetian and Luis E. Rodriguez, ***Fundamentals of turboexpander design and operation*** A Turboexpander is a rotating machine with an expansion turbine that converts the energy of gas into mechanical work. During this process temperature drop takes place due to Joule-Thompson effect which states that the change in temperature that accompanies expansion of a gas without production of work or transfer of heat. In turboexpander the gas stream is expanded to reduce its temperature also mechanical work is generated as a by- product.

Universal Industrial Gases, ***Overview of Cryogenic air separation and Liquifier systems,*** **2003** Molecular sieve units also known as pre-purification units are used to remove carbon dioxide and water from the incoming air by adsorbing these molecules onto the surface of molecular sieve materials. Molecular sieves are used to remove the impurities present in the air such as dust particles, moisture, etc.

2. Process Equipment's

Isothermal compressor: -

Isothermal compressors are special types of compressors compared to adiabatic compressors. As the temperature remains constant theoritically, in practical use, there is some temperature rrise which occurs due to various minor reasons like piston conductivity, metal wall resistances. The figure below shows the industrial isothermal compressor which has the temperature rise of 60-90 ℃ with flow rate of 100 gm/sec.(**Wenling Toplong Electrical and mechanical company)**

Cooler:-

Cooler used here is air to water heat exchanger which uses 50% water 50% ethylene glycol as a coolant, which has the freezing temperature of -30 ℃ . The air entering in the coolar is neede to be cooled before entering the turboexpander as the turboexpander gives a specific temperature drop.

Turboexpander:-

Turboexpander is a pressure reducing eqipment which is used in industrial cryogenic plant to increase the efficiency of the process, during this pressure reduction temperature of air is also reduced due to volume expansion of air .This reduction in temperature can be utilized in a small scale plant to produce liquid oxygen also turbo expander consist the shaft which can be used to produce power as by product. The pressure drop across turboexpander is 18 bar.

3.Process Description:-

Air is compressed by isothermal compressor at a pressure of 20 bar with temperature rise upto 90 ℃. After compressore air is received by the cooler where th temperature is dropped up. The 0 ℃ . the coolant used in cooler is 50% water 50% ethylene glycol. After cooler air is passed through turboexpander. Pressure of air is reduced to 2 bar by increasing the volume of air. In turbo expander the inlet air is introduced on the impeller in expanding chamber where the enthalpy of air is reduced as the impeller starts to rotate resulting in temperature and pressure drop of the air and on the other end of the turbine shaft power is produced. The Outlet of the turboexpander consist of partially condensed mixture of liquid oxygen and nitrogen. This is further feed into the distillation column to get the fractions of liquid oxygen and liquid nitrogen separately. A condenser and a reboiler are required around distillation column to get high purity of liquid oxygen which can be utilized in hospitals in oxygen cylinders. In this process generally adiabatic compressors are used over isothermal compressors because isothermal compression is a slow process, also efficiency is less as compared to adiabatic compression, but the rise in temperature is in considerable amount so to avoid the temperature rise we opted for isothermal compressor instead of adiabatic compressor.

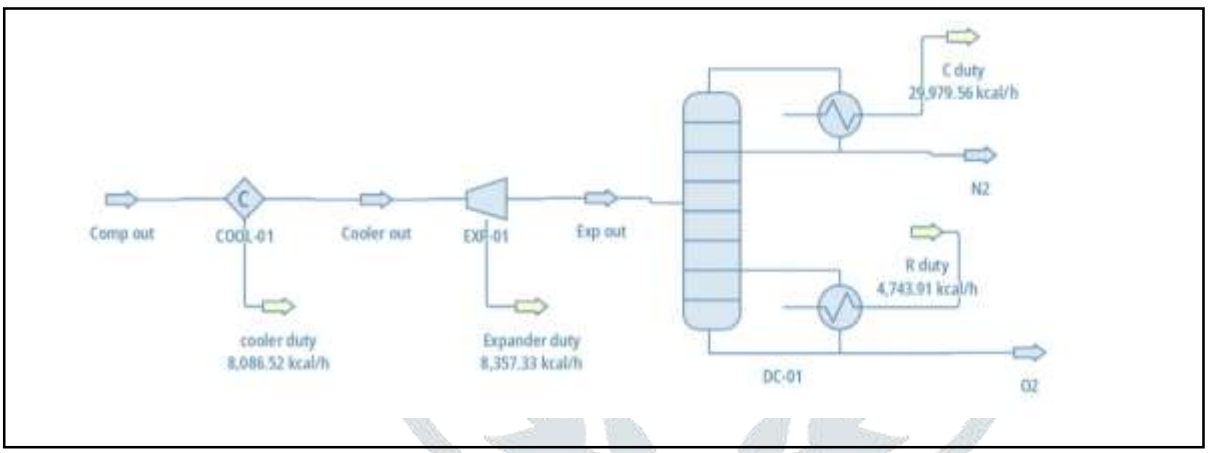
4.Simulation

The modified cryogenic process is simulated in the simulation software DWSIM (version 7.3.1)

Simulation enables us to find the stable operation point with optimal condition for the process examined.

- The isothermal compressor LW-30/40 of Welding Toplong Electrical & Mechanical Company is used as a reference, with the output pressure of 20 bar and flowrate of 100 g/s and temperature rise up to 90 °C.
- After compressor the air is send into cooler which reduces the temperature to 0 °C
- The outlet of cooler is send into the turboexpander where pressure is reduced to 2 bar resulting in the temperature drop upto -103 °C
- The outlet of Turboexpander is send into distillation column where the separate stream of liquid oxygen is obtained.
- Sensitivity analysis is performed for getting better purity of oxygen.
- By doing sensitivity analysis purity of oxygen is achieved to 98.14%

Process Flowsheet:-



Simulation Results:-

1. Material Streams

Object	O_2	N_2	Expander out	Cooler out	Compressor out	
Temperature	-183.59	-195.749	-101.461	0	90	C
Pressure	1	1	1.9739	19.7385	19.7385	atm
Mass Flow	21.7123	78.2876	100	100	100	g/s
Molar Flow	0.68	2.78403	3.4640	3.46403	3.46403	Mol/s
Density (Mixture)	1.136	0.815375	0.0040825	0.40825	0.019099	g/cm^3
Molar Fraction (Mixture)/Oxygen	0.98139	2.60297E-06	0.192661	0.192661	0.192661	
Molar Fraction (Mixture)/Nitrogen	0.01311	0.887188	0.715596	0.715596	0.715596	

2. Distillation Column

Object	Distillation Column	
Condenser Pressure	1	Atm
Reboiler Pressure	1	Atm
Reflux Ratio	1.26	
Distillate Molar flow	2.78403	Mol/s
Condenser Duty	29979.6	Kcal/hr
Number of stages	28	
Reboiler Duty	-4743.91	Kcal/hr
Condenser_calculated_value	1.26	
Reboiler_calculated_value	0.68	Mol/s

3. Turbo-expander Result

Object	Turboexpander	
Pressure Drop	17.7646	Atm
Adiabatic Efficiency	75	%
Temperature Difference	-101.461	C
Power generated	8357.33	Kcal/hr
Outlet pressure	1.9739	Atm
Rotation Speed	1500	RPM

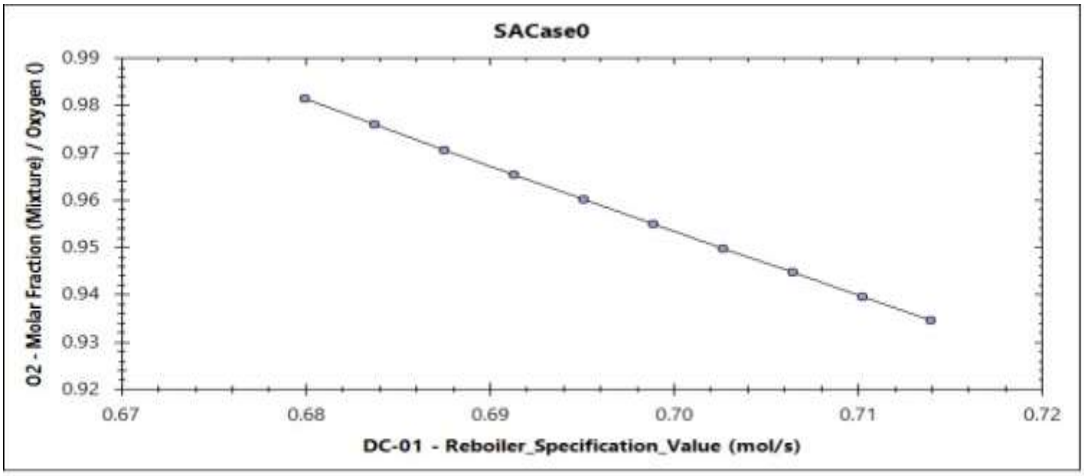
4. Cooler Result

Object	Cooler	
Pressure Drop	0	Atm
Efficiency	100	
Outlet Temperature	0	C
Heat Removed	8086.52	Kcal/hr

5. Sensitivity Analysis

Reboiler_specification_value	Molar fraction (Mixture)/O_2
0.68	0.98139
0.683778	0.975973
0.687556	0.970583
0.691333	0.965243
0.695111	0.959999
0.698889	0.954826
0.702667	0.949714
0.706444	0.944625
0.710222	0.939595
0.714	0.934614

6. Sensitivity Graph



Results and Discussion of Sensitivity analysis

- The sensitivity analysis is plotted against Reboiler specification value vs Molar fraction (mixture)/ oxygen.
- It is linear graph with negative slope.
- As reboiler specification value decreases molar fraction (mixture)/oxygen increases.
- The highest purity is calculated from the sensitivity analysis graph for respective reboiler specification value.
- By simulation the purity of liquid oxygen obtained was 93.46% and after the sensitivity analysis the reboiler specification value is readjusted to give the highest purity of 98.14%.

5.Conclusion:-

Oxygen is the most important element in any living being's life and it is the one which mostly taken for granted. During the Covid-19 crisis we faced the scarcity of medical oxygen and it became a need for each hospital to have proper oxygen supply. Cryogenic Oxygen production is the most used industrial method for production of ultra-pure oxygen and we convert this to a small-scale plant which can be placed for each and every hospital. Here we did theoretical study and with the help of DWSIM simulation software, we got required results, and the process is feasible from the simulation perspective.

6.Future Scope: -

- Energy Obtained from turboexpander can be utilised as a power source
- Heat integration may be a good option for further research
- Cooling media in distillation column can be further researched

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