Design and Construction of Portable Oxygen Concentrator Using Pressure Swing Adsorption (PSA) Technology

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DESIGN AND CONSTRUCTION OF PORTABLE OXYGEN CONCENTRATOR USING PRESSURE SWING ADSORPTION (PSA) TECHNOLOGY.

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Abstract. Oxygen is used in various chemical processes and for medical purposes around the world. During the Covid-19 pandemic, the need for medical Oxygen has increased sharply in all hospitals in the world. In this thesis, we will design Oxygen Concentrator with use an adsorption column design for an effective Pressure Swing Adsorption (PSA) unit to utilize heat exchange between an isothermic adsorption process and an endothermic adsorption process. Efficient operation of the PSA process is required to utilize the adsorbent capacity as much as possible and reduce the processing power requirements. This research is expected to provide suitable operating conditions to develop a better PSA process using the adsorbent type zeolite Alam Bayah and Synthetic zeolite Na-X.

Introduction

Oxygen is one of the essential ingredients to support life on earth and oxygen is abundantly available in gaseous form in our atmosphere at a concentration of about 21%. Today the need for oxygen in purer form has increased rapidly with the emergence of a variety of new manufacturing processes and the need for medical applications. The use of pure oxygen for the industrial world is found in industries that produce steel, chemicals, petrochemicals, glass, ceramics, paper, and the recovery of non-ferrous metals. The application of pure oxygen in medical applications, especially surgery, outpatient care, and COPD (Chronic Obstructive Pulmonary Disease) patients to help patients breathe [1].

The use of zeolite as an adsorption medium can help increase energy use efficiency, increase process efficiency, increase processing rate, improve product quality, and reduce the environmental impact of the oxygen purification process [1].

This thesis will conduct research to examine the effectiveness of the use of Natural Bayah zeolite and Na-X zeolite on the efficiency of the PSA process using an adsorption column design that has high efficiency by utilizing heat exchange from adsorption and desorption reactions.

During the Covid-19 Pandemic, the Ministry of Industry (Kemenperin) continues to coordinate with related parties such as the industrial sector and academia to provide support in meeting the needs of medical oxygen gas for handling Covid-19 patients. Based on data from the Ministry of Health, as of July 6, 2021, the need for medical oxygen has increased to 2,333 tons / day, while the national capacity is at 1,758 tons / day. This means that there is a deficit of around 575 tons / day. Therefore, it is necessary to find additional sources of oxygen, either from increasing available production capacity or looking for other sources both localized and imported [2].

Oxygen used in the medical sector aims to: [3].

1. Oxygen to help the patient's breathing.
2. Used during conditions in the operating room to maintain the breathing of the patient who is being anesthetized (in medical surgery).
3. Used for the recovery of patients in the treatment room.
4. Used in patients in conditions of curing pulmonary diseases or patients in critical condition (ICU, ICCU, NICU, PICU).
5. Used to help newborns who are experiencing difficulties in breathing independently.
6. Used to help the breathing of victims exposed to fire smoke and or patients who are poisoned by CO gas or other gases.

The quality and content of oxygen required as medical oxygen gas must contain an average of 93% (Medical grade Oxygen 93) with the following conditions: [4].

1. According to Ph Eur: contains oxygen between 90.0%V/V and 96% V/V and other residual gases should only be nitrogen and argon.
2. According to the USP: oxygen produced from the air with molecular sieve technology must contain oxygen of at least 90.0 % V / V and at most 96 % O2 V / V and the remaining gases should only be nitrogen and argon.

Teknologi PSA (Pressure Swing Adsorption): [3]

1. This technology uses an adsorbent medium (zeolite, or porous medium) laid out in two adsorption columns for the desired separation of molecules.
2. The installation of 2 operation columns allows the generation flowrate to be carried out continuously.
3. This technology uses 4 step processes:
    1. Adsorption & 2. Production
    3. Blowdown & 4. Desorption

A good design for adsorption-based gas separation processes depends on the dynamic behavior of the adsorbent/gas system. A commonly used assumption is that absorption in porous adsorbent media will be limited by mass transfer. The mass transfer of gases in porous adsorbents can become complex due to the presence of one or more mechanisms. Possible mechanisms are microporous diffusion (surface diffusion) mechanisms, Knudsen diffusion, macroporous diffusion, Poiseuille flow, transport across the surface barrier, and external mass transfer. In addition, changes in adsorbent temperature caused by heat of adsorption can further complicate the dynamic behavior of gas absorption in the adsorbent medium [5].

This PSA technology has several advantages such as: short start-up time, easy start and stop, low energy consumption, and relatively low operating costs and can be made automation. For application in highland areas such as in China. PSA technology is the most economical technology [6].

One application of PSA technology is in the development for the purposes of medical oxygen concentrators that are planned to be used in manned space missions. Currently, the compressed oxygen tank placed on the International Space Station has several disadvantages including that this tank is dangerous, heavy, and the oxygen supply is limited. In addition, the continuous use of pure oxygen during medical treatment causes the allowable oxygen levels in the spacecraft to be rapidly exceeded. However, the current availability of PSA concentrator oxygen is too heavy and uses too much power for use in space. The development of lighter and more efficient medical concentrator oxygen devices is a comprehensive effort that must be realized immediately [7].

The separation technology using PSA consists of several columns containing adsorbents that are carried out with several stages of operation with a pressure step (pressurization) and a pressure removal step (depressurization) that runs successively alternating each other to produce a continuous flow of pure product gas and purity as expected [8].

Gas preparation before entering PSA is by reducing the moisture content in the Silica Gel dryer [3]:

1. The purpose of this process is to reduce the moisture content and other impurity gases such as CO_2 gas . (data: Air at 100% humidity has a water vapor content equivalent to 3%).
2. The high water content will interfere with the absorption performance of N_2 and AR in the adsorbent and reduce the working efficiency of the adsorbent column.
3. The moisture content should be removed through Silica Gel or Alumina Gel. To obtain better efficiency, the silica gel regeneration process can be done with the help of a heating coil in the internal silica gel bed.

Zeolite as a PSA adsorbent

Zeolite made from aluminosilicate crystals is widely used in adsorption, catalysis, membrane, and sensor technology. The separation of gases through the adsorption process occurs in zeolite which has a porous structure. This is due to the interaction between the dipole moment of the gas molecule and the electric field in the pores of the adsorbent (separation to the equilibrium point) [9].

Zeolite can be classified according to the ratio of Si and Al. This classification is based on the range following ranges: [10].

a. Low Silica Zeolite ($1 < Si/Al < 5$),
b. Medium Silica Zeolite ($5 < Si/Al < 10$) and
c. High Silica Zeolite ($Si/Al > 10$

Zeolite adsorbent is widely used in gas separation processes on PSA technology and is suitable for purification of oxygen gas from air by using low-silica-grade Na-X type zeolite [8].

Type X zeolite which is low in silica in the form of bonding with Li^+ (Li-LSX) has a higher level of selectivity to N_2 gas than NaX type zeolite, this is due to the higher polarization power of Li^+ cations so that type x zeolite is widely used as zeolite adsorbent in the air separation process [8].

Zeolite adsorbents consist of several small-sized zeolite crystals formed into larger pellets or beads. Type zeolite crystals such as Na-X, mass transfer is expected to occur quickly due to the relatively large dimensions of the zeolite pore opening (0.74 nm) [5].

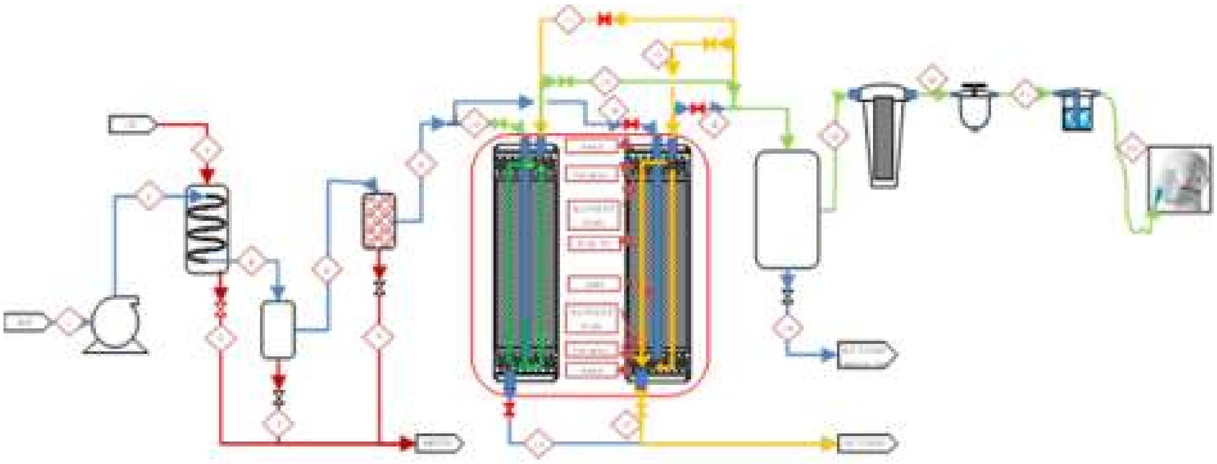


Figure 1. Unit O2 Concentrator arrangement.

Research equipment consists of:

1. Compressor
2. Cooling tubes
3. POT KO Fund
4. Dryer Tube (Silica Gel Dryer)
5. Adsorption Column
6. Oxygen storage tube
7. Filter
8. Regulator O2
9. User Indicator
10. User O2 Mask

The adsorption column is designed to be able to take advantage of the adsorption heat from the column under operation to warm the column that is in the desorption stage, so that the removal of nitrogen gas will be more perfect.

The installation of both columns is shown in the configuration as per Figure 1. The two columns are placed as close as possible to facilitate heat exchange between the two columns. The heat difference of around 10 oC can be used to increase equipment efficiency.

The inlet gas feed is also designed to be able to cool the zeolite fixed bed. The method used is to put an incoming feed pipe in the middle of the zeolite, so that it also cools the zeolite that is operating to absorb nitrogen gas. It is hoped that the cooling of this feed pipe will also increase the efficiency of nitrogen gas absorption. Please see Figure 2 for desain Zeolite column.

Around the column, a gas product output pipe that has a higher temperature is also placed in a column that is being desorbed, so that the column will be heated and make the release of nitrogen gas from zeolite more and produce better efficiency.

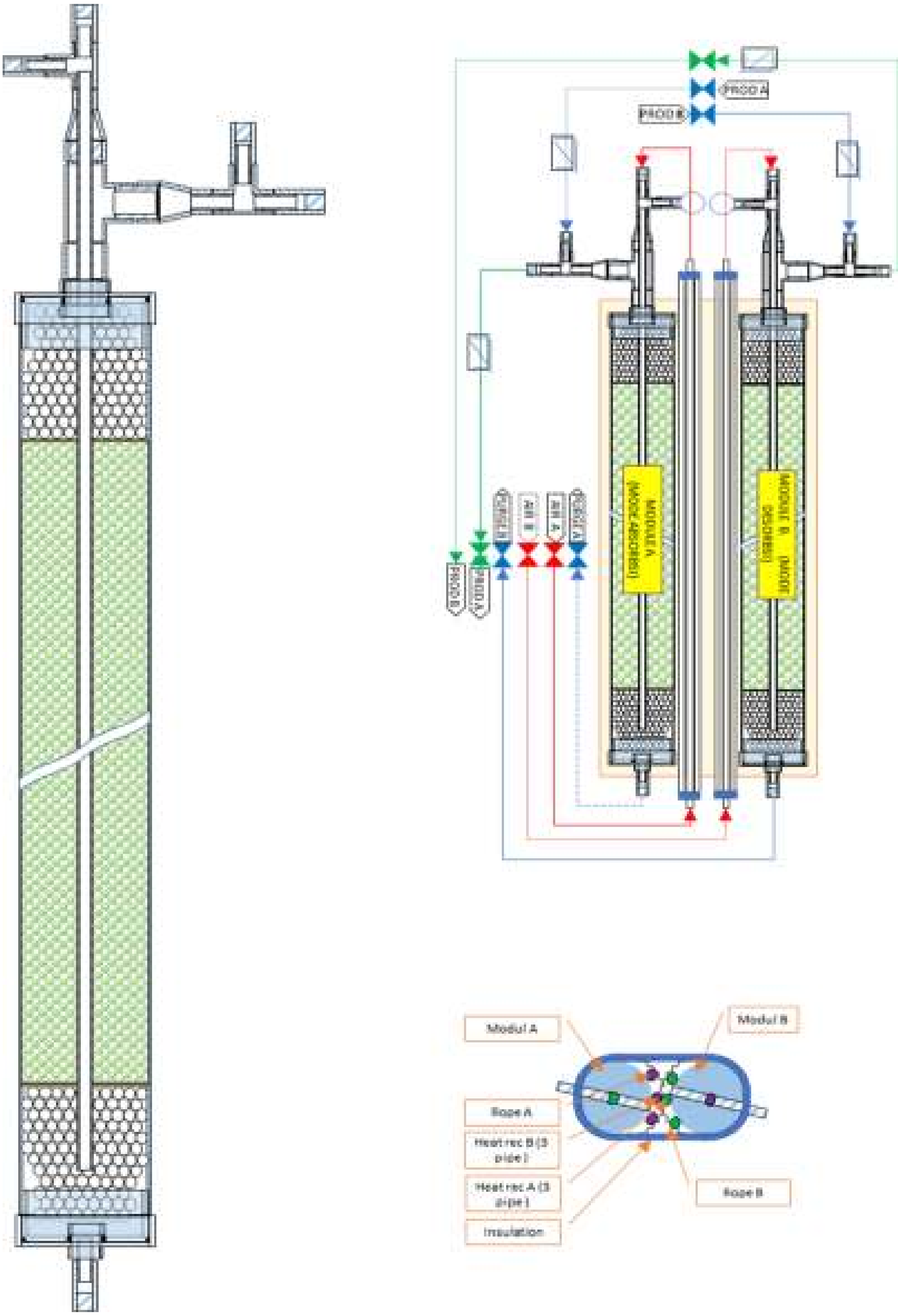


Figure 2. Column equipment design O2 concentrator (Adsorption)

Description of how the equipment works.

1. 1 unit of oil free type compressor will be operated to produce compressed air of 4 kg/cm2.G and a pressure of 25 oC with a moisture content of about 2.2%.
2. The air from the compressor is then sent to the cooling tube unit which contains ice water as a cooling medium. The air coming out of this cooling unit is targeted to reach 10 oC, so that it can reduce the moisture content in the compressed air to about 1.1%.

3. This cold air is then put into the KO POT Tube to trap the water vapor that has condensed, so that the air will be drier.
4. This air is then passed to the Silica Gel Dryer unit to be able to produce water vapor-free air (dry air).
5. This dry air is then passed to the adsorption column for the separation process of O2 from other gases. Air at the initial stage will be fed into the adsorption column A for the absorption of nitrogen gas and argon gas by zeolite media. The rest of the oxygen-filled air will continue to pass through the column to the oxygen storage tube.
6. Under the same condition the adsorption column B, lowered the pressure to remove nitrogen gas and argon gas trapped in zeolite. The operation of the two columns will alternate between column A and column B
7. The collected oxygen is then sent to the Filter to eliminate the possibility of zeolite particles being carried away.
8. Clean oxygen is lowered the pressure to the appropriate pressure for the patient/user to use through the O2 Regulator.
9. Oxygen will flow to the Indicator User unit to see the movement of oxygen to the user.
10. Oxygen ready to use via User O2 Mask tool

Timing and stages of column operations

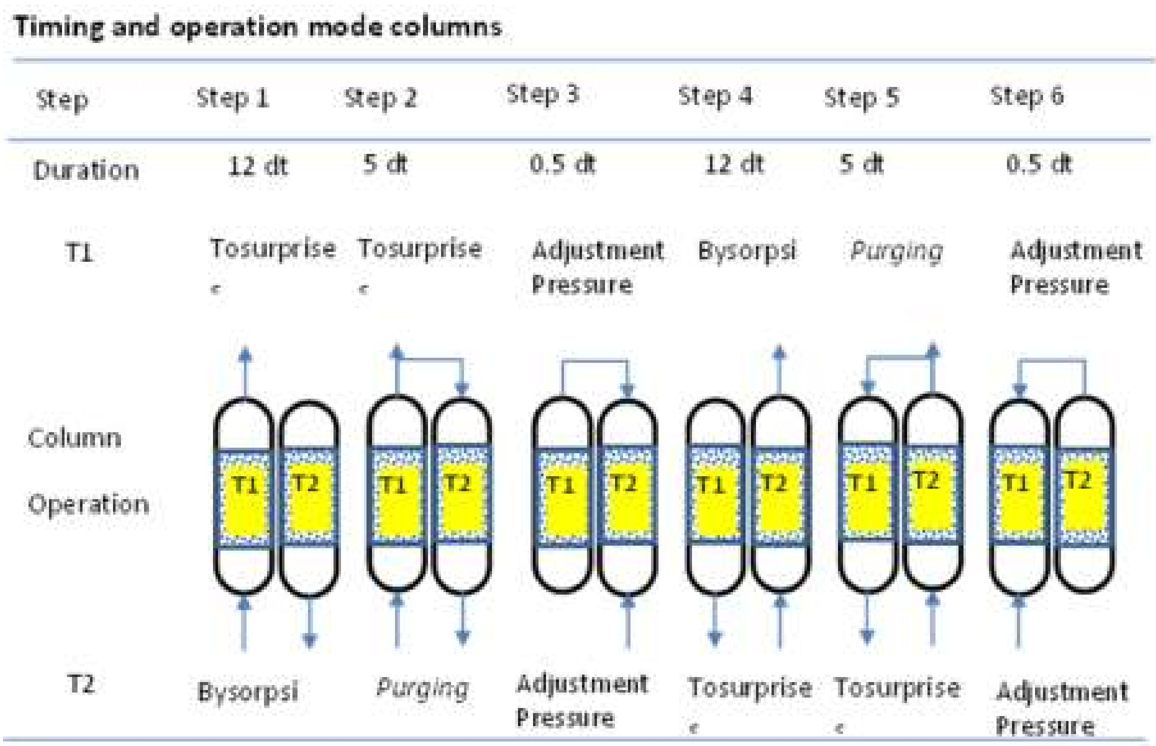


Figure 3. Timing and stages of column operations

Analysis of produk O2

One of the tools available in the market to measure O2 levels. In the gas are the following tools:
Tool name: Oxygen Concentration Tester CY-12C Content Meter
(Detector CY12C O Content 2. Portable)
Range: Oxygen gas concentration with a range of 0-100%
Accuracy: 0.10%
Measuring temperature: ambient temperature: -20~50 C
Use: Used to measure oxygen cylinder levels, medical or can also use for other research, industrial, commercial purposes.
Specification: Brand OEM,
Code SKU-60054-00424.
Product Code MTA-10439675.
Kode EAN -
https://www.blibli.com/p/oxygen-concentration-tester-cy-12c-content-meter-detector-cy12c-oksigen-oxigen-kadar-o2-portabel-tabung-gas/pc--MTA-10439675.

Variations of the experiment will be performed with several variables as shown in Table 1.

Table 1. Experiment Variables

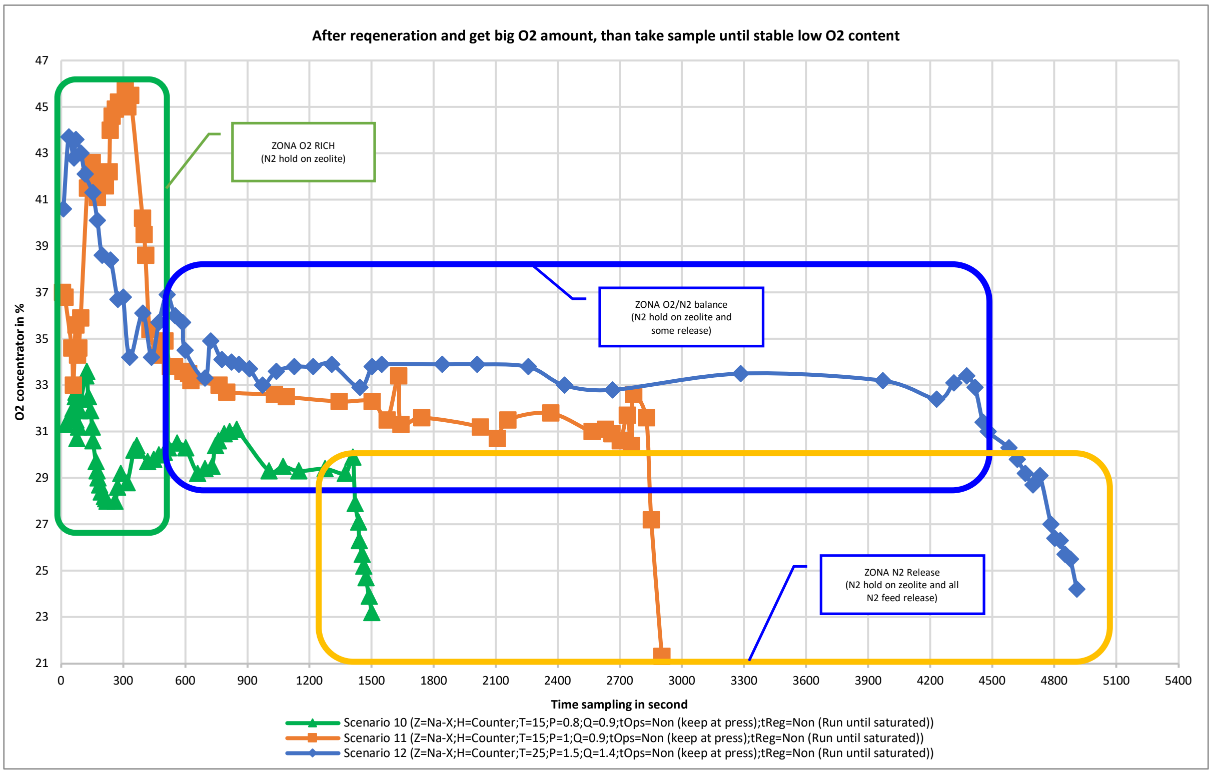
No	Experiment variables	Unit	Parameter			
1	The flow rate of air in the column	l/min	40	50	60	
2	Column inlet air temperature	oC	Ambien	10	15	20
3	Column inlet air pressure	kg/cm2.G	1	2	3	4
4	Direction of economic inflows		CoCurrent	Counter current		
5	Operating Time of column	Second	10	12	15	30
6	Column Regeneration Time	Second	5	8	10	12

The results of experiments with various variations.

For the initial stage, the O2 concentration gauge (O2 analyzer) is calibrated by setting the O2 hail display equivalent to 21.0%.

O2 Then the O2 analyzer tool is placed in the O2 output of the product so that an O2 concentration is obtained. The value taken is the value with the highest concentration O2 in the measurement range.

Graph 1: O2 condition concentration until saturated.



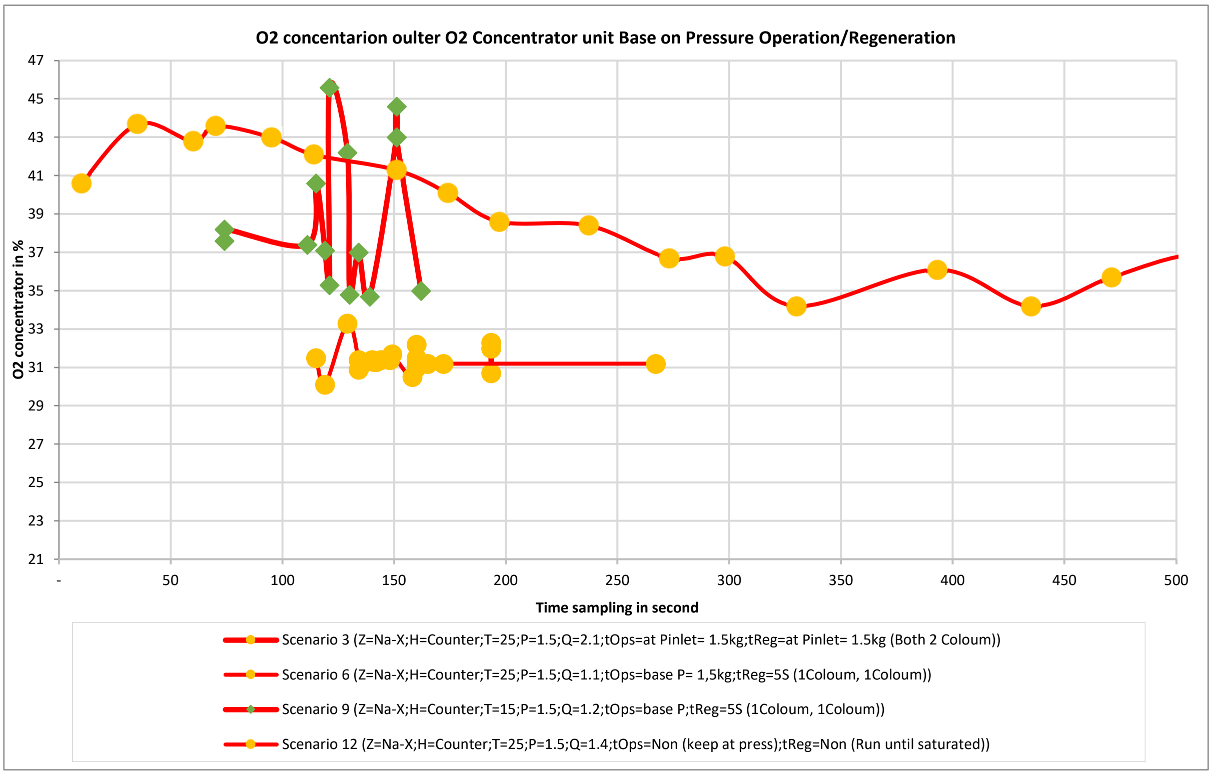
From Graph 1, it can be concluded that the oxygen concentrator of the scattered unit can produce high concentrations of oxygen and in operating time the concentration will n decrease due to the mixing of Nitrogen released from the pores of the zeolite.

Divided into 3 zones, namely:

1. Oxygen Rich Zone is when Nitrogen gas is bound to the zeolite pore so that what will pass through the zeolite is oxygen gas and a little nitrogen gas
2. Zonek ebalance Oxygen gas and nitrogen gas where part of the nitrogen gas is not bound in the pore of the zeolite pore and is carried away to the oxygen gas.
3. The nitogen release gas zone is that nitrogen gas can be bound again in the zeolite pore so that nitrogen gas will be carried entirely into the oxygen gas path.

Effect of Pressure operation

Graph 2: O2 condition concentration at operating conditions of pressure column 1.5 kg/cm2.G.



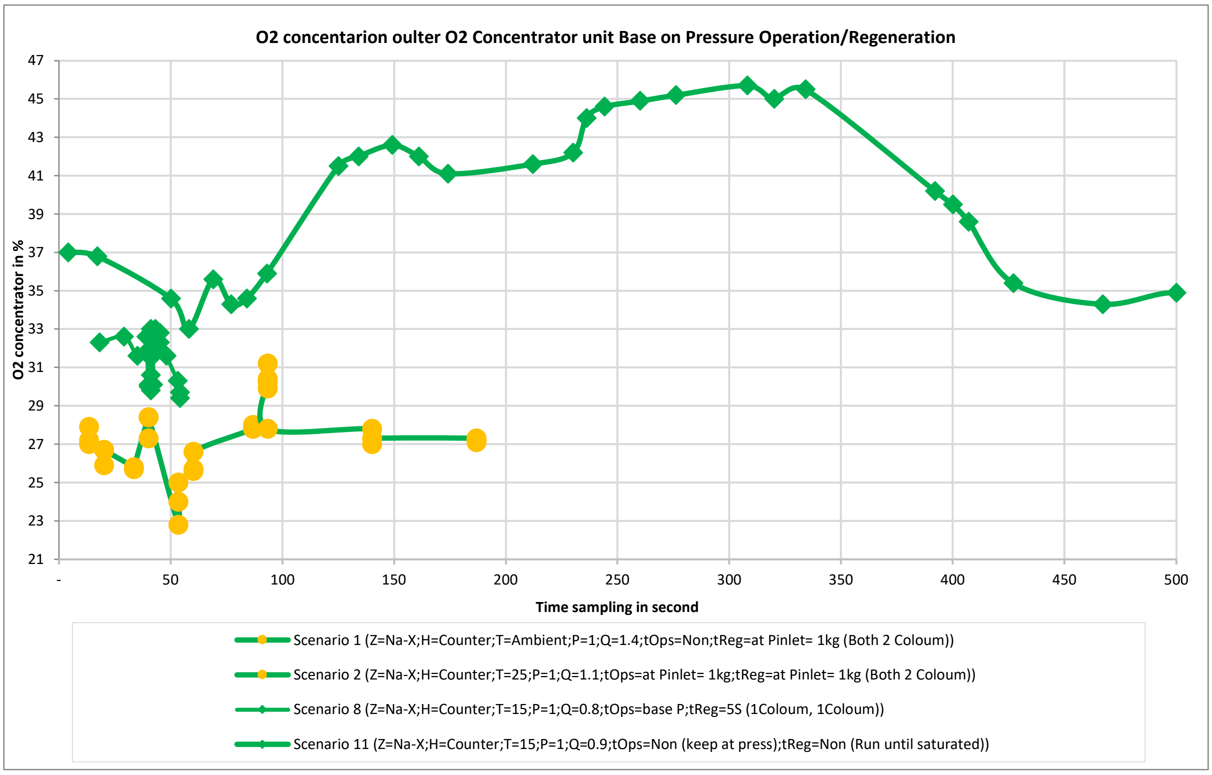
In graph 2, it can be seen at operating conditions of a column with an entry pressure of about 1.5 kg/cm2.G will produce oxygen concentrations ranging from 30 – 45% purity. This is because at this pressure more nitrogen gas is adsorbed into the pores of the zeolite, so that the air that is missed from the resin will be more oxygen gas as evidenced by the high concentration of O2. This is because the pores of zeolite hold more bound nitrogen gas, so that the output of gas in the form of oxygen gas concentration will increase.

The same is true at lower pressures as indicated by graph 3 and graph 4. The smaller the operating pressure, the lower the purity of the oxygen produced and accommodated into the storage tube.

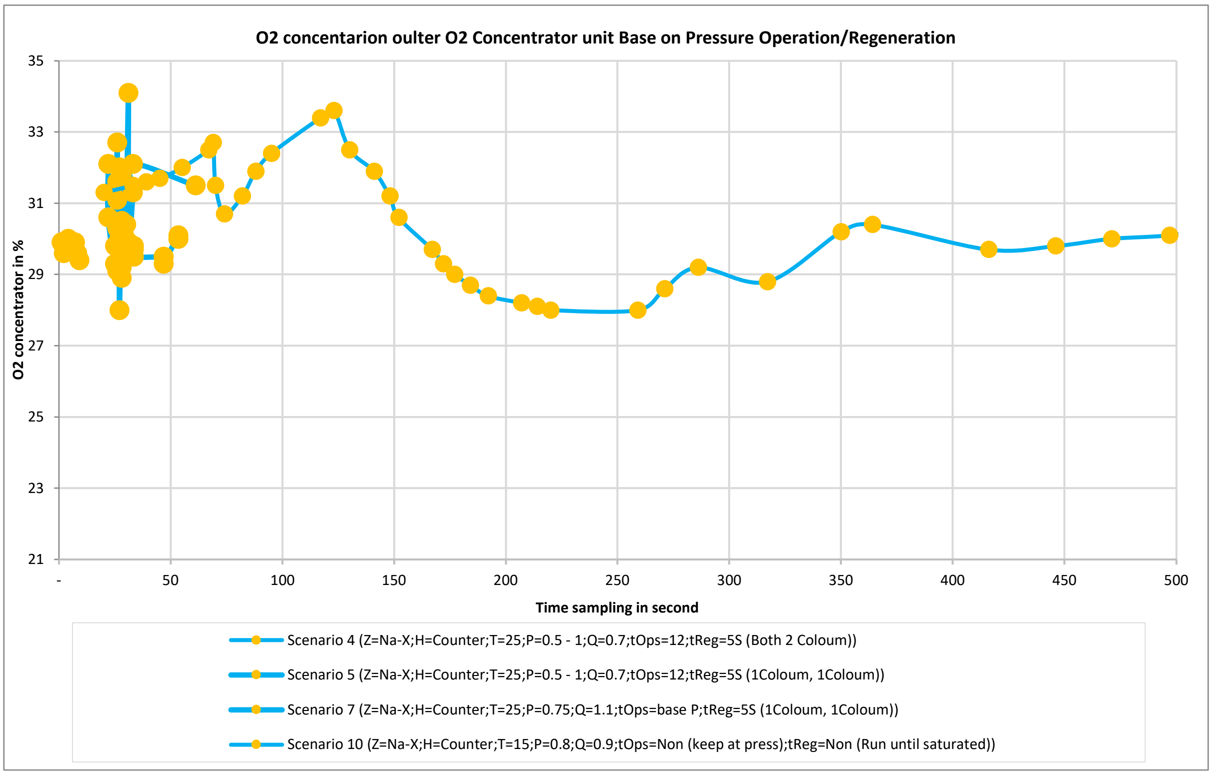
From simulations carried out with a theoretical approach and mathematical calculations, results were also obtained in accordance with the experiment directly in the designed concentrator [11].

Graph 5 shows the suitability of the results, although the precision operation is carried out below from the simulation. At this time the researcher does not run column operations above 1.5 kg because of the risk of leakage or the column will break. If the exploitation of graph 5 is the result, the results are appropriate.

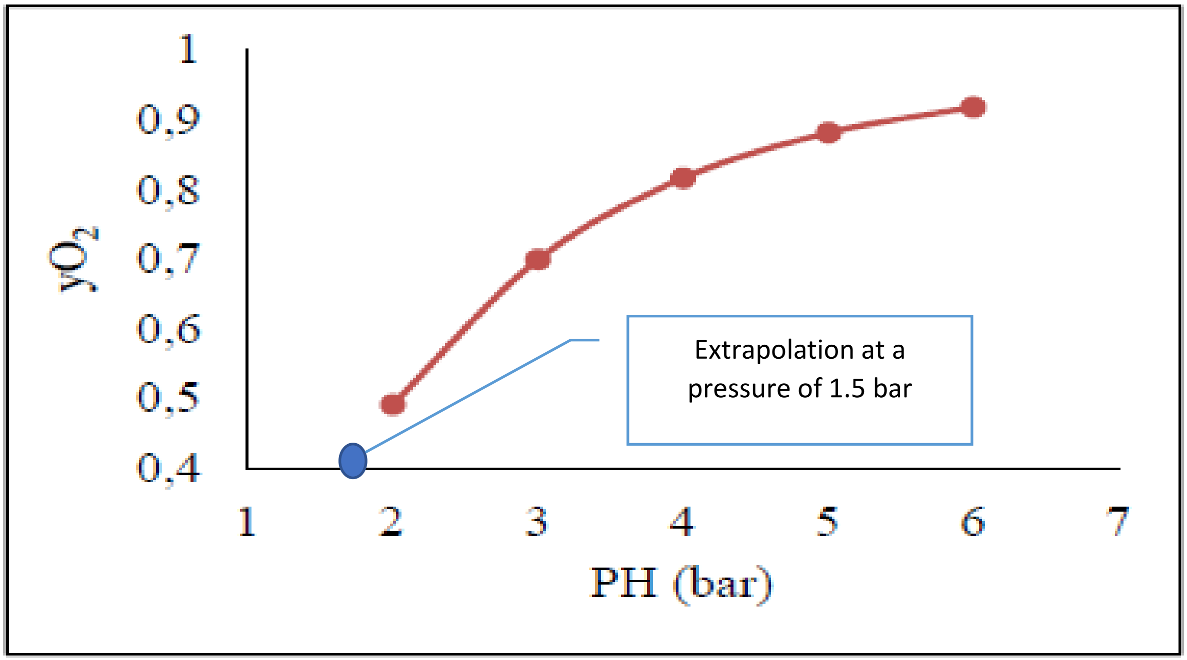
Graph 3: O2 condition concentration at operating conditions of pressure column 1 kg/cm2.G.



Graph 4: O2 condition concentration at operating conditions column pressure 0.75 kg/cm2.G.

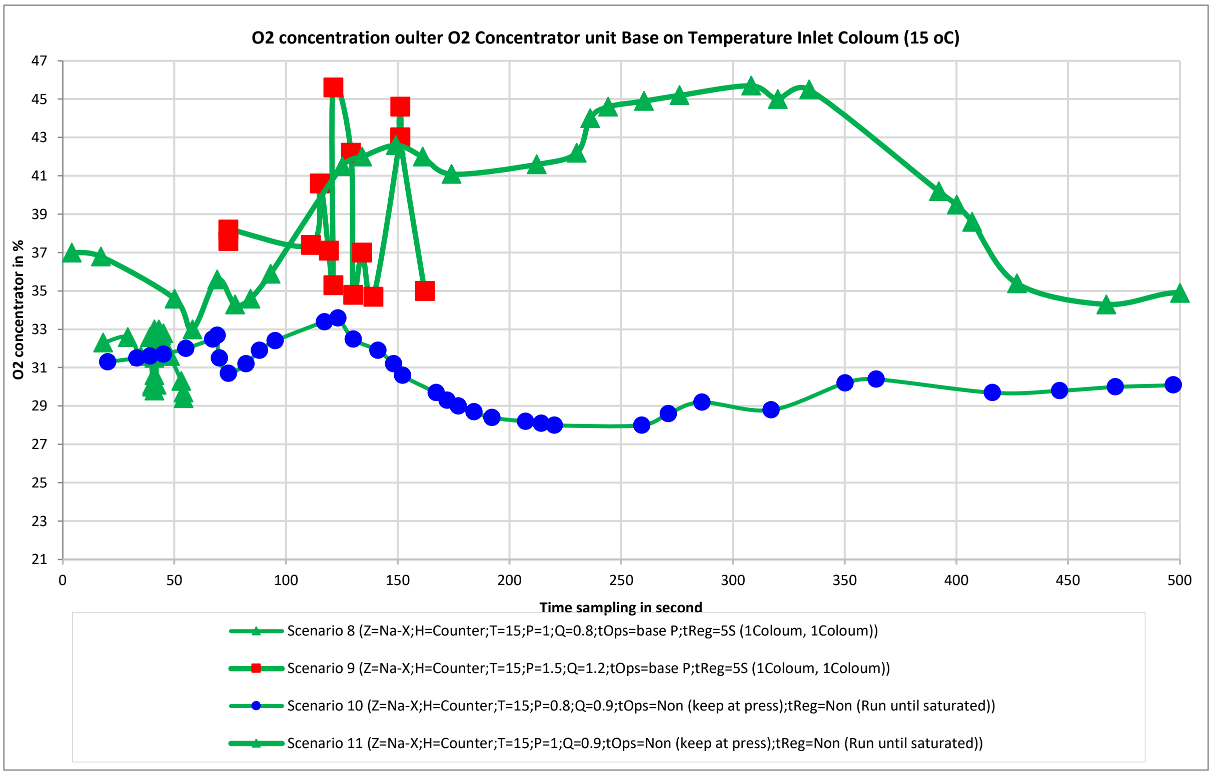


Graph 5: O2 condition concentrations from Simulations at various Pressures [11].



Effect temperature

Graph 6: O2 condition concentration at operating conditions of 15 oC temperature column.



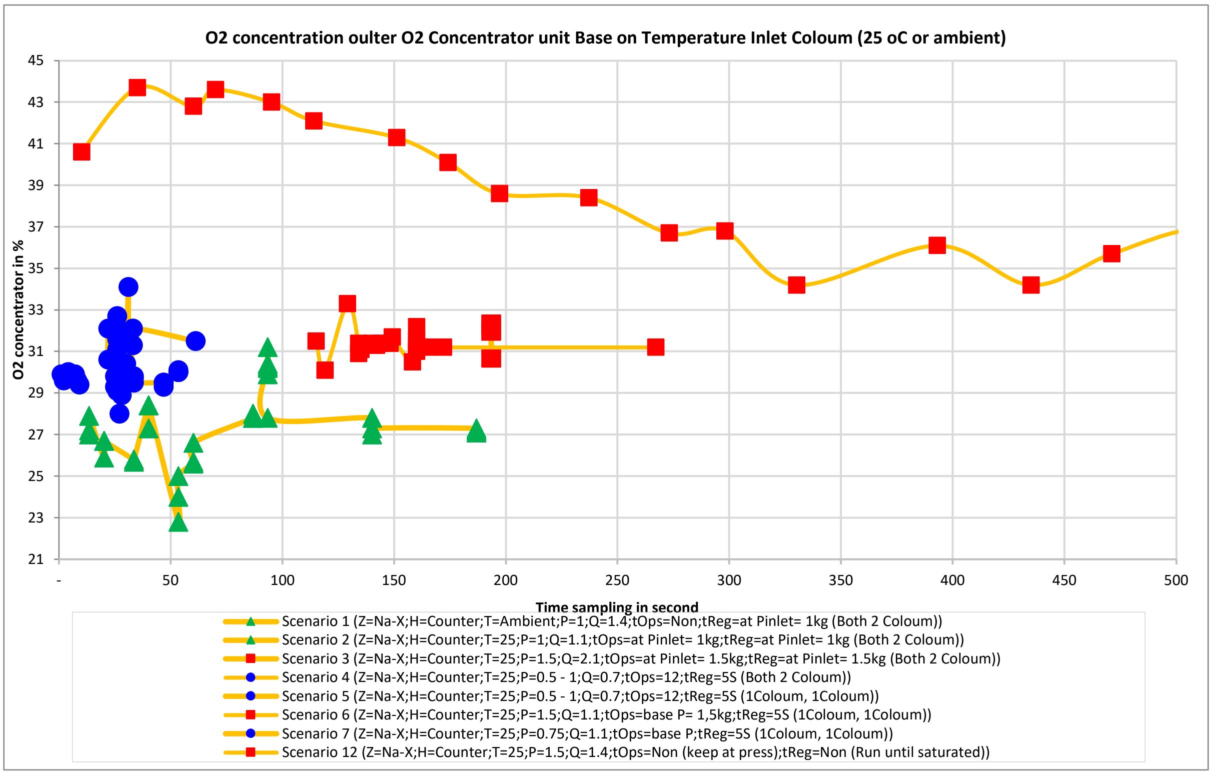
Graphs 6 and 7 show the influence of the temperature of the air entering the column containing zeolite.

At lower temperatures will get a higher concentration of oxygen. This can be indicated by air temperature data using cooling using ice or without using ice.

In designing this oxygen concentrator, it has been designed so that the reaction temperature that occurs during adsorption can be used to raise or lower the zeolite temperature. So that the efficiency of the adsorption process in zeolite media will be more optimal.

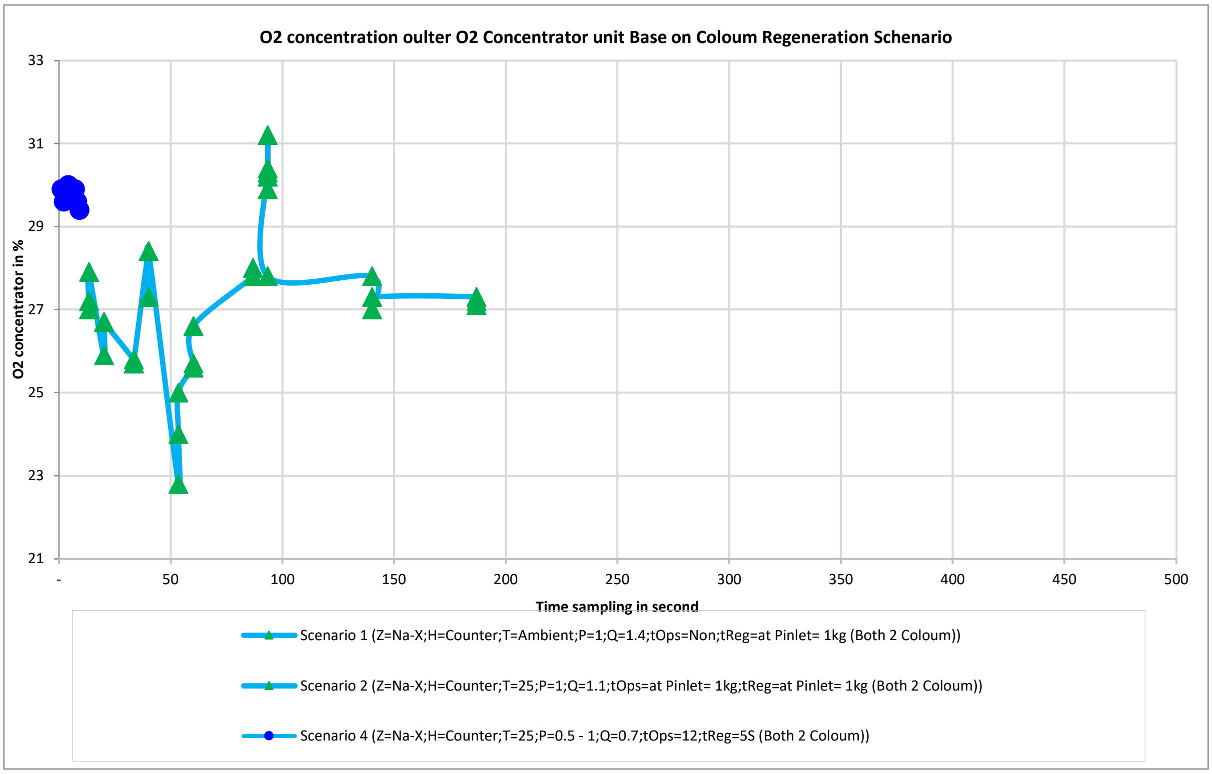
In addition, the adsorption column design also uses HE (heat exchanger) from the outside of the column which also helps the cooling process and heating the incoming air so that efficiency also increases.

Graph 7: O2 condition concentration at operating conditions of 25 oC/ambient temperature column.

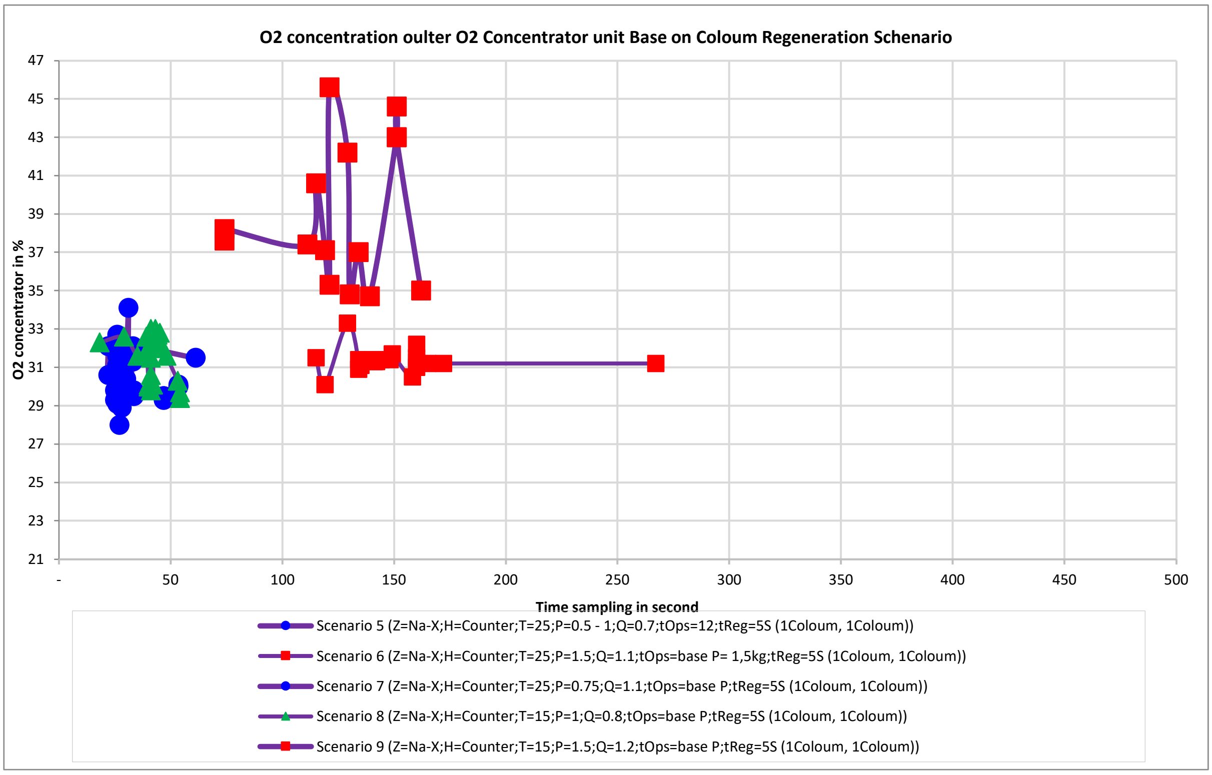


Regeneration scenario

Graph 8: O2 condition concentrates on the operation condition of the concurrent rewrite column of two columns.



Graph 9: The O2 condition concentrates on the operating conditions of one column regenerating one column followed by another column.



Another experiment was carried out by varying the way the column was regenerated.

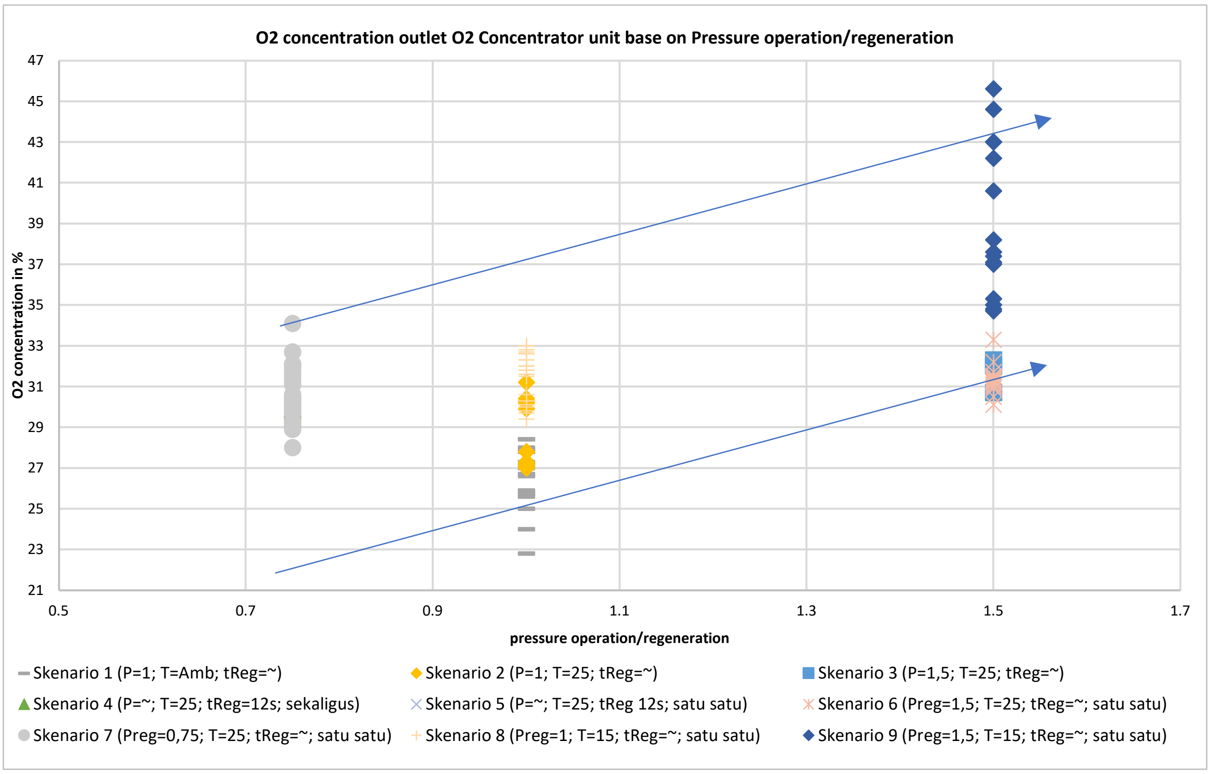
Regeneration column operations are performed one by one from the two columns by alternating or simultaneously between the two columns.

For this variation can be seen on graphs 8 and 9.

From the graph, the regeneration method with one column then continued with the other column to produce a higher concentration of oxygen.

Range pressure effect

Graph 10: O2 condition concentration at various pressure range conditions



From Graph 10 above, the greater the column operation pressure, the oxygen content that comes out of the oxygen concentrator will increase, this is because the efficiency of zeolite in nitrogen gas binding is greater.

At the time of regeneration, the amount of nitrogen gas wasted by pressure swing will also increase so that the concentration of oxygen gas after regeneration will increase sharply.

Summary

Our design can produce O2 concentration with concentration until 40% as oxygen concentration. This equipment must be testing another variable for completely image of oxygen concentration operation parameter and get good target result until 93% oxygen concentration.

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