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Optimization of Oxygen and Nitrogen Gas Production from Oxygen Pressure Swing Adsorption Plant

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ABSTRACT

The demand for reliable and efficient oxygen and nitrogen gas production has significantly increased across various industrial and medical sectors. To meet this demand, retrofitting existing Pressure Swing Adsorption (PSA) plants has emerged as a cost-effective solution, enhancing their capacity and performance. This study focuses on the retrofit design of an oxygen PSA plant to optimize the production of oxygen and nitrogen gases. The research begins with a comprehensive analysis of the existing PSA system, including its operational parameters, equipment condition, and performance limitations. Key areas for improvement are identified, such as enhancing the adsorbent materials, upgrading compressor systems, and optimizing process control strategies. Using advanced simulation and modeling techniques, various design modifications are proposed and evaluated for their impact on the overall efficiency of PSA plant. The objective is to achieve a balanced production ratio of oxygen and nitrogen gases, taking into consideration the specific requirements of the target industries. Furthermore, a thorough techno-economic analysis is conducted to assess the financial viability of the retrofit project. The cost-benefit analysis considers factors like capital investment, operating expenses, and the expected increase in gas production capacity. The environmental impact of the retrofit design is also evaluated to ensure compliance with sustainability goals. The outcomes of this study are expected to provide valuable insights into optimizing the production of oxygen and nitrogen gases through retrofitting PSA plants. This research contributes to the broader goal of achieving energy-efficient and environmentally sustainable gas production processes, catering for the growing global demand for these critical gases.

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Abbreviations

PSA: Pressure Swing Adsorption
O: oxygen
UMTH: University of Maiduguri Teaching Hospital
ASPEN: Advanced System for Process Engineering
Airsep: Air Separation
HX: Heat Exchanger
O2PSA: Oxygen Pressure Swing Adsorber
VF: Vapor Fraction
VW: Vapor Water
VP: Vapor Pressure
VPurge: Valve Purge
IAST: idealized adsorbed solution theory
TP: Temperature and Pressure
T1a, T1b, TW, T2a, T2b: Temperature-related variables in different process stages
F: Flow rate
TF: Total flow
W: Work or power input/output in energy calculations.
DEP: Depressurization or pressure drop
P1: Pressure at a specific point in the system.
VB1: Vapor-liquid equilibrium variable.
VD, D: Distillation or separation parameters.
TV: Temperature variable in vapor phase
COMP1: Compressor
A-Tank: A specific storage or reactor tank in the simulation
N2PSA: Nitrogen Gas Pressure Swing Adsorption.

Introduction

Oxygen is essential for the metabolic processes of living organisms and must be present in the atmosphere at a concentration of 21 percent in order for life to exist [1]. Oxygen is a non-metallic chemical element that may be found in the chalcogen group of the periodic table. It has the chemical symbol "O" and the atomic number "8" [2, 3] According to Tabassum, oxygen is the third-most prevalent element in the universe [4]. It is also a highly reactive element that is a powerful oxidizing agent [5]. Oxygen is very important, especially for health purposes, which include

assisting in the resuscitation of patients, providing life support for artificially ventilated patients, and being used during surgery to maintain oxygen anesthesia, among other uses [6]. The purity of oxygen used for medicinal purposes is 99.5%. Oxygen must adhere to strict requirements and must not be exposed to any sort of contamination [7].

Pressure Swing Adsorption (PSA) units, which stand for pressure swing adsorption, are quite common in the fields of atmospheric air separation as well as oxygen concentration [8]. However, the efficacy of such installations is reduced since there is a potential that the qualities of the atmospheric air that has to be separated may be altered in a manner that was not intended [9]. Using zeolite adsorbent 13X, the problem of optimizing the operation regimes of PSA units according to the criteria of oxygen recovery rate under the circumstances of interval uncertainty in composition, temperature, and pressure of ambient air is formulated and solved [10].

The technical process of separating atmospheric air may include argon and other pollutants, along with oxygen that may range from 18–21 volume percent and nitrogen that may range from 78–80 volume percent [11]. 1-2 volume percent is achieved by using granulated synthetic zeolite adsorbent 13X in a two-adsorber PSA unit [12, 13].

The majority of the time, a PSA system will be made up of two or more adsorbent-filled beds that are connected to one another by a network of interconnected switches. In order to regulate the simultaneous operation of product purification and adsorbent renewal [14]. These switch valves are responsible for managing the operation [15]. As a consequence of this, multiple bed assemblies are used in order to ensure that a consistent supply of product may be maintained even while the other beds are functioning in the mode of regeneration [16].

In an oxygen PSA plant, air is first compressed, then chilled, and then routed through an adsorbent bed [17]. The bed selectively adsorbs nitrogen, which results in the production of high-purity oxygen gas [18]. The adsorbent bed is then allowed to depressurize, which results in the release of the adsorbed nitrogen, which is subsequently allowed to escape into the surrounding air [19]. The procedure is then repeated in an iterative fashion in order to provide an unending supply of oxygen gas with a high degree of purity [17].

A PSA plant's performance may be affected by a variety of variables, including the characteristics of the input gas, the adsorbent material, and the operating parameters of the plant [18, 20]. The performance of the PSA plant may be improved by optimizing these elements, which will result in an increase in the purity of the product gases and a reduction in the amount of energy used [16,18]. As a result, this research work designs the oxygen pressure swing adsorption plant to optimize the production of oxygen and nitrogen gas.

Materials and Method

The plant in focus was installed in 2014, situated at the University of Maiduguri Teaching Hospital (UMTH). The plant is an air separation (Airsep) PSA oxygen plant. The plant is equipped with a Keaser ASD 37 air compressor, 22 kW (30 hp capacity), an ASD-600 oxygen generator, and a 25 Nm/hr. capacity with a three-stage reciprocating oxygen compressor.

The plant also has R134a refrigerated dryer which is integrated into the oxygen compressor designed and manufactured by Keaser Company. The plant is capable of producing (7 m3*45 cylinder of O2 per day) cylinder per day.

Mode of Operation

The air compressor receives the air and compresses it to a temperature of 800 °C and a pressure of 116 psi. The compressed air enters the air settling tank via the R134a refrigerated dryer at a temperature of 30-360 °C and a pressure of 100 psi. The temperature- and pressure-reduced air enters the twin PSA tank at 30-360 °C and 100 psi, with 5A zeolite incorporated in the tank for adsorption of undesired gas at high pressure (Nitrogen) and passing of desired gas (Oxygen) via the zeolite. In the pressure swing process, separation is achieved by alternate adsorption and desorption. During the adsorption of the gas mixture, at a high pressure of about 65–75 psi, zeolite adsorbs N2 gas and releases oxygen into the O_2 tank. At a low pressure of about 45 psi, N2 gas is released via the exhaust line with the aid of residual oxygen (weak air).

The oxygen compressor, which undergoes three stages of compression, compresses the O_2 at a pressure of 1000 psi–2500 psi. Compressed oxygen at about 1500 psi enters the cylinder filling ramp. Oxygen is produced at this stage with 95.9% purity. The residence time of each of the beds to undergo one cycle is about 90 seconds, i.e., in 3 minutes, the two beds have undergone a complete cycle.

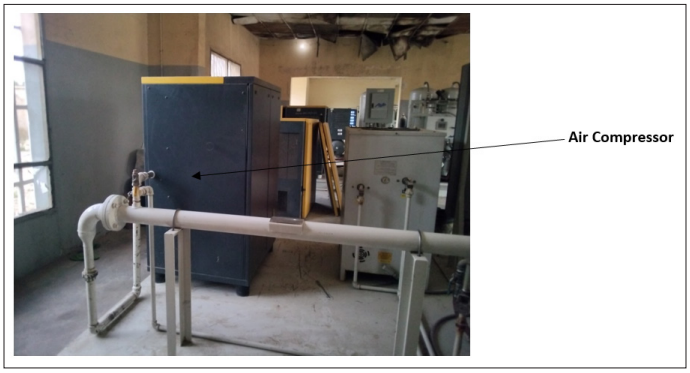

Figure 1: ASD 32 Air Compressor (Disc Pressure 8bar, Power 185kw)

Figure 2: Air Settling tank (MAWP 200psi at 150F, MIWP -20 F at 200psi)

Figure 3: PSA Tank A & B

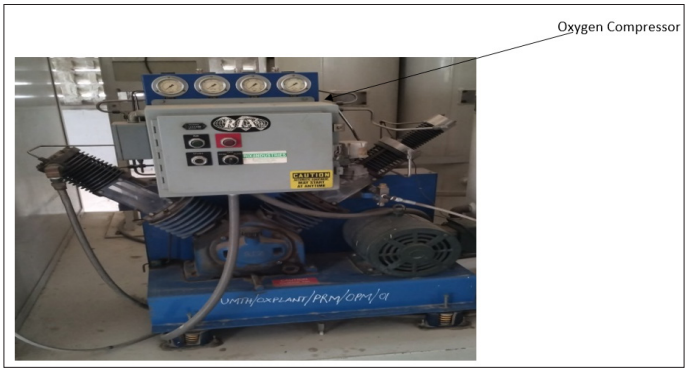

Figure 4: Oxygen Compressor

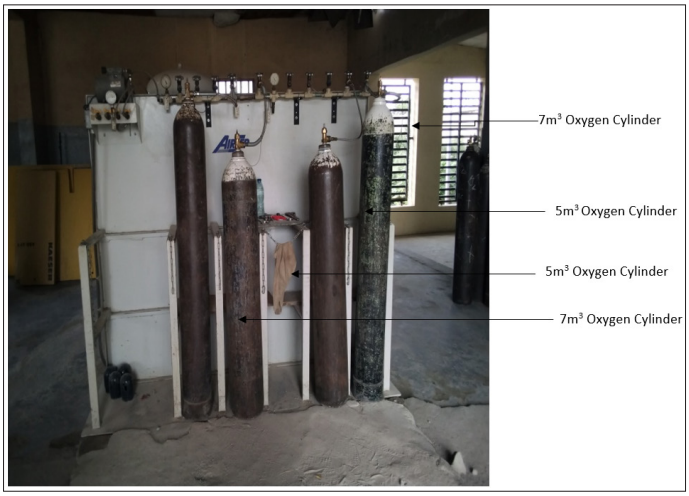

Figure 5: Cylinder Filling Ramp

The simulation is carried out in two (2) different phases, each of which includes different data (temperature, pressure) and configurations than the previous phase. In the first phase, the existing plant data are used to model the existing plant in which medical oxygen is generated and nitrogen gas is released.

In the second phase, the existing data from the existing plant is used to simulate a new plant model for the dual production of medical oxygen and nitrogen gas.

Materials

The materials are Existing plant manual, daily record book, HP Laptop, Soft Program and Microsoft office: -

- The manual and record book for the daily production records kept at the oxygen generation unit located at the University of Maiduguri Teaching Hospital (UMTH).
- A HP laptop with 8 gigabytes of random-access memory and a 9th generation Intel i3 processor.
- Software Program (ASPEN Plus)
- Microsoft Office software from Microsoft

Steady State Modelling of Oxygen PSA System

A schematic representation of an existing oxygen generation facility is shown in figure 2. Through the use of the compressor known as Comp1, air is brought from the atmosphere at a temperature of 25–350 °C and a pressure of 14.5 psi to 18.5 psi (stream 1). The temperature and pressure are increasing by 800 °C and 116 psi (stream 2). After being heated in HX-1, the compressed air is finally cooled before being stored in an air tank known as an A-Tank. After being compressed in the air tank, the air is then transported to an Oxygen Pressure Swing Adsorber (O2PSA), where the oxygen is separated and a stream of oxygen with a purity level of 90% is produced (via O_2). The separation is achieved by the use of a pressure swing adsorption (PSA) technique that consists of two beds filled with 5A Zeolite adsorbent in four stages. The fumes from the engine are released outside. This reflects the level of oxygen purity that is currently present in this plant. Because of this, the stream of gases needed further treatment in order to acquire a nitrogen gas with a higher purity level. As a result, there was a need for a second PSA for recovery, which is high enough to obtain an adequate quantity of nitrogen that might be helpful in other sectors.

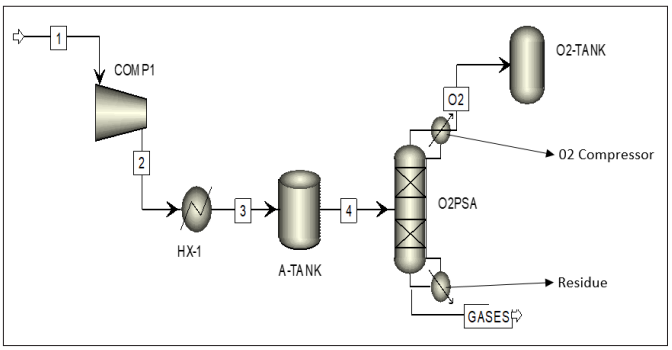

Figure 6: Process Flow Diagram of an Existing Oxygen Production Plant

Adsorbent Bed Dynamic Modeling

Figure 6 through 7, the "core" cycle of the PSA is comprised of four stages: pressurization, adsorption, countercurrent blow down, and countercurrent purging.

In step 1, valves VF, VF1, VW1, VW2 were opened. The feed is introduced into bed 1, which causes that pressure of the bed to rise, while at the same time, the extract product is linked to the second bed, which has been completely filled with atmospheric air. The next stage of operation begins after the system has attained the predetermined pressure.

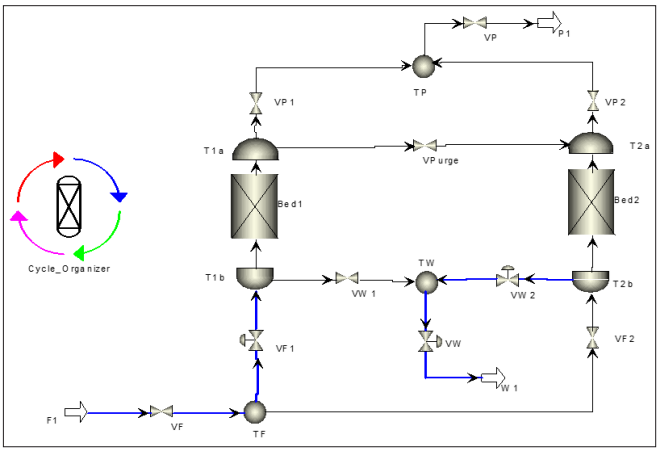

Figure 7: Step 1: Pressurize Bed 1 and Blow Down Bed 2

Step 2 involves retaining the component that has been firmly adsorbed in bed 2 while simultaneously enriching the gas output stream with the component that has been less strongly adsorbed. In order to facilitate complete regeneration, a part of the product of the raffinate is rerouted to the second bed. In this stage, the valves VF, VF1, VP, VP1, VW2, and VW were opened, and the gas and solid were allowed to contact one another in order to remove the components that were firmly absorbed. During this stage, the raffinate is extracted and collected.

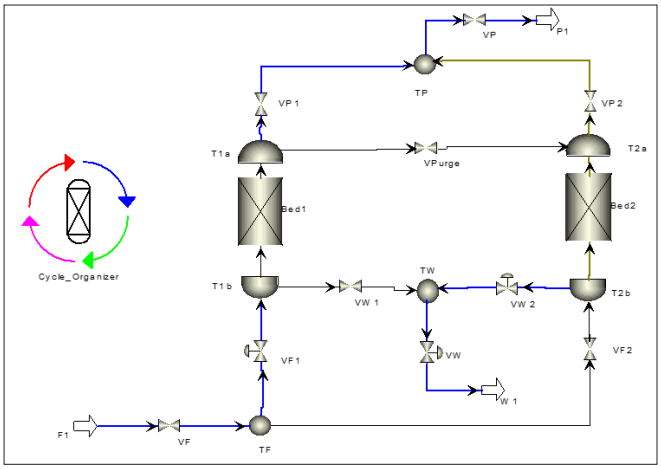

Figure 8: Step 2: Adsorbed bed 1 and Purge bed 2.

In phase 3, once the first bed has been loaded and the second bed has been regenerated, a pressure equalization phase will take place. In this step, the pressure on both beds will be brought to the same level. This results in a reduction in the amount of gas that has to be compressed, which in turn results in a saving of energy. In this stage, all of the valves other than the one labeled "VPurge In" are closed in order to purge the bed of any leftover raffinate gas and get it ready for the next step, which involves low-pressure desorption.

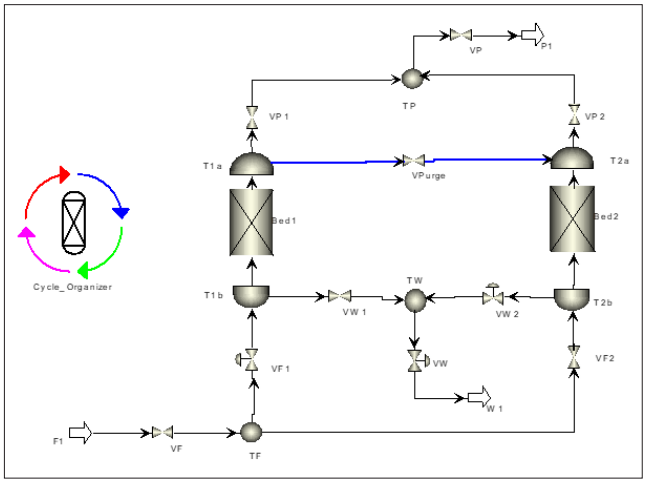

Figure 9: Step 3: Pressure Equilibration.

In step 4, do the identical process as in step 1, with the exception that the beds should be turned over. Valve VF, VF1, VF2, VW1 and VW were opened.

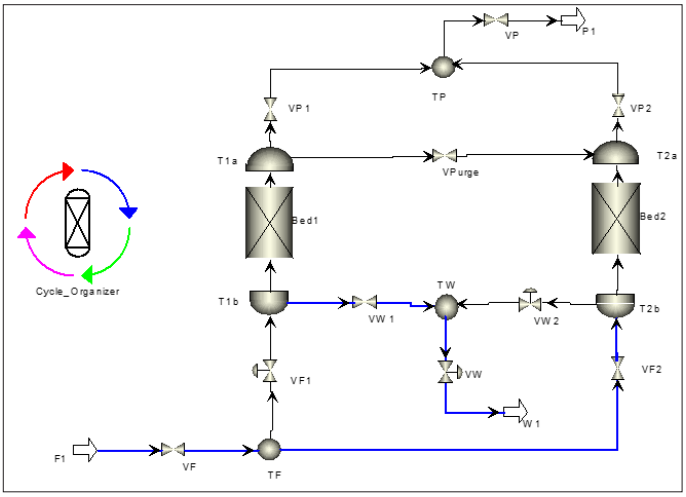

Figure 10: Step 4: Pressurize bed 2 and blow down bed 1.

In step 5; same operation with step 2, but the beds operation in reverse-order. Valve VF, VF_2, VW_2, VW, VPurge, VP_2 and VP were opened. This step regenerates the solid for the next adsorption cycle.

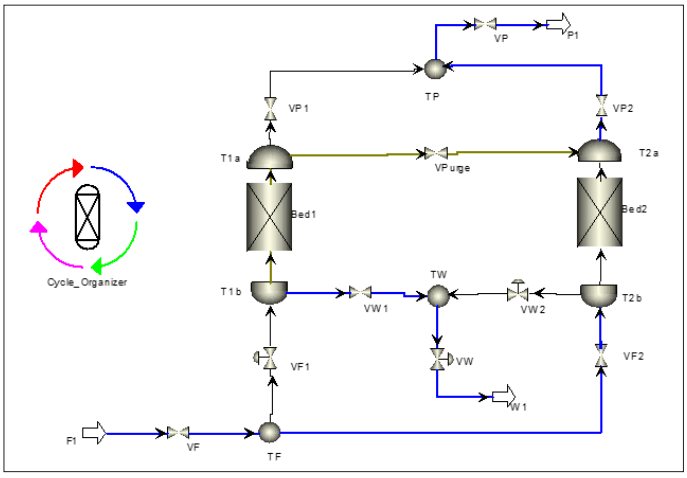

Figure 11: Step 5: Adsorbed bed 2 and Purge bed 1.
Step 6: This Process is Similar to step 3 but in Reverse-Order.

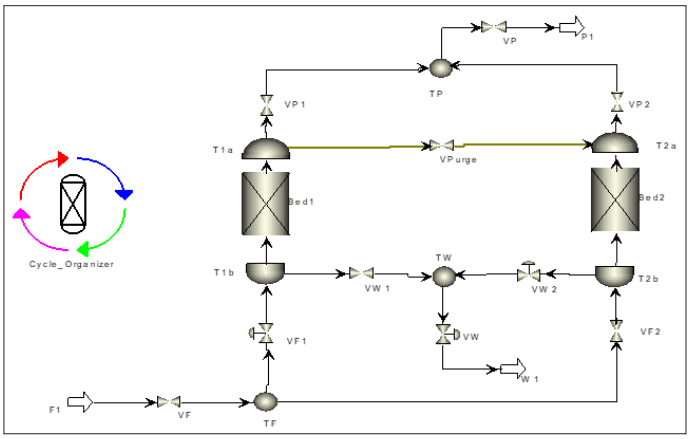

Figure 12: Step 6: Pressure Equilibration.

Adsorption Isotherm

In circumstances of equilibrium and with the temperature held constant, a mathematical description of the link that exists between the concentration of molecules of a certain species in the gas phase and the concentration of that species in the adsorbed phase is provided by this technique. A single adsorbate molecule may be classified into one of two basic categories: single site or multi-site adsorption isotherms. This classification is based on whether or not the molecule occupies one or more adsorption ions during the process. When it comes to this particular aspect, the single-site adsorption isotherms are depicted by well-known alternatives such as Langmuir and Freundlich, as well as the loading ratio correlation and the idealized adsorbed solution theory (IAST). On the other hand, the multi-site Langmuir adsorption isotherm that is developed and employed in this work is also utilized. This isotope was utilized in this investigation.

$$\frac{Q_i^*}{Q_i^{max}} = a_i K_i C_i RT \left[1 - \sum_{i=1}^{N_{comp}} \left(\frac{Q_i^*}{Q_i^{max}}\right)\right]^{a_i} \quad (1)$$

$$\text{Where } K_i = K_{\infty i} e^{\frac{-\Delta H_i}{RT}} \quad (2)$$

The Langmuir equation (eq. 1) that was just provided has the potential to effectively capture the adsorption kinetics of mixtures that have many components that are present. Despite the fact that multi-site adsorption isotherms require a significant amount of computational effort from a modeling perspective, they are able to more accurately represent the actual adsorption behavior of multi-component systems, even when subjected to a wide variety of dynamic pressure and temperature conditions [10]. This is an important point to keep in mind. It is important to pay attention to this particular aspect

Mass Balance

Fluid phase mass balance

$$-D_l \frac{\partial^2 c}{\partial^2 z} + \frac{\partial}{\partial z}(vc) + \frac{\partial c}{\partial t} + \left(\frac{1-£}{£}\right)\frac{\partial \bar{Q}}{\partial t} = 0 \quad (3)$$

Where: c = average liquid phase concentration
D_l=Axial dispersion coefficient, cm2/s
z=axial coordinate, m.
v=velocity, m/s.
t=time, (s)
£=bed porosity
Q=concentration, mg/g
Initial and boundary conditions.

$$\text{At } t=0,\ c=0 \quad (4)$$

$$\text{At z=0, } C_{in}=C - \frac{D_l}{V}\frac{\partial c}{\partial z} \quad (5)$$

$$\text{At z=L, } \frac{\partial c}{\partial z} \quad (6)$$

By introducing the dimensionless coordinates

$$Y=Z\backslash L, \qquad Ø=\frac{t_v}{L}$$

Equation (1) to (6) becomes,

$$-\frac{1}{P_e}\frac{\partial^2 c}{\partial Y^2} + \frac{\partial c}{\partial y} + \frac{\partial c}{\partial Ø} + \left(\frac{1-£}{£}\right)\frac{\partial \bar{Q}}{\partial Ø} = 0 \quad (7)$$

At Ø=0, c=0

$$\text{At, Y=0, } C_{in}=C-\frac{1}{P_e}\frac{\partial c}{\partial Y} \quad (8)$$

$$\text{At } \ Y=1, \ \frac{\partial c}{\partial Y} = 0 \quad (9)$$

Where peelet number Pe=Lv\DL
The uptake rate expressed on the basis of unit adsorbent volume, is given by

$$M=\frac{\partial \bar{Q}}{\partial t} \quad (10)$$

In terms of external mass transfer, M may be written as

$$M = \frac{3kf}{R_p}(c - c_s) \quad (11)$$

The answer to the correct equation for intra-particle diffusion may be used to calculate the uptake rate in terms of the intra-particle diffusion. The following is an expression for the absorption rate that is derived from the linear driving force (LDF) model of solid diffusion [21]:

$$M = \frac{15D_s}{R^2 p}(q_s - \bar{Q}) \quad (12)$$

In addition, Cs are the absorbed phase and fluid phase concentration, respectively, at the fluid-solid interface. They are in equilibrium and defined by the Langmuir equation

$$q_s = \frac{q_{mkc_s}}{1+kc_s} \quad (13)$$

After combining all the above equations, the final fluid phase balance equation become

$$-\frac{1}{P_e}\frac{\partial^2 c}{\partial y^2} + \frac{\partial c}{\partial Ø} + \frac{\partial c}{\partial z} + 3\beta_i T \left(\frac{1-£}{£}\right)\left(c_b - \frac{q_s k p_p}{q_m k - q_s k}\right) = 0$$

And where the solid phase mass balance:

$$\frac{\partial q_s}{\partial Ø} = \left[\frac{3\beta_i T\left(\frac{1-£}{£}\right)\left(c_b - \frac{q_s k p_p}{q_m k - q_s k}\right) + \left(\frac{\beta_i}{5}\right)\left(\frac{\partial c}{\partial Ø}\right)}{1+\left(\frac{\beta_i}{5}\right)\left(\frac{k}{q_m k - q_s k}\right)^2}\right] \quad (15)$$

Where, $\beta_i = \frac{k_f R_p}{D_s}$ is the Biot Number

$$T = \frac{D_s L}{P^2 pv} \text{ is constant}$$

Momentum Balance

For the calculation of the pressure drop in the PSA system, Ergun equation was used, which is valid for both laminar and turbulent flows and is the most popular option.

$$\frac{\partial C_i}{\partial t} + \frac{(1-\varepsilon)}{\varepsilon}\frac{\partial q_i}{\partial t} + u\frac{\partial C_i}{\partial z} = D_L\frac{\partial^2 C_i}{\partial z^2} = 0$$

C_i is the concentration of component in the gas phase, q_i is the concentration of component in the solid phase, and ε is the total bed void age. These three variables are represented in the equation. In addition, the axial distance across the column is denoted by the letter z, and the axial dispersion coefficient is denoted by the letter DL. The reduction in pressure that takes place inside the column is denoted by the letter P, and the letter u represents the surface velocity of the gas flow.

ψ =particle shape factor [21].

Variations in the bed's internal pressure are a vital component at each and every step of the PSA cycle. While the adsorption and purge processes are being carried out, neither pressure drop nor pressure transients are taken into account. The reason for this is that at this stage, both ends of the column are wide open, and the bed is functioning in a condition that allows for continuous flow. The depressurization and re-pressurization phases, on the other hand, are distinguishable from one another by the presence of significant pressure transient gradients. This occurs due to the fact that the pressure not only varies over the course of time but also in the axial direction when these steps are being performed.

In order to accurately capture momentum transmission inside the packed bed, the PSA model has to include full-scale Navier-Stokes equations. This is a fundamental need for the process. Within a PSA bed, it is possible for both laminar and turbulent conditions to be in play at the same time. This fact is very crucial to keep in mind. In the semi-batch processing phases of the PSA cycle, for instance, the flow conditions at the closed end of the column are laminar, but the flow conditions at the opposite end of the column, where the fluid is exiting the bed at high speeds, are turbulent. Because it is capable of accounting for both flow regimes, the use of the principle-based Navier-Stokes equation is much more significant when applied in a situation like the one described. As a second option, the quasi-steady-state Ergun equation, which can be seen in the following example, is often used to make an approximation of the pressure changes occurring inside the packed bed.

$$-\frac{\partial P}{\partial z} = \frac{150\mu(1-\epsilon_b)^2}{\epsilon_b^3 d_p^3}U + \frac{1.75(1-\epsilon_b)\sum_{i=1}^{N_{comp}} C_i MW_i}{\epsilon_b^3 d_p^3}|U|U \quad (17)$$

The condition of quasi-steadiness In the Ergun equation, b and p are considered constant parameters since it is assumed that they do not vary under any of the many hydrodynamic circumstances that are experienced during the PSA cycle. In particular, the constant b assumption is put to the test at the beginning of each and every PSA processing step, which, by its very nature, involves semi-continuous flow. For instance, it is not unusual to inoculate transient flow spikes during the re-pressurization or blow-down stage, which may somehow adjust the packed bed configuration. This is because the packed bed is subject to some degree of pressure change throughout these steps. In addition, it is assumed that the thermodynamic and transport parameters Cpi, p, and Cps remain unchanging under the feed conditions.

Valve Flow/Pressure Behavior

It is governed by the valve equation:

$$U = \frac{R}{\epsilon\pi D^2}CV\sqrt{1-\left(\frac{P_{low}}{P_{high}}\right)^2} \; if \left(\frac{P_{high}}{P_{low}}\right) < P_{critical}$$

$$= \frac{R}{\epsilon\pi D^2}CV\sqrt{1-\left(\frac{1}{P_{critical}}\right)^2} \; otherwise \quad (18)$$

$$\text{Where } P_{critical} = \left(\frac{2}{1+\gamma}\right)^{\frac{\gamma}{1-\gamma}} \gamma = \frac{C_p}{C_p - R} \quad (19)$$

$$C_p\left(=\sum_{i=1}^{N_{comp}} C_{p_i} y_{feed_i}\right) \quad (20)$$

Because it is presumed that Cp is unchanging in feed circumstances, $P_{critical}$ is also expected to be unchanging for valves that are associated with various processing processes. This is in spite of the fact that the stream conditions during the blowdown and purge operations at the feed end (z = 0) are significantly different from the stream conditions throughout the duration of the incidents during those operations. Cp is assessed at the same temperature (as feed circumstances), but at the expected off-gas composition, for these two valves, this is done in order to account for variances of this kind.

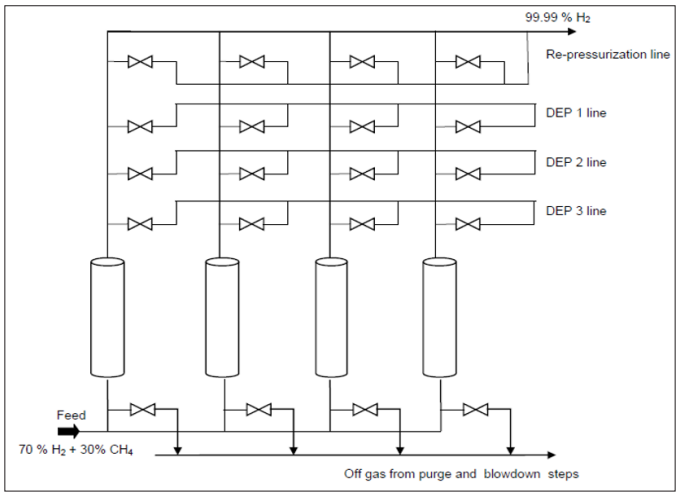

Figure 13: Stages Feed-depressurization

Cyclic Steady State Model

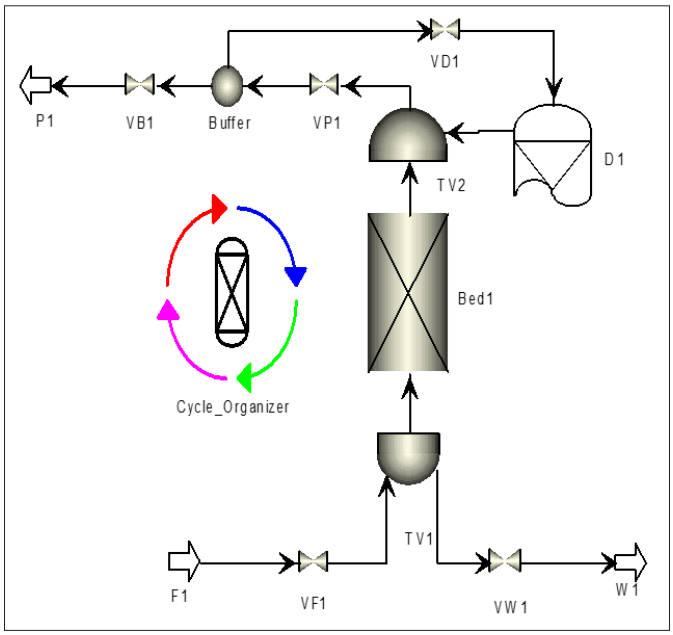

Figure 14: Cyclic Steady State Model

Optimization of Retrofit Process

Nitrogen Production

In order to collect nitrogen gas, a supplementary unit has been installed at the plant that is already in operation. In addition to that, this unit makes use of a two-bed pressure swing adsorption method, with a carbon-molecular sieve serving as the adsorbent. The Aspen Plus Model of the updated process is shown in its entirety in Figure 15. Within the context of this concept, nitrogen is combined with the oxygen plant in such a way that the production of oxygen gas and nitrogen gas occurs concurrently.

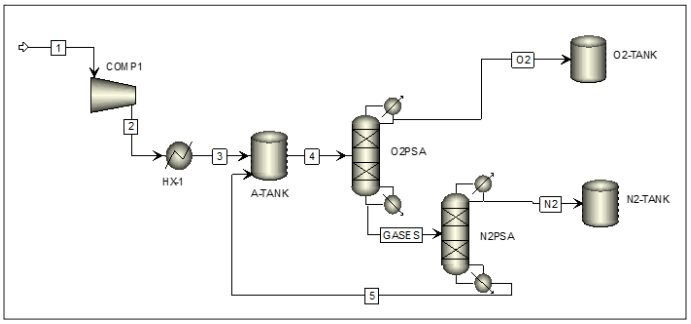

Figure 15: The Redesigned Oxygen and Nitrogen Production plant

Results and Discussion

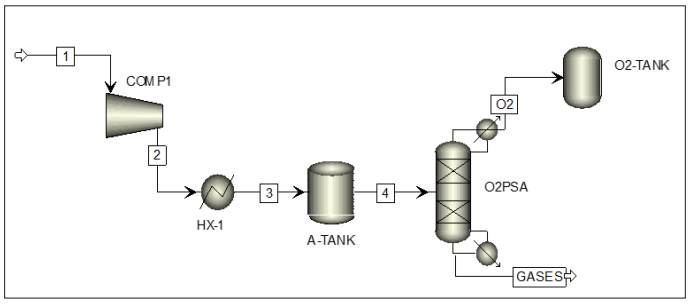

Figure 16: Process flow diagram of an existing oxygen Production Plant

A schematic representation of an existing oxygen generation facility is shown in figure 3.1. Through the use of the compressor known as Comp1, air is brought from the atmosphere (stream 1) down to 8.5 bar (stream 2). After being heated in HX-1, the compressed air is finally cooled before being stored in an air tank known as an A-Tank. After being compressed in the air tank, the air is then transported to an Oxygen Pressure Swing Adsorber

(O_2 PSA), where the oxygen is separated and a stream of oxygen with a purity level of 90% is produced (via O_2).

The separation is accomplished by the use of two beds that are jam-packed with 5A zeolite adsorbent using a pressure swing adsorption (PSA) technique that has four stages.

The fumes from the engine are released outside. This reflects the level of oxygen purity that is currently present in this plant.

The results of the simulation are shown in Table 1. It can be seen from this table that the concentration of nitrogen gas (N2) in the exhaust gases is 81.29% with a flow rate of 21.8 kmol/hr. This concentration is high enough to acquire a respectable quantity of nitrogen that may be helpful in other sectors. The flow rate is 21.8 kmol/hr. Because of this, the GASES stream needed further treatment in order to achieve a greater level of nitrogen gas purity, which is what led to the necessity of the second PSA for nitrogen recovery.

Present Simulation and Optimization Output Table or Figure in Subsection

The findings of the existing oxygen generation plant that is now in operation are reported, and the model is adjusted and improved upon.

Table 1: Displays the Results of a Simulation run on the Current Oxygen Producing Facility

Streams	1	2	3	4	O_2	PSA
Mole Flow Kmol/hr.	COMP1	HX-1 COMP1	A-TANK HX-1	O2PSA A-TANK	GASES O2PSA	O2 O2PSA
Ar	0.256606	0.256606	0.256606	0.256606	0.256606	0
N2	20.27187	20.27187	20.27187	20.27187	19.90697	0.364894
O2	5.132119	5.132119	5.132119	5.132119	1.642278	3.489841
Mole Fraction						
Ar	0.01	0.01	0.01	0.01	0.011768	0
N2	0.79	0.79	0.79	0.79	0.812919	0.094661
O2	0.2	0.2	0.2	0.2	0.175314	0.905339
Mass Fraction						
Ar	0.013809	0.013809	0.013809	0.013809	0.016521	0
N2	0.764975	0.764975	0.764975	0.764975	0.898783	0.08386
O2	0.221216	0.221216	0.221216	0.221216	0.084696	0.91614
Total Flow Kmol/hr.	25.66059	25.66059	25.66059	25.66059	21.80586	3.854734
Total Flow kg/hr.	742.3581	742.3581	742.3581	742.3581	620.4655	121.8927
Total Flow l/min	10457.45	2670.991	1321.546	1321.546	1123.584	197.9747
Temperature °C	25	363.6105	40	40	40	40

Adsorption Breakthrough Dynamics

Figure 17 below depicts the outcomes of an initial breakthrough simulation that took place at an adsorption pressure of 8.5 bars. The breakthrough time for the oxygen purification occurred after 1050 seconds had elapsed. According to the research that has been done, the capacity for dynamic adsorption is typically 40 to 60 percent lower than the capacity for static adsorption (Campbell, 1976). As a result, taking into account the pushing time, which is 25 seconds, the actual breakthrough time might take place anywhere between 410 and 615 seconds after the adsorption stage has been initiated. It was required to cease the adsorption phase after 405 seconds had passed from the beginning of the adsorption process, according to the industrial data acquired from the target plant (UMTH), in order to avoid hitting the breakthrough point. As a result, the lower margin of the simulated breakthrough time (410 seconds) could be trustworthy enough to be used as a criterion in the process of designing the PSA plant.

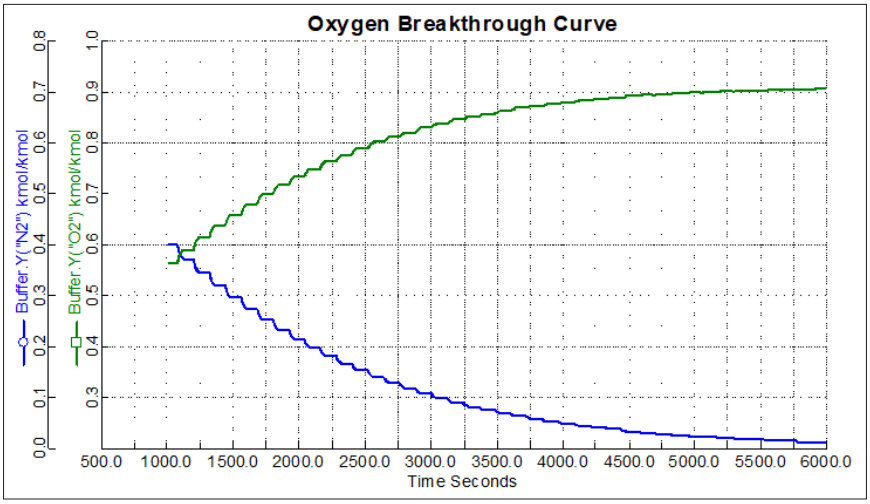

Figure 17: O_2 Breakthrough Curve Obtained From the (O2PSA model) Aspen Adsorption Simulator

Effect of Adsorption Pressure

The amount of pressure exerted during adsorption is directly proportional to the capacity of the item being adsorbed. Increasing the adsorption pressure results in higher oxygen purity, but at the price of oxygen recovery. This is because the total adsorbent capacity rises as the pressure is increased, and this includes the ability to absorb O_2. Additionally, a higher adsorption pressure results in a greater need for compression, which in turn leads to a greater amount of energy being used. On the other hand, a lower pressure raises the possibility that the ideal level of purity will not be achieved. The influence that adsorption pressure has on PSA process performance is seen in figure 18 for P/F ratios that remain constant. When the pressure is increased over 5 bars, there is a significant jump in the rate at which the product's purity improves. When the pressure is increased by 6 bars, there is also a rapid rise in the amount of oxygen that is recovered. The purest kind of operation is one that strikes a balance between oxygen recovery and oxygen purity.

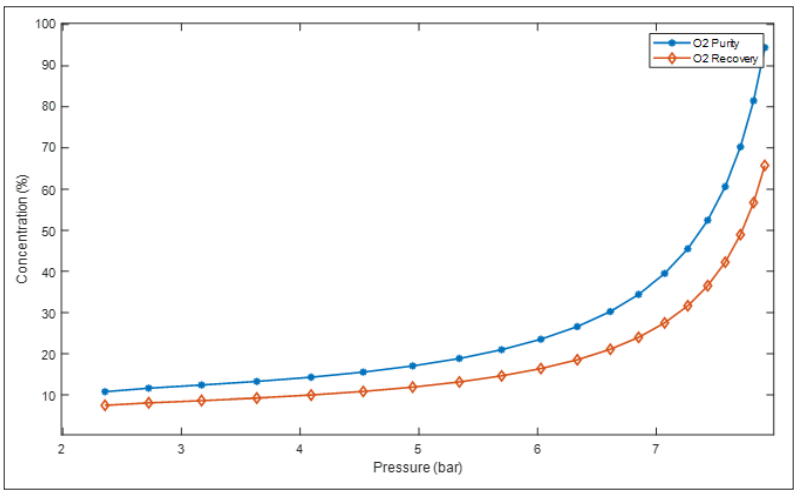

Figure 18: Effect of Adsorption Pressure on Oxygen Purity and Recovery at Constant Purge to Feed Ratio.

Results

Modified Oxygen Integrated with Nitrogen Plant

In order to collect nitrogen gas, a supplementary unit has been installed at the plant that is already in operation. In addition to that, this unit makes use of a two-bed pressure swing adsorption method, with a carbon-molecular sieve serving as the adsorbent. The Aspen Plus Model of the improved process is shown in its entirety in Figure 19. Within the context of this concept, nitrogen is combined with the oxygen plant in such a way that the production of oxygen gas and nitrogen gas occurs concurrently. The results of running the simulation on the improved model of the oxygen plant are shown in Table 2. The conclusion that can be drawn from these findings is that the concentration of O_2 that is created has increased from 90.5% to 92.2%, while the concentration of N2 that is produced is 99.76%, which is a level that is high enough to be used by other processes.

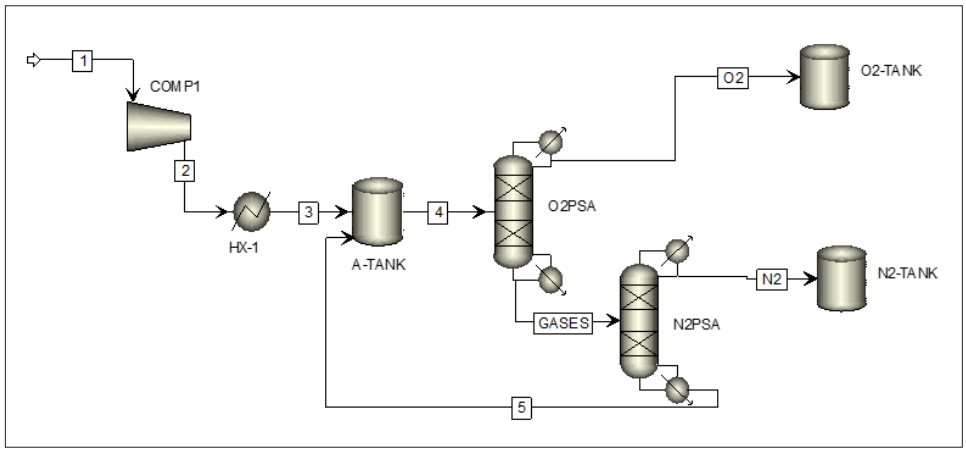

Figure 19: Process Flow Diagram of the Modified Oxygen Production Plant

Optimization

The performance of PSA is dependent on a wide variety of process factors. Due to the fact that the purity of the PSA product gas would have an impact on the kinetics of the O2PSA system, the breakthrough order of the impurities is of utmost significance in this investigation. The length of time that is spent in the adsorption stage is determined by the breakthrough time of each component, which varies based on the parameters of the process. Consequently, research will be carried out in order to ascertain the manner in which the performance of PSA is influenced by the adsorption pressure and the adsorption time that occur during a cycle. All of the parameters, including the size of the bed, the feed flow rate, and the temperature of the adsorption, remained unchanged.

Table 2: Simulation Result of the Modified Oxygen Production Plant

Streams	1	2	3	4	5	GASES	N_2	O_2
	COMP1	HX-1 COMP1	A-TANK HX-1	O2PSA A-TANK	A-TANK N2PSA	N2PSA O2PSA	N2PSA	O2PSA
Mole Flow (Kmol/hr)								
Ar	0.256606	0.256606	0.256606	1.03E+16	1.03E+16	1.03E+16	0	0
N_2	20.27187	20.27187	20.27187	23.77245	3.500577	23.34454	19.84286	0.427904
O_2	5.132119	5.132119	5.132119	7.471118	2.338999	2.390758	0.047815	5.08036
Mole Fraction								
Ar	0.01	0.01	0.01	1	1	1	0	0
N_2	0.79	0.79	0.79	2.31E-15	3.40E-16	2.27E-15	0.997596	0.077684
O_2	0.2	0.2	0.2	7.26E-16	2.27E-16	2.32E-16	2.40E-03	0.922316
Mass Fraction								
Ar	0.013809	0.013809	0.013809	1	1	1	0	0
N_2	0.764975	0.764975	0.764975	1.62E-15	2.38E-16	1.59E-15	0.997255	0.068673
O_2	0.221216	0.221216	0.221216	5.81E-16	1.82E-16	1.86E-16	2.74E-03	0.931327
Total Flow (Kmol/hr)	25.66059	25.66059	25.66059	1.03E+16	1.03E+16	1.03E+16	19.89068	5.508264
Total Flow (kg/hr)	742.3581	742.3581	742.3581	4.11E+17	4.11E+17	4.11E+17	557.3976	174.5525
Total Flow (l/min)	10457.45	2670.991	1321.546	4.21E+15	4.21E+15	4.21E+15	9.840784	2.220555
Temperature (C)	25	363.6105	40	-231.194	-231.194	-231.194	-231.194	-231.194
Pressure (bar)	1.01325	8.5	8.4	8.4	8.4	8.4	8.4	8.4

Conclusion

In the context of this investigation, the medical oxygen production facility at the University of Maiduguri Teaching Hospital (UMTH) generates medical oxygen while simultaneously expelling nitrogen gas. The hospital (UMTH) benefits from the plant's production of medicinal oxygen. The present plant is modeled and optimized, the adsorption period is raised from 100 to 120 seconds, the recovery rate is improved from 5% to 40.0%, and the product purity is increased from 8% to 62% in a single adsorption circle. An additional model unit for the recovery of nitrogen gas has been incorporated to the plant, the Aspen Plus model has been used to include a nitrogen production unit into the current model. The nitrogen plant is combined with the oxygen plant so that both oxygen and nitrogen gas will be produced concurrently. In addition, the concentration of the oxygen that is produced has increased from 90.5% to 92.2%, while the concentration of the nitrogen that is produced is 99.76%, which is sufficient for it to be utilized in other processes. Despite the initial investment expenses for improvements and new equipment, the new design method turned out to be more economical in the long run. Significant cost reductions and a quicker return on investment are a result of the increased productivity and enhanced efficiency. The plant's dual production capabilities increase its adaptability and give UMTH access to an extra vital resource—nitrogen—for a range of industrial and medical uses. Additionally, this diversification increases operational flexibility and opens up new revenue streams.

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A. S. Girei[4]: Data Curation
Ali Lawan Yaumi[3]: Writing – review & editing

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Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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