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ENERGY SAVING IN CRYOGENIC AIR SEPARATION PROCESS APPLYING SELF HEAT RECUPERATION TECHNOLOGY

Asma-Ul-Husna[1], Razia Hasan[2], Sk. Aysha Rashid[3] and Muhammad Ruhul Amin[4]

[1-4]Department of Chemical Engineering, BUET, Dhaka-1000, Bangladesh.
[1,*]asmaul2509@gmail.com, [2]rhasan.che@gmail.com, [3]tweet.tisa@gmail.com, [4,*]ruhulaminbuet@gmail.com

Abstract- *In modern times, energy-saving technologies are of great demand due to immense energy crisis. Cryogenic air separation unit (ASU) is one of the essential process associated with high energy consumption. Components of air are separated by means of this technology. Based on self-heat recuperation principle, an innovative and energy friendly cryogenic process incorporating both latent & sensible heat circulation from heating loads is proposed in this paper. The paper presents the simulation of both conventional and energy efficient air separation process using Aspen-HYSYS to compare energy consumption and heat loss between the processes. Pinch point technology is used to locate the availability of energy. According to the simulation analysis, the energy consumption of the proposed process decreased by more than 24.35% compared with the conventional one and the energy loss was reduced up to 24% reusing it within system when producing 98.0% oxygen, 98.0 % nitrogen and 99.9% argon*.

Keywords: Energy utilization, pinch point, Cryogenic process, self-heat recuperation, process simulation

1. INTRODUCTION

Due to wide range of application in several industries like production of steel, chemicals, semiconductor; aeronautical engineering, food processing, refining and medical sectors, separation of oxygen, nitrogen and argon from air has gained attention in modern era [1]. Mainly there are two types of air separation techniques— non-cryogenic process such as pressure or vacuum swing adsorption, polymer membrane separation and cryogenic process. Among all these available techniques, air separation using cryogenic technology is the preferred one [2].

Cryogenic air separation is currently the most efficient and cost-effective technology [3] for producing large quantity products of moderate to high-purity level (especially producing > 95% oxygen) compared to non-cryogenic systems [4]. Cryogenic processes are operated at very low temperature (at about -170°C to -195°C) and thus sometimes called 'cold box process' [8] and at a pressure of 8-10 atm in which the air starts to liquefy [5]. The breakthrough of cryogenic air separation was marked by an experiment of Carl Von Linde in 1895 which was based on the Joule-Thomson effect. In 1902, the very first cryogenic air separation plant was constructed by Linde which was established for oxygen separation only. But with further advancement, it is now possible to separate oxygen, nitrogen & argon simultaneously [6].

But cryogenic process consumes a huge amount of energy. Due to energy crisis, people are now seeking for energy efficient technologies. The essence of energy-saving is to utilize energy efficiently resulting more production and work. Based on thermodynamic principles, pinch technology offers a systematic approach to optimum energy integration in a process. This technology creates scope for using energy produced within process units. In this way reduction in both energy wastage and demand can be possible. The improvements in the process associated with this technique are due to generation of a heat integration scheme. Pinch technology allows one to set energy target for the design which is minimum theoretical energy demand for the overall process [7].

Aspen HYSYS is one of the major process simulators that are widely used in chemical and thermodynamic process industries for optimization and steady state analysis [8]. Optimization of a chemical process has the potential to significantly affect not only the capital investment, but also the future economic performance [9]. In this project, our aim is to simulate both the conventional and energy efficient separation process of argon, nitrogen and oxygen from air by means of cryogenic technology using Aspen HYSYS software and compare its energy requirement with the optimized energy intensive proposed one.

2. PROCESS DESCRIPTION

2.1 Original Air Separation Process

2.1.1 Nitrogen and Oxygen Separation Unit

In the conventional design (Fig. 1), a two-stage centrifugal compressor, with inter-stage cooling, is used to compress air to 9 atm. Air is compressed in 'Compressor-1' to 5 atm (Stream-2) which is then fed to

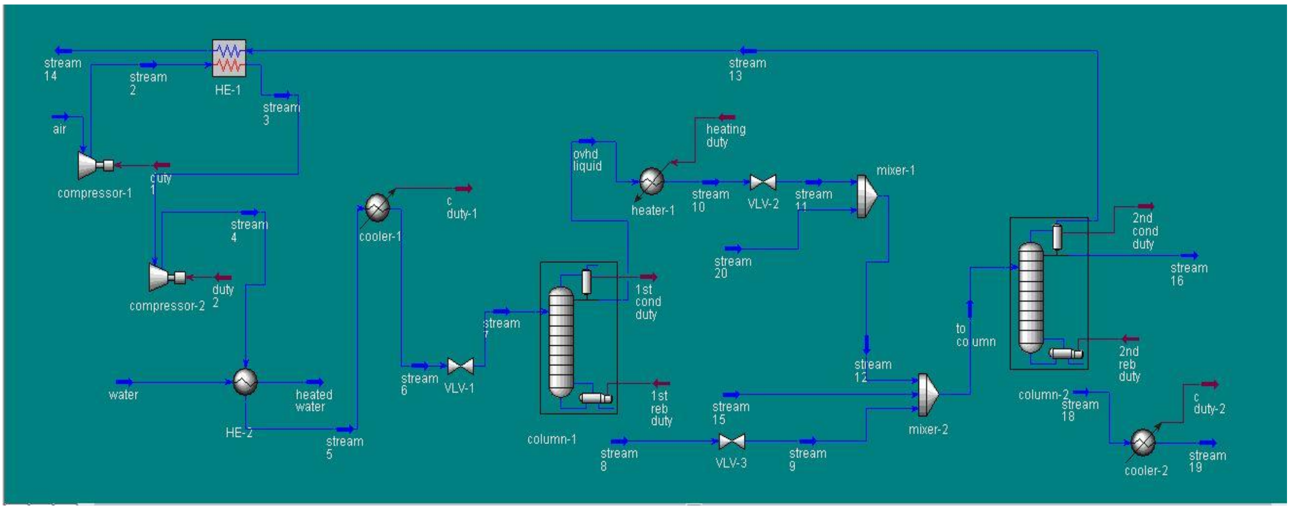

Fig 1: Process flow diagram of Oxygen and Nitrogen separation unit.

'LNG heat exchanger' and cooled down to 45°C. Stream-3 is finally compressed to 9 atm in 'Compressor-2' and sent to 'HE-2'. (Stream-4). 'HE-2' is a counter current shell and tube heat exchanger in which water at 40°C is used to cool Stream-4 which is then fed (Stream-5) to 'Cooler-1' to lower the temperature to -166.1°C (Stream-6). Stream-6 is then throttled to 5 atm (Stream-7) and sent to distillation column, 'Column-1'.Stream-7 is fed to the stage 5 of the distillation column. A total condenser and partial reboiler is used and pressure is maintained at 5 atm. The overhead liquid, which is 98% nitrogen is throttled to 1.0 atm (Stream-11), and mixed with Stream-20 from argon purification unit which is 99.5% nitrogen. It is then fed to the column, 'Column-2' (Stream-12).The bottoms, Stream 8, is also throttled to 1.0 atm and fed to 'Column-2' (Stream-9). Stream-9, Stream-12 and oxygen rich Stream-15 (99% oxygen) from argon purification unit is mixed and fed to stage 5 of 'Column-2'. The column pressure is maintained at 1 atm. A partial condenser and partial reboiler is used here. The overhead product (Stream -13) consists of 98.71% nitrogen and is cooled in the LNG exchanger and sent to storage (Stream-14). The bottom product (Stream-18), which is 98.5% oxygen, is cooled and sent to storage (Stream-19).

2.1.2 Argon Separation Unit

The presence of argon makes it impossible to obtain pure oxygen and nitrogen streams from the air separation plants. Therefore, argon is drawn out of 'Column-2' of the cryogenic system and purified for sale. Since the boiling point of argon is between that of oxygen and nitrogen, it acts as an impurity in the product streams. If argon were collected and separated from the oxygen product, an oxygen purity of less than 95% by volume would result. On the other hand, if argon were collected with the nitrogen product, the purity of nitrogen would not exceed 98.7% by volume. Both oxygen and nitrogen must be greater than 99.9% pure to sell, so the elimination of argon is necessary. This process requires very complicated heat integration techniques because the only heat sink for cooling or condensation is another cryogenic stream in the process.

Stream 16, from nitrogen-oxygen separation unit is sent through 'Heater-1'to increase the temperature. Stream 17 is then sent to 5th stage of 'Tower-1' where nitrogen is separated from oxygen and argon (Fig. 2). The column is operated at 1atm and a total condenser and partial reboiler is used. The nitrogen-rich distillate, Stream 20 (99% nitrogen), is recycled back to nitrogen-oxygen separation unit. The bottom, Stream 21(66% oxygen), is then sent to 'Tower-2' where the argon and oxygen are separated. 'Tower-2' is operated with a partial reboiler and total condenser at 1atm. The oxygen-rich bottom stream from 'Tower-2' (80% oxygen) is heated in 'Heater-2' to -184.1°C and recycled back to nitrogen-oxygen separation unit (Stream-15). Stream-22 is argon rich and its composition is 78% argon. Stream-22 is now combined with hydrogen (Stream- 23) and the combined stream 24 is allowed to be heated in 'Heater-3'. The new Stream 24 is compressed to 5 atm pressure and heated in 'Heater-4' to increase temperature to 132°C. The Stream-26 is sent to a combustion chamber where hydrogen is combusted with oxygen to form water. The effluent, Stream-27, which is at 25°C is cooled to -24.39°C (Stream-28) in 'Cooler-1' and then flashed in 'Separator' to remove excess oxygen and water. The oxygen and water are removed in Stream-29 and the argon-rich stream, Stream-30 is cooled in 'Cooler-2' and sent to 'Tower-3' to separate out the remaining nitrogen that is present. The nitrogen exits as the distillate, Stream-32 (89% nitrogen) and vented to the atmosphere. 99.9% pure argon exits as the bottom Stream-33.

2.2 Proposed Process

In the proposed process, number of units remain same as the conventional process. Major difference between two processes is that heat evolved in one unit is recirculated to the unit where Heat needs to be supplied from outside. Doing so reduces the theoretical energy demand for overall process. Again heat required in any unit may not be present in the system. Availability of the

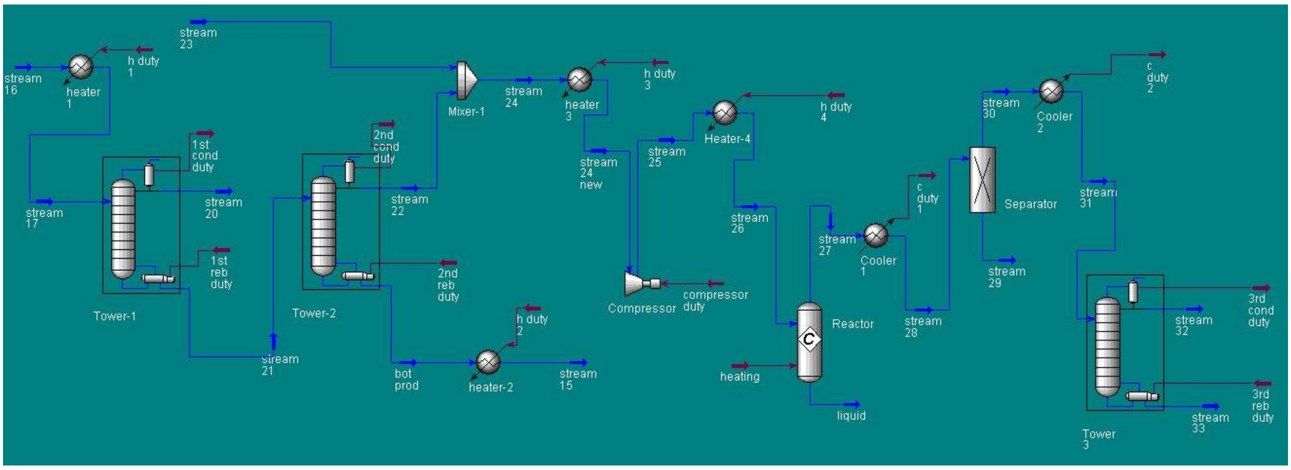

Fig 2: Process flow diagram of Argon Separation unit

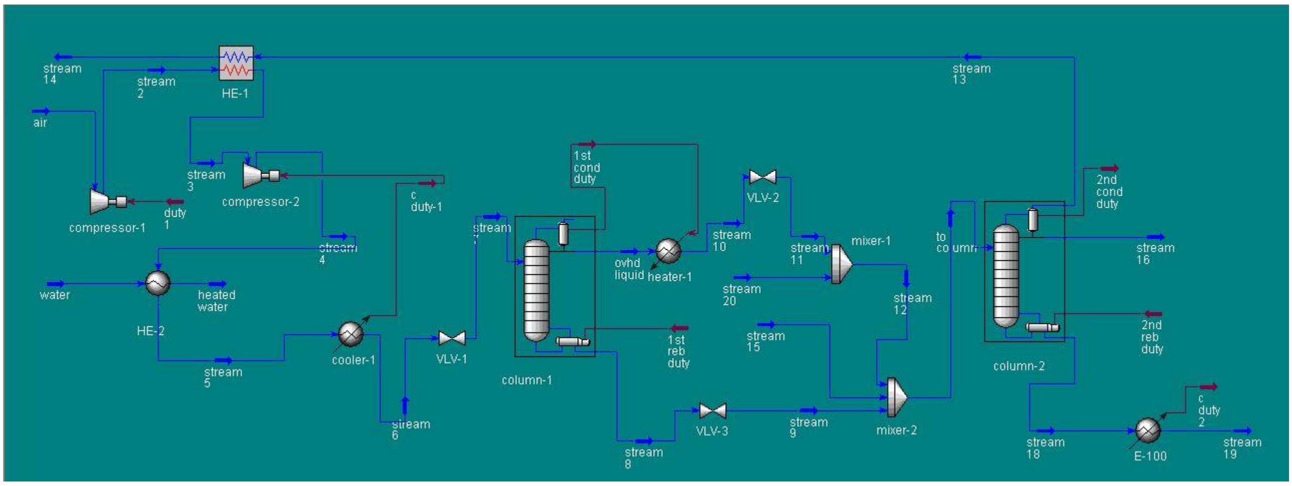

Fig 3: Alternate process flow diagram of energy efficient Oxygen and Nitrogen separation unit

streams that can be used as a heat source is determined by pinch point analysis. The principal objective of this technology is to match cold and hot process streams with a network of exchangers so that demand for externally supplied utilities are minimized. Pinch point is mainly a temperature difference that separates the overall operating temperature region observed in the process into two temperature regions. Once a pinch point has been established heat from external source must be supplied to the process only at temperatures above the pinch and removed from process by cooling media only at temperature below the pinch [7]

2.2.1 Pinch Point Analysis for Nitrogen and Oxygen Separation Unit

Figure 3 illustrates the pinch point simulation of proposed process.

Using data from table 1 a graph of temperature vs. rate of enthalpy change is drawn to determine pinch point. The graph is illustrated in Fig. 4. From Fig. 4, pinch point temperature difference is 19.5℃ having lower limit -19.5℃ and upper limit 0℃. In this graph cooling line lies over the heating line. That means there is no process stream available that can heat the cold streams but all heated streams can be cooled down within system. 1st condenser duty from column one acts as external source for 'heater 1' which was not included in the calculation. At one point two lines intersects. It means maximum energy utilization in that unit.

Table 1: Table for pinch point analysis oxygen and nitrogen separation unit

Stream number /name	Inlet temp (^{o}C)	Rate of enthalpy change (MJ/hr)	Outlet temp (^{o}C)	Rate of enthalpy change (MJ/hr)
Streams to be heated				
Ovhd liquid	-178.80	-6220	-178.10	-3440
13	-195.50	-4730	-19.15	-962
Streams to be cooled				
2	172.10	4330	45.00	561
4	198.30	5110	41.85	425
5	41.85	425	-166.10	-5880
18	-184.20	-3970	-200.00	-4210

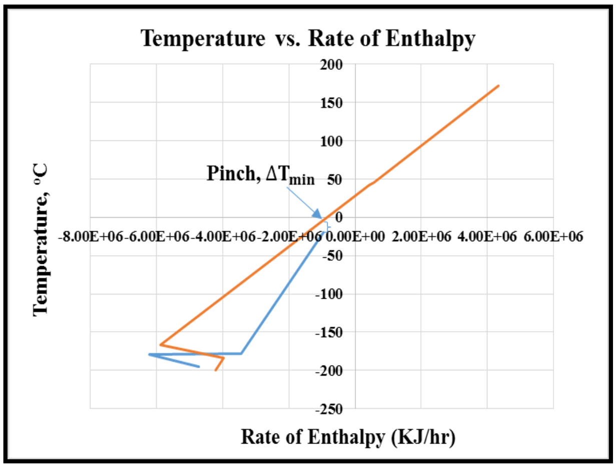

Fig.4: Graph of temperature vs. Rate of enthalpy

2.2.2 Pinch Point Analysis for Argon Separation Unit

Similar procedure was carried on for argon separation unit. Argon separation unit proved itself more energy efficient than the oxygen-nitrogen separation unit. Pinch point analysis data for argon separation is given in table 2.

Table 2: Table for pinch point analysis of argon separation unit

Stream number/ name	Inlet temperature (°C)	Rate of enthalpy change (MJ/hr)	Outlet temp (°C)	Rate of enthalpy change (MJ/hr)
Streams to be heated				
16	-195.60	-715.00	-187.4	-365
bot product	-184.10	-17.40	-150	-6.68
24	-192.20	-4.65	-160	-2.53
25	-46.86	-1.01	85	0.81
Streams to be cooled				
27	25.00	-0.54	-23	-0.98
30	-17.31	-0.32	-180.0	-0.36

Corresponding graph of temperature vs. rate of enthalpy change resulting from above data is given below in fig. 5

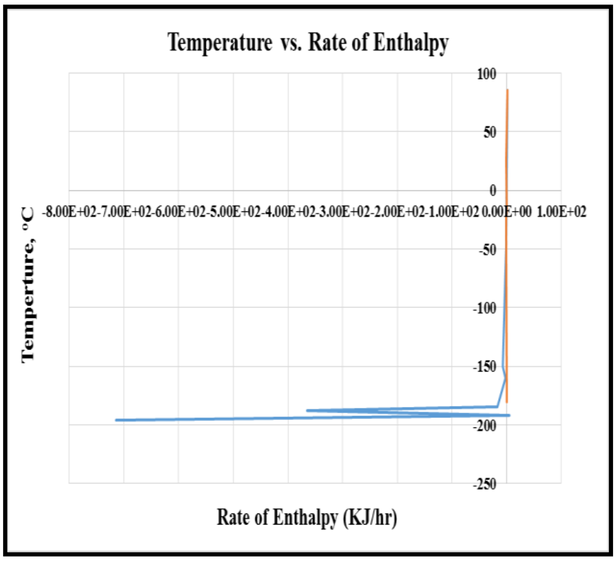

Fig.5: Graph of temperature vs. Rate of enthalpy

In this figure, there is no distinguishing pinch point observed. Heating and cooling line overlapped throughout the cooling line indicating cooling streams present in the process can be heated without consuming any external energy. All the energy required to run the heaters can be found within the system. But hot streams having temperature below -170°C must be cooled from extracting energy from outside. Resulting simulation of the process is given below (fig. 6). This simulation agrees with the result of pinch point analysis.

3. ENERGY SAVING

A typical ASU requires enormous amount energy supply. Again energy is also produced also in different units. All of these energies are released in the environment and therefore wasted. In this section it is shown that how the proposed process reduces energy loss by using the energy produced within the system. Table 3 gives an idea regarding energy requirement and energy evolved in various unit.

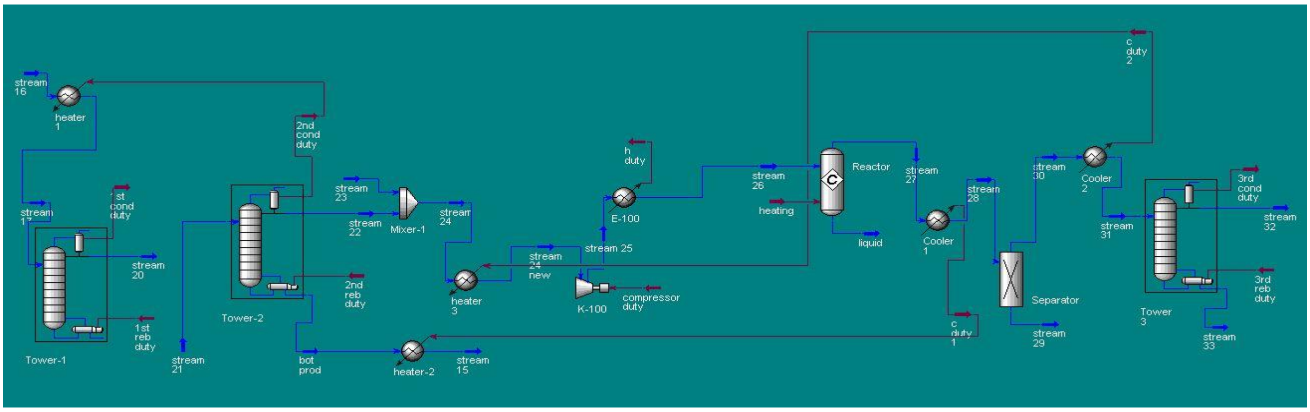

Fig.6: Process flow diagram of energy efficient argon separation unit

Table 3: Table showing energy requirement and released by a conventional air separation unit

	Unit name	Input energy (MJ/hr)	Unit name	Exited energy (MJ/hr)
Oxy-Nitro unit	Compressor 1	4287	Cooler 1	6302
	Compressor-2	4546	1st cond duty	7932
	1st reb duty	2675	2ndcond duty	4587
	Heater-1	2779	Cooler 2	239.9
	2nd reb duty	4011	-	-
Argon unit	Heater-1	349.80	1st cond duty	648.2
	1st reb duty	298.70	2nd cond duty	139.1
	2nd reb duty	139.10	Cooler-1	0.4525
	Heater-2	10.71	Cooler-2	3.266
	Heater-3	2.12	3rd cond duty	33780
	Compressor duty	1.52	-	-
	Heater-4	1.82	-	-
	3rd reb duty	33780	-	-
Total		52881		53631

Instead of releasing off the heat produced in different units it is used in the proposed process. Table 4 shows the units acting as sources and amount of heat transferred to different units.

Table 4: Table showing energy reused within system

	Unit name		Energy reused (MJ/hr)
	From	To	
Nitrogen-oxygen separation	Cooler-1	Compressor-2	2255
	1st cond duty	Heater-1	7932
	E-100	1st reb duty	2675
Argon separation unit	2nd cond duty	Heater 1	13.18
	Cooler-1	Heater-2	0.47
	Cooler-2	Heater-3	3.27
Total			12878

4. RESULTS AND DISCUSSIONS

Energy reused within system = 24%

Reduction in energy requirement = 24.35%

The composite curves show overall profile of heat availability and heat demand in the process over the entire temperature range. These curves represents cumulative heat sources and heat sinks in the process. It can be used to evaluate the overall tradeoff between energy and capital cost. Some energy must be supplied and there will always be heat loss because thermodynamics doesn’t allow 100% energy utilization.

5. CONCLUSION

The purification of various components of air, in particular oxygen, nitrogen, and argon, is an important industrial process. Here by using the proposed process, nitrogen, oxygen and argon can be separated at low cost.

The efficacy of cryogenic cycles can be increased using versatile techniques. User friendly Aspen HYSYS can be used for the optimization and simulation of these cycles.

6. REFERENCES

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