www.ijemr.net ISSN (ONLINE): 2250-0758, ISSN (PRINT): 2394-6962

Vandana Publications
IJEMR

Volume-8, Issue-5, October 2018
International Journal of Engineering and Management Research
Page Number: 173-176
DOI: doi.org/10.31033/ijemr.8.5.07

Analysis of Steady State Cryogenic Air Separation Unit and Simulation of Fixed Bed Adsorption Separation of Air

Siddharth Ranjan Mohanty[1] and Dr. A.M. Mohanty[2]
[1]M.Tech Scholar, Department of Designing and Manufacturing Mechanical, Centurion University, INDIA
[2]Professor, Department of Mechanical Engineering, Centurion University, INDIA

[3]Corresponding Author: mohantysiddharth087@gmail.com

ABSTRACT

Atmospheric dry air contains approximately 78% nitrogen, 21% oxygen, and 1% argon plus low concentrations of noble gases like carbon dioxide, hydrocarbons and other impurities. An air separation unit divides atmospheric air into the three pure gaseous components (nitrogen, oxygen and argon). Nitrogen, oxygen and argon are used by industry in large quantities and hence termed industrial gases. The current work aim is to simulate the cryogenic air separation unit including adsorber and cryogenic distillation. Simulation of absorber is carried out using ADSIM of Aspen Tech to remove carbon dioxide (CO_2) and water vapour (H_2O). The breakthrough curves of carbon dioxide (CO_2) and water vapour on 5A molecular sieve and activated alumina respectively are found at different Reynolds number. The study helps to find out schedule time adsorber/desorber unit. ASPEN Plus simulator is used to simulate cryogenic air separation into nitrogen, oxygen and argon.

***Keywords*—** Cryogenic, Distillation Column, Pressure Swing Adsorption, Aspen Plus, Aspen Dynamics, Aspen Adsim, Steady State Simulation, Composition, Molecular Sieve, Activated Alumina, Isotherm Parameter

I. INTRODUCTION

The first application of computer control an air separation plant was done in the early 1970s. Since that time, best advanced control technologies have been useful to improve the productivity and efficiency of air separation plant [1].

The components presented in air (Oxygen, Nitrogen, Argon etc.) are very often useful components in chemical technology. The biggest marketplaces for oxygen are in primary metals production, gasification and chemicals, petroleum refineries, concrete and glass products, clay and welding. Gaseous nitrogen (N_2) is used in the petroleum and chemical industries and it is also used widely by the metals industries and electronics for its inert properties. Liquid nitrogen (LN_2) is used in applications ranging from food freezing to cryogenic grinding of plastics. Argon, the third key constituent of air, uses as mostly in steelmaking, heat treating, welding, and manufacturing procedures for electronics.

Techniques such as Membrane, PSA (Pressure Swing Adsorption) and VPSA (vacuum Pressure Swing Adsorption), are normally used to separate a single constituent from normal air. The only possible sources of the rare gases krypton, xenon, and neon are the distillation of air using at least two distillation columns.

II. EXPERIMENTAL WORK

Process of Cryogenic Air Separation

The process is shown on the attached process flow sheet.

Air compression

In the mechanical air filter the process air is cleaned from dust and other particles. It is then compressed to the required process pressure by a multistage, intercooled turbo compressor.

Pre-cooling

The process air cooler cool down and washes the compressed air in counter flow with water. There are two streams of water injected into air cooler, cooling water at normal temperature at the lower section and chilled water from evaporation cooler and refrigeration units at the top of air cooler.

The descending cooling water also scrubs the water-soluble chemical impurities from the process air. A wire mesh on top of the process air cooler removes the water mist from the process air. In the evaporation cooler the dry and pressure less nitrogen absorbs part of the injected cool water. The required heat for the evaporation is provided by the water which is cooled down by this effect. This water is called chilled water. The water losses of this system due to evaporation will be recovered by cooling water out of the cooling water system.

Purification with molecular sieve

The air purification system comprises two cyclic operating adsorber vessels passing through an adsorber vessel, the molecular sieve retains the remaining moisture, CO_2 and potentially hazardous hydrocarbons from the air steam.

While one adsorber is purifying the air, the other adsorber is regenerated. During the heating cycle the regeneration gas (waste nitrogen gas from the coldbox) is heated by an electric heater and desorbs water and CO_2 from the molecular sieve. During the cooling cycle the heater is switched off and the adsorbent is cooled down with cold dry waste nitrogen gas. After the completion of the regeneration sequence, the adsorber is pressurized before being switched over to the adsorption cycle.

The regeneration cycle consist mainly heating, cooling, pressurizing and depressurizing.

The regeneration gas coming from the rectification unit as waste gas is heated up in the regeneration gas electrical heater at heating period. At the cooling period the heater is bypassed. An important indication for sufficient regeneration is the regeneration peak temperature which appears during the cooling cycle. At the end of the regeneration cycle the regenerated adsorber is set into operation and the other one starts with a new regeneration cycle.

Process refrigeration

The main stream of the purified air enters the coldbox. It is cooled down in the main heat exchanger to about liquefaction temperature while the cold gaseous oxygen and nitrogen streams cooling from the column are heated up. The air is feed to the bottom section of the pressure column.

A side steam of the purified air is channelled through the booster heat exchanger. Afterward the stream is split in two. One fraction is further compressed by a multistage intercooled turbo-type air booster compressor while the second one is compressed by the turbine coupled booster compressors with after cooler. Both streams are cooled down in the booster heat exchanger and in the main heat exchanger. The turbine boostered stream leaves the main heat exchanger in the middle section and is expanded in the expansion turbine. The gaseous air is fed into the middle section of the low pressure column. A second turbine is on stand-by and can be used during start up to accelerate the cooling down process [33]. The air stream passes the booster heat exchanger. This side stream is then cooled in the main heat exchanger, where it serves as heating medium to evaporate and warm up the internally compressed product (LOX). Downstream the heat exchanger this side stream is expanded into the pressure column by an expansion valve.

Air separation

In the pressure column the air is separated into pure N_2 at the top, and oxygen enriched liquid air at the bottom. The required reflux for the rectification is provided by condensing the gaseous nitrogen in the condenser/reboiler. The condensation heat of the nitrogen is transferred to the boiling oxygen. Part of the liquid nitrogen serves as reflux for the pressure column. The other part is used as reflux for the low pressure column [32, 34]. Part of the N_2 is withdrawn from the top of the pressure column and passes the main heat exchanger before it serves as sealgas for the plant. In the low pressure column the final separation takes place into pure oxygen at the bottom and pure nitrogen at the top. Liquid oxygen from the bottom of the low pressure column evaporates in the condenser/reboiler and rises in the low pressure column. The gaseous oxygen product originates at the bottom of the low pressure column. The oxygen internal compression pump increases the pressure to the required value. The pressurized liquid evaporates and warms up in the main heat exchanger while high pressure air coming from the booster air compressor cools down and liquefies. The oxygen leaves the coldbox as high pressure gaseous oxygen product. Liquid oxygen product is withdrawn at the top of the main condenser and channeled to the oxygen storage system.

Liquid nitrogen product is withdrawn at the top of the low pressure column and transferred to the nitrogen storage system. Impure gaseous nitrogen (GAN) from the top of the low pressure column warms up in the sub-cooler and in the main heat exchanger and split into two streams. One stream passes the evaporation cooler in order to produce chilled water for the process air cooler. The remaining part is used as regeneration gas and passes the regeneration gas heater and molecular sieve adsorbers.

Argon production by rectification

In the crude argon column the oxygen is removed from the crude argon by means of cryogenic rectification. Argon enriched gas from the low pressure column is used as a feed for the crude argon column. The oxygen free crude argon on the top of the crude argon column condenses in the crude argon condenser exchanging heat with oxygen enriched liquid from the pressure column. The liquid crude argon serves as reflux. After passing the crude argon condenser part of the oxygen free crude argon is withdrawn at the top of the crude argon column and fed to the middle section of the pure argon column. In the pure argon column the remaining nitrogen is removed by cryogenic rectification. The top gas of the pure argon column liquefies in the condenser against boiling, oxygen rich liquid from the pressure column. The liquid argon serves as reflux for the rectification.

The remaining nitrogen does not condense and is vented from the outlet of the pure argon condenser to atmosphere. Liquid argon from the sump of the pure argon column is evaporated in the pure argon evaporator and fed back to the column. Pure liquid argon is withdrawn as product from the sump of the pure argon column and transferred to the argon liquid storage tank.

Table No. 1 : Observation Table

Parameters	Quantity
HP Column Pressure	535kpa to 549kpa
LP column pressure	133kpa to 140kpa
Crude argon column pressure	123kpa to 138kpa
Pure argon column pressure	115kpa to 120kpa
No. of stage in HP column	62
No. of stage in LP column	80
No. of stage in crude argon column	175
No. of stage in pure argon column	50
Input air temperature	28.79^0C
Input air pressure	101.3kpa
Input air molar flow rate	4521kgmole/h
Input air composition	Nitrogen78.12%, Oxygen20.95%, Argon 0.93%

Figure No.1 Testing Lab

III. RESULT

The liquid oxygen product withdrawn from the cold box is stored in an atmospheric flat bottom tank. This liquid storage serves as a backup supply of oxygen in case of a plant shut down. The liquid oxygen withdrawn from the tank pressurizes to the required value by means of the backup pumps, evaporates in the hot water bath vaporizer and is fed to the high pressure gaseous oxygen buffer vessels. Additionally a truck filling pump is available to fill liquid oxygen into a truck.

The liquid nitrogen is stored in an atmospheric flat bottom tank from where it is pressurized with the backup pumps and evaporated in the hot water bath vaporizer and is feed to the pressure reducing station where the desired amounts of high- mid- and low pressure GAN can be regulated. A buffer vessel for high pressure gaseous nitrogen is available. The liquid storage serves for backup the supply of pressure nitrogen in case of a nitrogen compressor shut down. Additionally a truck filling pump is available to fill liquid nitrogen into a truck.

The liquid argon is stored in a pressure tank from where it is further pressurized with the backup pumps, evaporated in the LAR backup evaporators and fed to the pressure reducing station. A buffer vessel for high pressure gaseous argon is available. The liquid storage with evaporators serves as gaseous argon supply to the customer. A truck filling pump is available to fill liquid argon into a truck. Additionally liquid argon from the tank can be pressurized, evaporated and bottled into gas cylinders at the available station.

Gas purifications

- Removal of CO_2 from natural gas
- Removal of organics from vent streams
- Removal of NO_x from N_2
- Removal of solvents and odors from air
- Removal of water vapour from air and other gas streams
- Removal of SO_2 from vent streams
- Removal of sulphur compound from gas streams

Liquid purifications

- Removal of water from organic solutions
- Removal of organic from water
- Removal of sulfur compounds from organic solutions
- Decolorization of solutions

This chapter discusses the simulated result of air separation plant in steady state, purity level of product gases, performance of column, carbon dioxide (CO_2) and water vapour (H_2O) adsorption in adsorber.

IV. CONCLUSION

From the present work we can summarize the followings;

In this thesis report, we conclude that an air separation plant processing 4702 kmol/hr of air to the basic air components Nitrogen (3667.4037 kmol/hr), Oxygen (985.26 kmol/hr) and Argon (42.39 kmol/hr) was designed. Purity of produced Nitrogen is 99.6%, Oxygen is 99.4% and purity of Argon is 99.5%. But Rourkela steel plant purity of product nitrogen is 99.99%, oxygen is 99.55% - 99.8% and argon is 99.9%.

To simulate cryogenic air separation unit, ASPEN Plus software is used.

At stable states, the breakthrough time of CO_2 is about 267 minute and H_2O is about 67 minute. But Rourkela steel plant breakthrough time of CO_2 and H_2O are 240 minute.

To adsorb carbon dioxide (CO_2) and water vapour (H_2O), molecular sieve and activated alumina bed are used. Adsorber is simulated through ADSIM of Aspen Tech.

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