Analysis of Cooler Performance in Air Supply Feed for Nitrogen Production Process Using Pressure Swing Adsorption (PSA) Method

by Adi Syakdani

Analysis of Cooler Performance in Air Supply Feed for Nitrogen Production Process Using Pressure Swing Adsorption (PSA) Method

View the article online for updates and enhancements.

Analysis of Cooler Performance in Air Supply Feed for Nitrogen Production Process Using Pressure Swing Adsorption (PSA) Method

Adi Syakdani[1*], Yohandri Bow[1], Rusdianasari[1], and Muhammad Taufik[1]

[1]Chemical Engineering Department, Politeknik Negeri Sriwijaya, Jl. Srijaya Negara Palembang, 30139, Indonesia

[*]Corresponding author: adis@polsri.ac.id

Abstract. Air is one of the essential needs that used by living things either directly or indirectly. The demand for nitrogen in the chemical industry in the world continues to increase every year, especially in the fertilizer industry. In the industry, nitrogen can be used to manufacture ammonia or start tipping on an ammonia plant, also to protect materials from bacterial and fungal disorders. In addition, in the field of nitrogen transport is often to add to vehicle restrictions Pump the wheels using nitrogen will make the wheels more durable and the wheel rim is not easily damaged. Based on the amount of demand for nitrogen gas, the nitrogen production process is conducted by Pressure Swing Adsorption (PSA) method. The adsorption capacity of the adsorbent depends on the temperature, pressure, type of adsorbent and characteristic of the adsorbent. In this case, the temperature at the process is one of the most important parameters, the temperature, in this case, is the temperature of the adsorbate. When a gas or adsorbate molecule is attached to the surface of the adsorbent, there will be an energy release called an exothermic event. The reduced temperature will increase the amount of adsorbate adsorbed and also for the opposite event. Because of that, it is needed an air conditioner in the form of a cooler that serves to maintain and reduce the air temperature of the feed (adsorbate) does not experience an increase when operating conditions take place. The highest nitrogen purity was 95.7%, at 7 bar PSA, cooling fluid flow rate 35.4 m/s, daily cooling 41.58%, and air feed temperature 30.7°C.

1. Introduction

Nitrogen is a principal compound in the chemical industry. Nitrogen is an inert compound so it is suitable for a wide range of applications covering various aspects of chemical manufacturing, processing, handling and shipping [1]. Nitrogen demand in the chemical industry in the world continues to increase every year, especially in the fertilizer industry. Among Asian countries, Indonesia's nitrogen demand is 6% of world demand. Besides being used in the fertilizer industry, nitrogen is also used in various other industries such as the food industry, electronics, manufacturing, medical, mining, and transportation. Considering the high demand for nitrogen in various industries, it takes a high nitrogen production. Ordinary nitrogen is obtained from free air, this is because the content of the air is mostly composed of nitrogen as much as 78% [2]. In general, nitrogen is separated from the air using cryogenic methods. This method is conducted by decreasing the temperature to reach a very low temperature until the critical temperature is reached. The main disadvantage of cryogenic distillation is an ineffective use of energy [3]. Energy is wasted by converting gas to liquid, and a lot of pure gas is wasted during the process [4]. In addition, nitrogen products in the form of

liquid make nitrogen cannot be used directly by the public because temperatures of -196 ° C must be understood in their use. [4]. The energy use of cryogenic systems is 2.56 kWh / kg liquid nitrogen. Along with the development of technology, the process of nitrogen production is also developing. This is proven by the non-cryogenic technologies in the form of membrane systems and the Pressure Swing Adsorption system [5]. PSA technology is a technology that separates air by the method of adsorption. In this technology, the air component is adsorbed based on differences in adsorption equilibrium and differences levels of diffusion [6]. Nitrogen production using the PSA system uses the energy of 0.31-0.63 kWh / kg nitrogen gas. And also nitrogen products using the PSA method can be purchased and sent quickly [7]. In the PSA system, there is two adsorber containing adsorbents in the form of Carbon Molecular Sieve (CMS). At high pressure, the CMS will absorb oxygen and allow nitrogen to pass through the desired purity level. In the nitrogen production process with the PSA method, the resulting nitrogen purity is influenced by the adsorption power of the adsorbent used. The adsorption power of the adsorbent depends on temperature, pressure, contact time, type of adsorbent and adsorbent characteristics [8].

In this case, the temperature of the adsorption process is one of the most important parameters. It is the adsorbate temperature. When the gas or adsorbate molecules attach to the surface of the adsorbent, there will be a release of a number of energies called exothermic events. The reduced temperature will increase the amount of adsorbate adsorbed and also for the opposite event. It is also because if the adsorbate temperature is passing through the adsorbent with high temperature conditions, it will cause the adsorbate molecule to diffuse more quickly into the adsorbent pores. Therefore, there will be competition between adsorbates which will cause a decrease in the amount of adsorption [9]. So, before reaching the specified cycle time, the CMS has saturated faster. And then this will cause CMS is not able to adsorb O_2 molecules and cause O_2 molecules to be missed together with N_2 molecules. If this happens, it will affect the level of purity of the nitrogen product produced. In this case, it is needed an air conditioner in the form of a cooler that serves to maintain and reduce the air temperature of the feed (adsorbate) does not experience an increase when operating conditions take place. Under these conditions, the authors take the title Analysis of Cooler Performance In Supply Air Feed For Nitrogen Production Process Using Pressure Swing Adsorption (PSA) Method.

1.1. Air
Air is a mixture of gases that make up the earth's atmosphere. The composition of air consists of nitrogen, oxygen, argon, and carbon dioxide and the number of other constituents that are very small. The atmospheric air composition can be seen in Table 1[10].

Table 1. Atmospheric air composition

Gas	Volume (%)
Nitrogen (N_2)	78.08
Oxygen (O_2)	20.94
Carbon dioxide (CO_2)	0.03
Argon (Ar)	0.093
Neon (Ne)	0.0018
Helium (He)	0.0005
Krypton (Kr)	Trace
Xenon (Xe)	Trace
Ozone (O_3)	0.00006
Hydrogen (H_2)	0.00005

1.2. PSA System

PSA technology originally came from laboratory studies from Skarstom [11], Montgareuil and Domine [12]. The change from laboratory scale to industrial scale tends to slow down but has been growing over the past few decades.

PSA is one of the technologies used to separate several types of gases from a gas mixture according to the type of molecular characteristics and their affinity from the adsorbent material. Special adsorption materials such as carbon, are used as molecular sieves so it is easier to absorb the main gas at high pressure. The next process is the swing process, which is the process of changing from high pressure to low pressure to dissipate or release compounds absorbed by adsorbent materials [13].
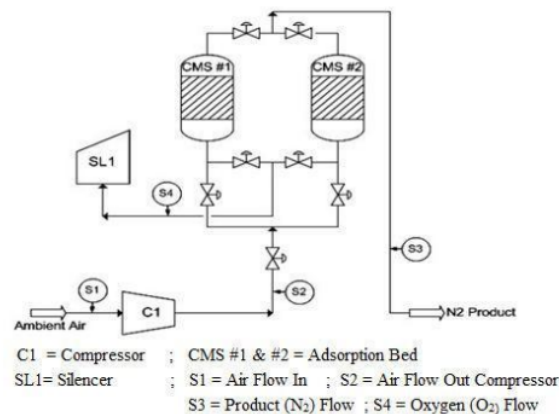

C1 = Compressor   ;   CMS #1 & #2 = Adsorption Bed
SL1= Silencer   ;   S1 = Air Flow In   ; S2 = Air Flow Out Compressor
                           S3 = Product (N_2) Flow ; S4 = Oxygen (O_2) Flow

Figure 1. Flowsheet PSA Process

The technology of separating nitrogen from the air with the PSA process has the advantages, that if the nitrogen needed is less than 560 m3 / hr (20,000 SCFH) then this process is cheaper compared to cryogenic processes. Also, other advantages of the PSA process is during the shutdown, losing its components is smaller than cryogenic, and PSA Products can be sent and used quickly. For the disadvantages of PSA process itself are, if the flow rate increases to 1120 m3 / hr (40,000 SCFH), it is cheaper if it is produced with cryogenic processes, another downside is it takes a long time to repair and maintain compressor and it is very noisy compared to other processes.

1.3. Adsorption

Adsorption is the process of accumulating adsorbate on the surface of the adsorbent caused by the pulling force between molecules or a result of the force field on the surface of the solid (adsorbent) which attracts gas, vapor, or liquid molecules. Adsorption power on adsorbent depends on temperature, pressure, type of adsorbent and adsorbent characteristics.

The factors that could influence the adsorption power on the adsorbent [14] are first, Adsorbate Pressure for each type of adsorption based on molecular interactions that occur, the adsorbate pressure will affect the number of adsorbate molecules. In physical adsorption, if the adsorbate pressure increases, the number of adsorbate molecules will also increase. However, in chemical adsorption, the number of moles of the adsorbate will decrease if the adsorbate pressure increases. Second, Temperature of the adsorbate when gas molecules of adsorbates attach to the surface of the adsorbent, there will be a release of a certain amount of energy called an exothermic condition. The reduced

temperature will increase the amount of adsorbate adsorbed as well for vice versa, heating or activating the adsorbent will increase the adsorption capacity of the adsorbate than could affect the adsorbent pores to open and damaging the adsorbent so that the absorption ability can be decrease. Third, Time Contact produces maximum adsorption capacity at equilibrium time. Fourth, Types of Adsorbates, can affect the absorption of adsorption, which are: Molecular Size, the appropriate adsorbate is important so that the adsorption process can occur, because molecules that can be adsorbed are molecules which have smaller or equal diameters with adsorbent pore diameter and Polarity Substances when the diameter is the same, polar molecules are stronger adsorbed than non-polar molecules. More polar molecules can replace less polar molecules which are first adsorbed. Fifth, Characteristics of adsorbent surface area and pore volume could affect the adsorption process where the adsorbate number of adsorbed molecules increases with increasing surface area and pore volume of the adsorbent.

1.4. Carbon Molecular Sieve (CMS)

A molecular sieve is a material unit that has small/fine pores where the size is very standardized and uniform. These pores can selectively "continue" and "capture" passing molecules based on molecular size. Material that can be used as a molecular sieve including zeolite and carbon. Molecular sieve from carbon or Carbon Molecular Sieve (CMS) is produced through special manufacturing procedures so that it has a selective and very narrow pore size. Raw materials can be in the form of chemicals such as polyvinylidene dichloride and phenolic resin or using natural materials in the form of anthracite coal and coconut shells. The surface of CMS is basically non-polar and is often used in nitrogen production processes with high purity by the PSA method [15].

CMS is an adsorbent that has an important role in the process of gas separation. Various types of adsorbents derived from carbon such as activated carbon and CMS has different pore sizes. This is because each adsorbent is produced differently. In general, the physical properties of CMS can be seen in Table 2.

Table 2. Physical Properties of Carbon Molecular Sieve

Particle Shape	: C
Internal Porosity	: 35 − 50%
Density	: 0,5 − 0,7 kg/L
Pore diameter	: 0,3 − 0,6 nm
Adsorptive capacity kg/kg (dry)	: 0,5-0,2

CMS included in Molecular Sieve 3A. Molecular Sieve type 3Å has a composition of 0.4 K_2O: 0.6 Na_2O: 1.0 Al_2O3: 2.0 SiO_2: 4.5 H_2O, made by substituting potassium cations from sodium ions in the 4A structure so that it can reduce porosity effective up to 3Å [16]. When CMSN2 is used in separation in the PSA process, oxygen molecules have a smaller diameter than nitrogen molecules. So that oxygen molecules can penetrate pores faster. Therefore, nitrogen will achieve a higher purity while almost all oxygen is absorbed [17].

2. Research Method
The design of nitrogen production equipment can be seen in Figure 2. In general, this design consists of 5 parts, which are a compressor, air tank, adsorber column, buffer tank, and a nitrogen tank. A 7 bar compressor is installed at the beginning of the process to increase atmospheric air pressure. Then, this

pressurized air is filtered using a filter, and the process of reducing the water content by absorption by silica gel is occurred.
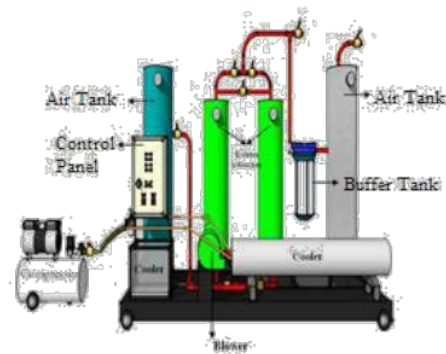

Figure 2. Design of Nitrogen Production Equipment using the PSA method

The air tank used is made of a capacity of 20.10 L. The adsorber column consists of 2 columns with a capacity of 14.62 L each. The adsorber column is made of stainless steel, this material is chosen because the pressure on the adsorber column will reach a maximum pressure of 7 bar. In each adsorber column, there is an adsorbent bed. Inside the adsorbent bed with a capacity of 10 L contains adsorbents in the form of CMS each of 8 kg.

3. Results And Discussion

Cooler is a heat exchanger used to cool liquids or gases by using water or gas as a coolant medium. In the cooler, there is no phase change, and along with the development of current technology, the cooler uses air as a coolant with the help of a fan. The type of cooler used in this study is the Double-Pipe Exchanger because it can be used in small fluid flow rates and high operating pressure. Heat transfer that occurs in the fluid is a convection process, while the conduction process occurs in the pipe wall. According to Sholeh [18] heat flows from high temperature fluids to low temperature fluids. In this research, cooler performance, in this case, is how much cooler ability to reduce the temperature of the hot air from the compressor which will be used as raw material for nitrogen production, because that the reduced temperature will increase the amount of adsorbate that adsorbed as well as for the opposite event.

To find out the cooler performance used in the research, it is necessary to know the effect of the variation of the cooling fluid velocity with the operating conditions of the constant heat fluid velocity on the cooler efficiency produced, it can be seen from the value of Long Mean Temperature Difference (LMTD), the overall heat transfer coefficient (U) produced, and heat received by the cooling fluid (Q). So that it can be known the relationship between cooler efficiency and the temperature of feed air produced on nitrogen purity, it is because of the value of the feed temperature that influenced by how the cooler works. Based on the results of the research and calculations, we got the graphs 3 and 4 below.
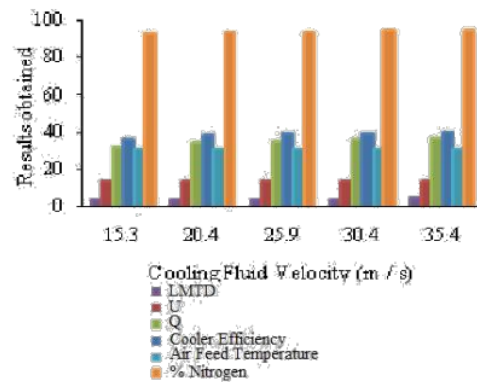
Figure 3. Graph of Effect of Cooling Fluid Velocity on LMTD, U, Q, Cooler Efficiency, Air Feed Temperature,% Nitrogen produced during PSA 6 Bar Pressure Conditions.
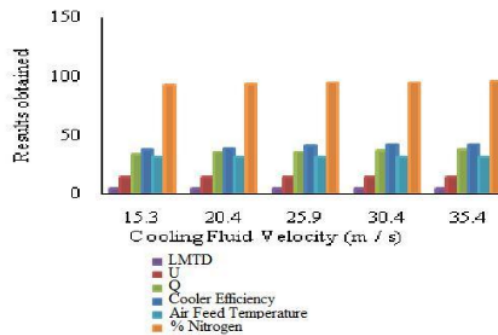

Figure 4. Graph of Effect of Cooling Fluid Speed on LMTD, U, Q, Cooler Efficiency, Air FeedTemperature,% Nitrogen produced during PSA 7 Bar Pressure Conditions

Based on Figure 3 and 4, it can be seen that the faster the velocity of the cooling fluid is, the greater its efficiency of the cooler produced due to the influence of the amount of heat received by the cooling fluid (Q), LMTD and the overall heat transfer coefficient (U) produced. So that the greater the efficiency of the cooler is, the greater its % nitrogen produced due to a decrease in feed air temperature. It can be seen from the data of research observations and the results of the condition of 6 bar PSA pressure, with hot fluid velocity as a steady operating condition was 44.45 m/s, when the cooling fluid velocity at 15,3 m/s, the heat received by the cold fluid (Q) was 32.16 Btu/hr, LMTD was obtained 4.1330^oF, and the overall heat transfer coefficient (U) was obtained 13.71 $Btu/hr.ft^{2}.^oF$, thus the result of cooler efficiency was obtained at 36.4%, and with the flow rate, the feed air temperature was obtained 31.1oC, and the nitrogen concentration was 92.5%. When the cooling fluid velocity was 20.4 m/s, the heat received by the cold fluid (Q) was obtained 34.50 Btu/hr, the LMTD was obtained 4.1820^oF, and the overall heat transfer coefficient (U) was obtained 13.63 $Btu/hr.ft^{2}.oF$, thus the result of cooler efficiency was obtained at 38.25%, and with the flow rate, a feed air temperature was 31oC, and a nitrogen concentration was obtained at 93.1%. When the cooling fluid velocity was 25.9 m/s, the

heat received by cold fluid (Q) was obtained 35.17 Btu / hr, the LMTD was obtained 4.3104 F, and the overall heat transfer coefficient (U) was obtained 13,66 Btu/hr.ft^2.^{o}F, thus the result of cooler efficiency was obtained at 38.99%, and with the flow rate, the feed air temperature was 30.9oC, and the nitrogen concentration was obtained at 93.5%. When the cooling fluid velocity was 30.4 m/s, the heat received by cold fluid (Q) was obtained 35.83 Btu/hr, LMTD was obtained 4.5040^{o}F, and the overall heat transfer coefficient (U) was obtained 13.68 Btu/hr.ft^2.^{o}F, the result of cooler efficiency was 39,73%, and with this flow rate, the feed air temperature was 30.9oC and a nitrogen concentration was obtained by 94.2%. When the cooling fluid velocity was 35.4 m / s, the heat received by cold fluid (Q) was obtained 36.50 Btu/day, LMTD was obtained 4,7379 ^{o}F, and the overall heat transfer coefficient (U) was obtained 13.70 Btu/hr.ft^2.^{o}F, thus the result of cooler efficiency was 40.47%, and with this flow rate, the feed air temperature was 30.8oC, and nitrogen concentration was obtained at 94.2%. However, when the cooling fluid velocity was 30.4 m / s and 35 m / s, the result of % nitrogen is equal to 94.2%, although the efficiency has increased and the feed air temperature has decreased, it is because the saturation factor of the CMS in absorbing oxygen, because the CMS regeneration process is not good, so there are still oxygen molecules trapped inside the CMS pores. Likewise the result of observations and calculations at 7 bars. For the relationship between fluid velocity and the value of efficiency produced is in accordance with the theory according to Irvan Prananda and Prabowo on his research that the faster the air velocity, the greater the potential for heat transfer is, the greater the effectiveness its tool. And also supported by the results of research by Irvan Paramananda and Prabowo that the increase in air velocity (coolant) with the same water discharge (hot liquid), water particles that carry heat energy transferred to the air will be greater. And the greater the air velocity is the greater its mass flow rate, thus causing the effectiveness value to increase. Because this research is in accordance with the results of research from [19], the relationship between the effect of fluid flow discharge on heat transfer rate and heat exchanger efficiency was obtained from the research that the greater the fluid flow discharge is, the greater its heat transfer rate and the greater its efficiency of the tool. According to [20] the greater the fluid mass flow rate is, the greater its coefficient of convection. This is in accordance with the theory according to Cengel, 2003 that the **value of ΔT LMTD is directly proportional to the value of U and also directly proportional to the value** of Q.

However, in this study, neither the efficiency produced by the cooler nor the result of LMTD is not too high, because the inlet temperature of the hot fluid and the inlet temperature of the cold fluid are not much different from one another. It is in accordance with the results of research by Miranto, I Made Adi Sayoga, and Zulkarnain. The effect of discharge on the rate of heat transfer becomes **insignificant so that a high ΔT cannot** be obtained because the difference between the inlet water and air temperature before the water was flowed has not much different, it was only about 20-30°C. And also it has been explained that the faster the velocity of the cooling fluid is, the more its temperature of the feed air decreases. This is also in accordance with the theory in the research of Miranto, I Made Adi Sayoga, and Zulkarnain, that the outlet temperature of the fluid from HE is not affected by the shape of HE, but it is affected by flow discharge. It is acceptable because, with a high fluid discharge which in this research is the cooling fluid discharge, the heat from the cold fluid absorbed by the hot fluid will also increase, so that the temperature decreases in the hot fluid. As a result, the lower the feed air temperature is, the higher its Nitrogen produced. It is because the temperature of the feed air will affect the adsorbate in the O_2 absorption process. According to the theory of that, the increase in temperature is the main cause of the decrease in purity of N_2 [21].

4. Conclusion
Based on the results of research on nitrogen production equipment using the Pressure Swings Adsorption (PSA) method and the results of data processing, it can be concluded:
1. From the research was obtained one unit of nitrogen production using the Pressure Swings Adsorption (PSA) method, which can produce nitrogen from the air.
2. Effect of cooling fluid flow rate on cooler performance and the temperature of the feed air produced. The greater the coolant fluid flow rate under 6 bar PSA operating conditions, the greater the thermal efficiency of the cooler produced. And the greater the coolant fluid flow rate

with the same operating conditions, the lower the temperature of the feed air temperature. The same operating conditions occur at 7 bar PSA

3. Effect of temperature and cooler performance on% nitrogen produced. The lower the air feed temperature under 6 bar PSA operating conditions, the higher the purity of nitrogen produced. The greater the thermal efficiency of the cooler, the greater the purity of nitrogen produced. The same operating conditions occur at 7 bar PSA.

4. The optimal operating conditions obtained in this study were^0 at 7 bar operating conditions, cooling fluid flow rate 35.4 m / s, feed air temperature 30.7 C, and nitrogen purity 95.7% with thermal cooler efficiency 41.58%.

5. Reference

[1] Banerjee,R. Narayankhedkar,K,G. danSukhatme S.P, 1990. Exergy Analysis of Pressure Swing Adsorption Process for Air Separation. India: Department of Mechanical Energy. Indian Institute of Technology.

[2] Cengel, Yunus. A. 2003. Heat Transfer. Mc-Graw Hill. New York.

[3] Donald. Q. Kern. 1965. Process Heat Transfer. McGraw Hill.

[4] Ehsan JavadiShokroo, Mohammad Shahcheraghi, & Mehdi Farniaei. StudyTemperature Effects on Performance of a Domestic Industrial PSA Plant.Part – SHIMI Company: Springerlink.com

[5] Ermani.A.S, Saber, M., danFarhadi, F. 2011. A Decision Tree for Technology Selection of Nitrogen Production Plant,45. Iran: Sharif University of Technology

[6] Ivanova.S and Lewis.R. 2012. Producing Nitrogen via Pressure Swing Adsorption. American Institute of Chemical Engineering (AIChE).

[7] Juntgen, H., Knblauch, K., & Klaus, H. 1981 . **Carbon Molecular Sieve : Production from Coal** and Application in Gas Separtion, 60.Germany: Butterworth-Heinemann Ltd.

[8] Kotas,T. 1985. The Exergy Method of Thermal Plant Analysis. London: Department of Mechanical Engineering. Queen Mary College. University of London.

[9] McCabe, W., Smith, J., dan Harriot, P. 1993. Unit Operations of Chemical Engineering (5 ed.).Singapore : McGraw Hill

[10] Poling.E.B, Thomspon.G.H, Friend D.G, Rowley.L.R, Wilding.V.2008. Perry's Chemical Engineering's Handbook (8 ed.). United State of America : McGraw Hill.

[11] Schroter, H.J. 1993 . Carbon Molecular Sieve for Gas Separation, 7 No 4(Gas Separation & Purification), 247–251. Germany : Butterworth-Heinemann Ltd.

[12] Schulte.A, Berndt.S and Krabiell.K. 1993. Nitrogen Generation by Pressure Swing Adsorption on Carbon Molecular Sieve. Germany: Butterworth-Heinemann Ltd.

[13] Shen.S.Y, and Wolsky,A.M. 1980. Energy and Materials Flows in the Production of Liquid and Gaseous Oxygen. United State of America: U.S Department of Energy.

[14] Shofa. 2012. Manufacture of activated carbon made from bagasse with activation of potassium hydroxide. Depok: Universitas Indonesia.

[15] Siyono, A., and Sumijanto. 2012., Analysis of the effect of pressure and temperature on the CO_2 and H_2O screening process in molecular sieve. **16.** .Field of development of reactors, Center for reactor technology and nuclear safety

[16] Sularso and Tahara, H. 2000. Pumps and Compressor: Selection, use, and maintenance. Jakarta: PT Pradnya.

[17] Spellman RF. 2008. The Science of Ai**r : Concepts and Application (2**ed.). New York: CRC Press Taylor & Francis Group.

[18] Syarief. 2010. Effect of adsorbate concentration, temperature, and surface voltage on glycerol adsorption process by alumina. Surakarta

[19] Syauqiah, I., Amalia, M., and Hetty A, K. 2011. Analysis of variations in time and speed of stirrers in the process of heavy metas waste adsorption with active charcoal. **12**. Banjarmasin: Faculty of Engineering, Unilam

[20] Thomas, W. dan Crittenden, B. 1998. Adsoption Technology and Design. Elsevier Sciene & Technology Books.

[21] Yogesh.K J. 2016. Cryogenic Liquid Nitrogen Vehicles (ZEV'S). Belagavi: Department of Mechanical Engineering. Jain Engineering Collage.

Analysis of Cooler Performance in Air Supply Feed for Nitrogen Production Process Using Pressure Swing Adsorption (PSA) Method