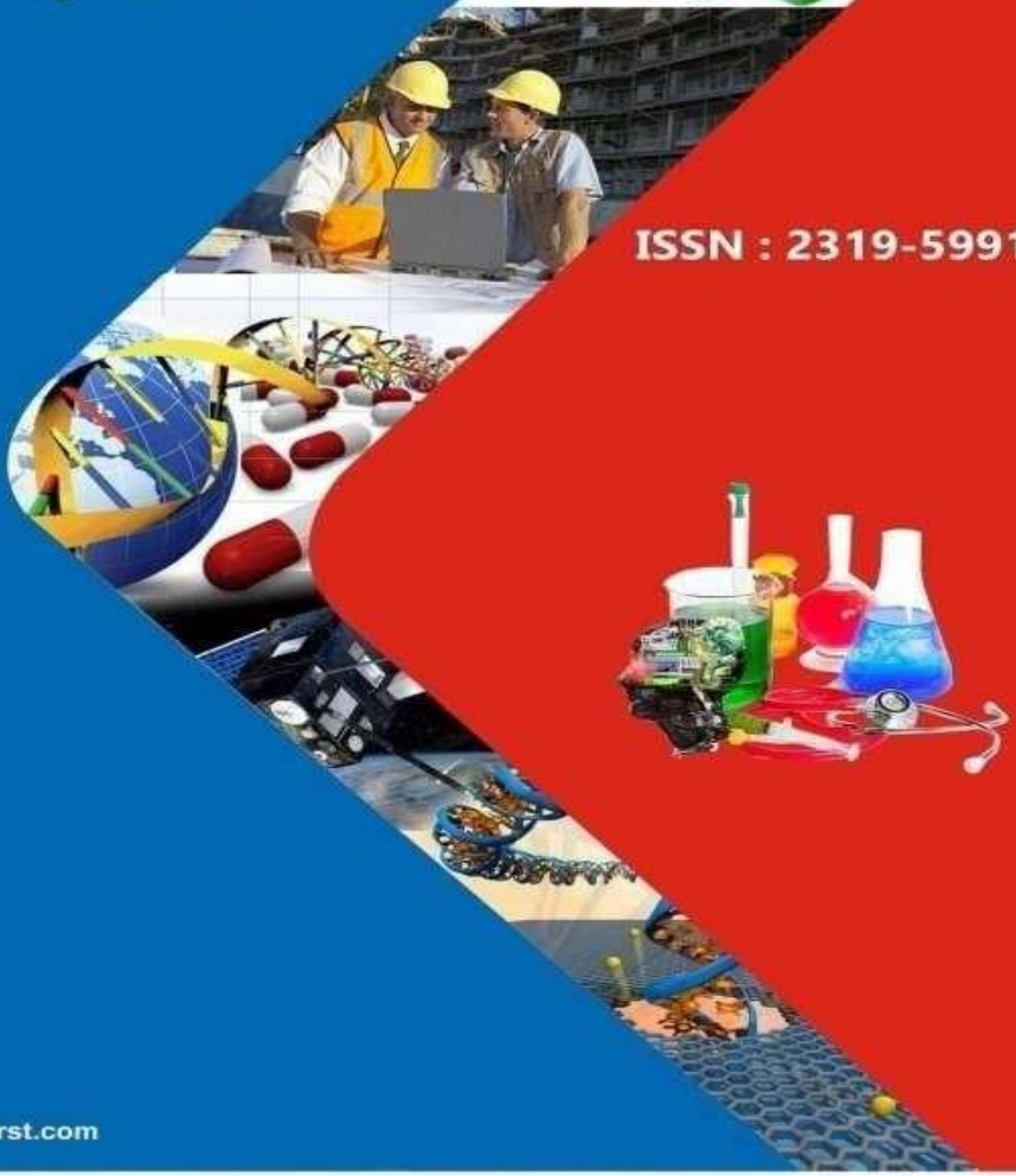
International Journal of Engineering Research and Science & Technology

IJERST

ISSN : 2319-5991



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International Journal of Engineering Research and Science & Technology
ISSN 2319-5991 www.ijerst.com
https://doi.org/10.62643/ijerst.2022.v15.i4.pp103-123
Vol. 18 , Issue 4, 2022

DESIGN AND ANALYSIS OF LOW COST OXYGEN CONCENTRATOR

Kalali Naveen Goud[1], A Padma Rao[1]

[1]*Department of Mechanical Engineering, B V Raju Institute of Technology Narsapur Telangana India*

Article Info

Received: 19-08-2022 *Revised: 13 -09-2022* *Accepted: 12-10-2022*

ABSTRACT

The main concept of this paper is to designed human powered oxygen concentrators based on pressure swing adsorption and their vast medical applications. This thesis demonstrates the design, techniques, applications, and importance of oxygen concentrators in health care centres. This paper illustrates the types of commercially available oxygen -concentrator modules, types of oxygen separation techniques such as pressure swing adsorption, membrane air separation and cryogenic air distillation, uses of different adsorbent materials such as zeolites and carbon nanotubes, operation of the most efficient pressure swing adsorption (PSA) technique, and its components. This paper illustrates the simplest experiment which gives details about PSA process for oxygen purification. This paper also proposes the design and analysis of the most efficient Portable Oxygen Concentrator (POC) which satisfies all consumer needs. Future work of this thesis is focused on the thermodynamics of POCs, testing of some efficient market-available POC modules, and designing the most efficient and cost-effective portable oxygen concentrator module for local manufacturing and consumer markets. The modelling of the oxygen concentrator components is created by CATIA-V5, Solid works, ANSYS Software.

Key words: Oxygen Concentrator, CATIA, ANSYS, pressure swing adsorption

1. INTRODUCTION

The goal of biomedical engineering is to narrow the gap between engineering and healthcare. It blends the traditional and advanced principles of engineering and medicine to create a whole new field which addresses health care issues worldwide and suggests probable solutions. Within this field, there are many disciplines, each focusing on a specific problem related to the abnormal

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ISSN 2319-5991 www.ijerst.com
https://doi.org/10.62643/ijerst.2022.v15.i4.pp103-123
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gas. Oxygen is one of the most important key factors of life on Earth and is abundantly present in gas form in our atmosphere at a percentage of approximately 21%. However, the demand of oxygen in much purer form has increased massively with the growth of advanced industrial processes and medical uses. Industrial/ manufacturing applications of purified oxygen include the fabrication of steel, chemicals, petrochemicals, glass, ceramics, paper, and the recovery of non-ferrous metal etc. Medical applications of oxygen mainly involve oxygen therapy, emergency medical services such as resuscitation, anaphylaxis, major trauma, major bleeding, shock, active convulsions, and hypothermia, treatment of COPDs and cystic fibrosis in which patient suffers from chronically low level of oxygen. According to statistics oxygen has grown from the 4 th largest distributed chemical in the mid 1990's to the 2nd largest in 2006.

Oxygen concentrators, also known as Oxygen generators, can be used as an alternative to compressed oxygen gas cylinders, the only difference is that they provide continuous supply of oxygen-enriched gas stream without the need of refill. They produce 90–95% pure oxygen by only using atmospheric air as a raw material. Oxygen concentrators can be large and heavy for industrial and stationary uses or can be small, lightweight and portable for mobile and travelling purposes. Both stationery and portable OCs work on the same principles, the only difference is in their sizes and flowrates. SOCs can deliver 3-10 liters per minute of oxygen whereas POCs deliver 1-5 liters per minute. SOCs weigh between 40lbs-60lbs and POCs weigh between 5lbs-10lbs only.

2. LITERATURE SURVEY

Kulish and Swank (2000) [1], studied the design of an oxygen concentrator based on the RPSA principle. They used more than three beds operated sequentially so that the time for the adsorption was shorter than that for the desorption of nitrogen. The oxygen concentratorswere capable of delivering 96% pure oxygen at a rate of 2-5 SLPM.

Huang and Chou (2003) [2], theoretically compared the performance of radial and axial RPSA processes for air separation. They also studied the effect of process variables on the performance of a radial RPSA process. It was shown that the oxygen product purity was maximum at an optimum adsorbent particle size. They demonstrated that the radial RPSA process had the advantage of lower pressure drop for the same imposed pressure gradient, gasflow rate and adsorbent particle size due to the large cross sectional area compared to an axialRPSA process.

International Journal of Engineering Research and Science & Technology
ISSN 2319-5991 www.ijerst.com
https://doi.org/10.62643/ijerst.2022.v15.i4.pp103-123

Ackley and Zhong (2003) [3], patented a medical oxygen concentrator design based on a very fast cycling PSA process. They used Li substituted zeolite (Oxysiv-7) as adsorbent forair separation. The oxygen concentrator had a bed size factor of approximately 0.15 kg adsorbent/kg O_2/day and was capable of delivering 15 SLPMof oxygen from air. Khiavi *et al.,* (2007) studied the separation of hydrogen from syngas using a RPSA process. They usedmore than three adsorption columns, each comprised of at least one thin adsorbent sheet material with one or more adsorbents. The bed size factor was less than 4 s and a hydrogen recovery was >70% at a veryhigh purity from a syngas feed mixture of 50% hydrogen.

Mendes *et al.,* (2004) [4], developed a simulator and optimization procedure to design smallscale oxygen PSA/VPSA unit for air separation. Later in 2006, they implemented equalization steps to improve the oxygen recovery and lower power consumption. Among the adsorbents studied, the oxygen productivity was highest using Oxysiv 7 adsorbents. The top-top equalization step showed better performance than the other equalization configurations. They validated the simulation and optimization results with experimental oxygen concentrator data. Further, Mendes *et al.,* (2007) developed a PSA process for producing very high purity oxygen (>95%) using AgLiLSX zeolite adsorbent within the same column.

LaBuda *et al.,* (2008) [5], studied a layered RPSA process for air separation. Afeed air containing moisture was treated in a column packed with two layers of adsorbents. The first layer, near to feed end, was selective for water and the second layer was selective for nitrogenadsorption. The oxygen product purity was >90% with cycle time >5 s

McCombs *et al.,* (2006) [6], patented a compact, light-weight two-bed oxygen concentrator operated on PSA and VPSA cycles for ambulatory applications of COPD patients. The oxygen product purity was greater than 90% at product flow rate of 3 SLPM. The overall weight of the device was only about 5 lb

Jagger *et al.,* (2011) [7], designed an ambulatory oxygen concentrator for personal medical applications using VSA process and LiLSX zeolite adsorbent. The oxygen concentrator delivered oxygen product purity in the range of 85-95% at a product flow rate of 5 SLPMin the pulsed mode and recovery was 60%. The oxygen concentrator weighted around 3 lb (1.36 kg)

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3. PROBLEM STATEMENT

Oxygen Concentrators, especially POCs are becoming more and more popular worldwide as they are economic and convenient. They are much more reliable than the gas cylinders as they do not run out of the oxygen supply and do not require any refills. Oxygen concentrator is a lucrative alternative for patients who need regular supply of oxygen as a medical intervention. Thus, a need for POCs exists because they are lightweight, maneuvers at low pressure, and require minimal power for their operation. Therefore, manufacturing markets are struggling to design new lightweight, portable, less power consuming with power backup, low pressure operating oxygen concentrators which can provide almost about 99% purified oxygen gas at much higher flowrates through a venturi system. A further object of this study is to provide

1. An experimental setup which will illustrate the basic process of PSA technology.

2. An improved and much more efficient design specifications of an oxygen concentrator which satisfies the needs of consumers. The advantage of this formulation will be its cost reduction and quality when compared with the other market imported products. This fabrication will help the local industry of Pakistan to set up the plant for this product in any area of the country, thereby reducing the burden of import expenses.

AIMS AND OBJECTIVES

Following are the objectives/goals of this study

1. To collect vast knowledge of oxygen concentrators and types of oxygen concentrators.

2. To study a variety of medical and industrial applications of oxygen concentrators.

3. To compare and contrast different oxygen separation techniques to sort out the best out of them.

4. To study the basic principle and related components behind Pressure Swing Adsorption Technique.

5. To study different types of absorbent materials available in markets and which one is the best

to extract highly purified oxygen.

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ISSN 2319-5991 www.ijerst.com
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6. To compare and contrast different types of zeolites to ensure which type is best for efficient performance of PSA process.

7. To set a laboratory experiment which will illustrate the basic process of PSA technology.

8. To introduce an improved and much more efficient design specifications of an oxygen concentrator which satisfies the needs of consumers. This part is briefly discussed in this study and will be the focus of our work in future.

4. DESIGN, ANALYSIS AND APPLICATIONS OF OXYGEN CONCENTRATORS

4.1 Design

It is developed a PSA testbed system to check the performance of the zeolite we bought. This system requires an AC power (220V) to derive the compressor which sucks in the air throughinlet and compresses the atmospheric air, this compressed air passes into a chamber through a valve which have a built-in flow meter and pressure gauge to give pressure and flow readings of air. This chamber contains zeolite which will adsorb the nitrogen from the compressed air and vents the filtered oxygen into the atmosphere through an opening. An oxygen analyzer is connectedto this opening to measure the concentration of oxygen gas.
Following are the components we used in our experimental design:

1. Air Compressor.
2. Flow Meter Regulator.
3. A-3 Granular Zeolite.
4. Oxygen Analyzer.
5. Stopwatch.

Both portable and stationary oxygen concentrators have numerous uses for those patients needing oxygen therapy. Oxygen concentrators are much less dangerous than traditional oxygen cylinders, which can, if ruptured or leaking, cause or increase the combustion rate of a fire. Oxygen concentrators, on the other hand, pose no such danger. The other main benefit of oxygen concentrators is the ease and increased ability to be mobile with oxygen. Portable oxygen concentrators provide the necessary oxygen anywhere the user goes, even on airplanes.

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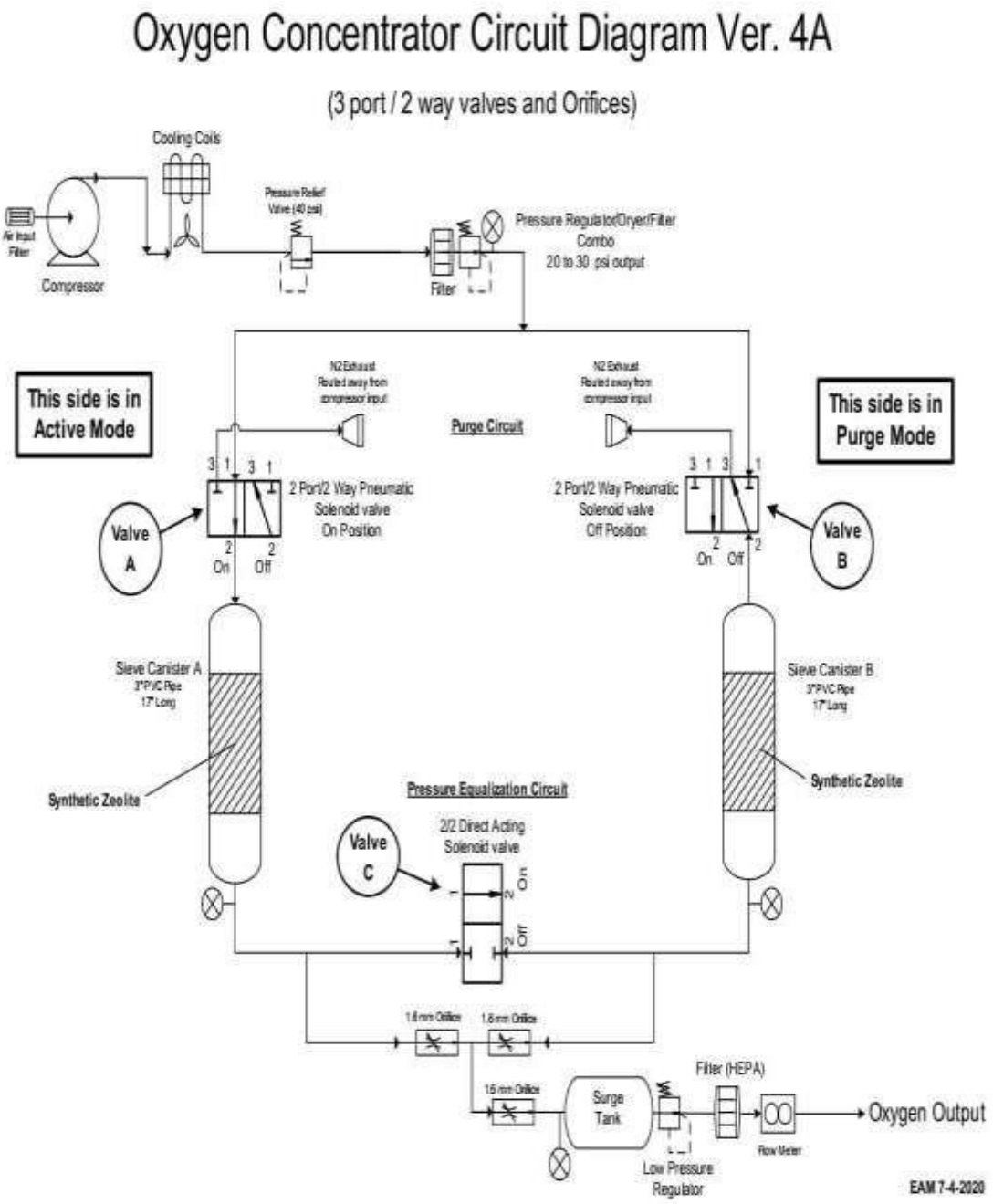

Fig 4.1.1 Oxygen concentrated circuit diagram

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3D modelling components of molecular seive bed is shown in below Figure.

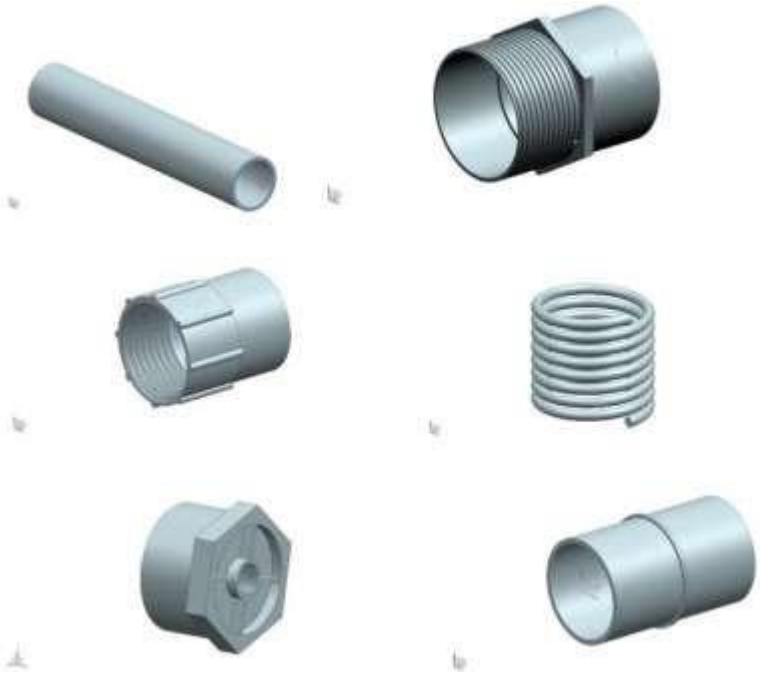

Fig 4.1.2 3D modelling components of molecular seive bed

The assembly of molecular seive bed is shown in Figure 4.1.3.

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Fig 4.1.3 Assembly of molecular seive bed

4.2 Design of Oxygen Concentrator

The below figures show the different views of the oxygen concentrated models

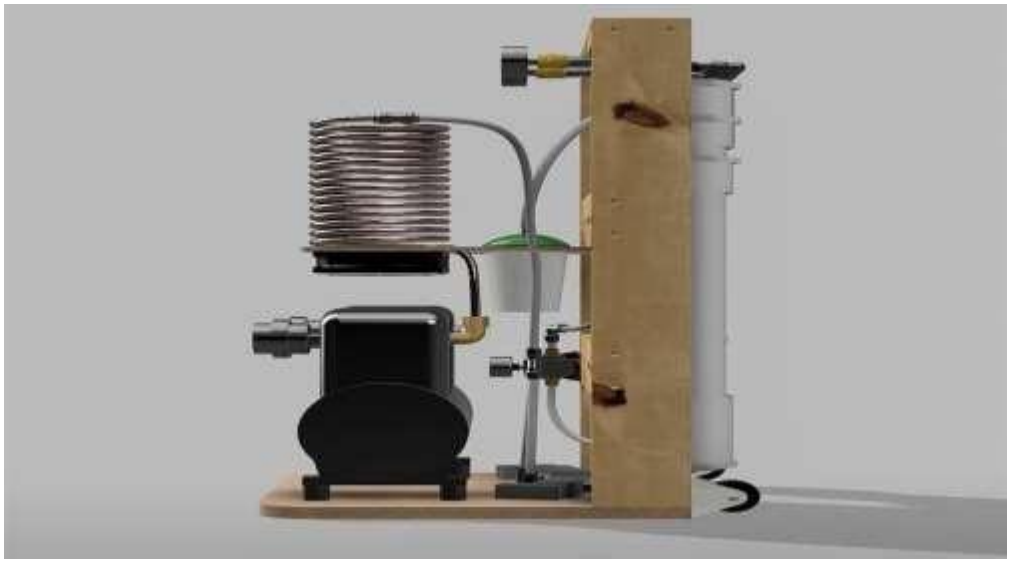

Fig 4.2.1 Side view of oxygen concentrated assembly

Fig 4.2.2 Isometric view of oxygen concentrated assembly

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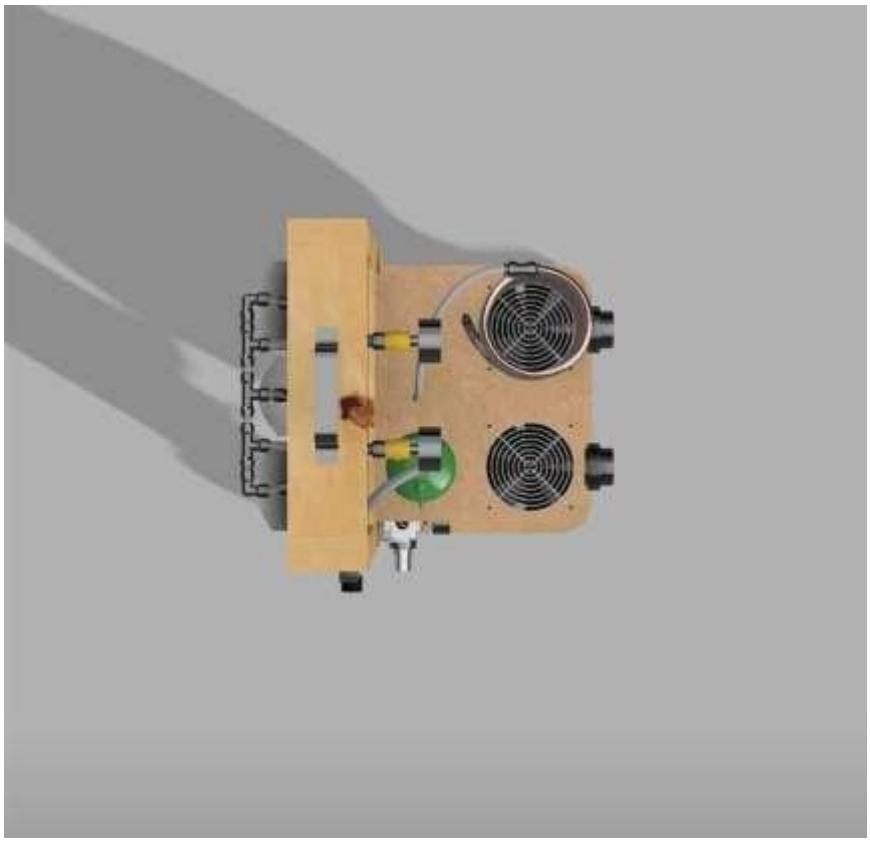

5. RESULTS AND MODEL VALIDATION

5.1 Velocity profile

Figure 5.1.1 compares the experimental flow rate with the simulation results. The experimental and model output flowrates are 1.226 L/min and 1.24 L/min, respectively. The difference of the experimental data and simulation results is 1.1% which means the modified Free and Porous Media Flow Interface is able to represent the outlet flow condition. Before 21s, the adsorption column is in the pressurization stage without any gas flowing out through the outlet.The flow rate of the outlet is maintained at 1.226 L/min at the production stage which means the same amount of mass flow entering and exiting the adsorption column to maintain the adsorption pressure after t = 21s.

https://doi.org/10.26643/ijerst.2022.v15.i4.pp103-123
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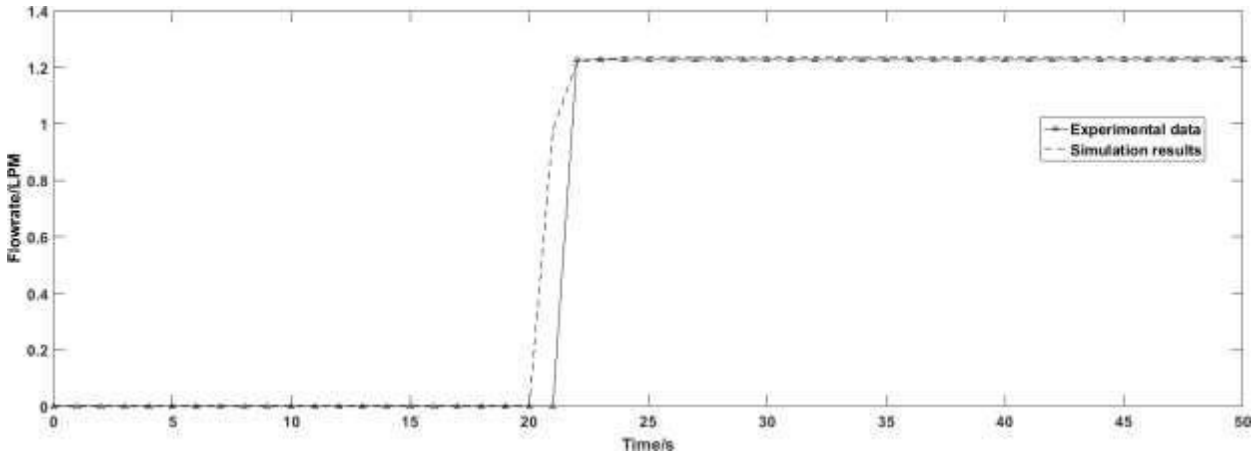

Fig 5.1.1 Comparison of the experimental and simulation results of the column outlet flow rate

Figure 5.1.2 shows the internal gas velocity profile at different times during the adsorption step. The 'arrow' surface represents the direction of velocity vector. When the bed is being pressurized, the velocity decreases from the inlet to the outlet due to the closed outlet boundary condition (Figure 5.1.2 (a) and (b)). The velocity distribution at the production stage (Figure 5.1.2 (c)) is uniform which means the column is saturated and concentrated gas is transported out from the outlet of the column at a constant pressure.

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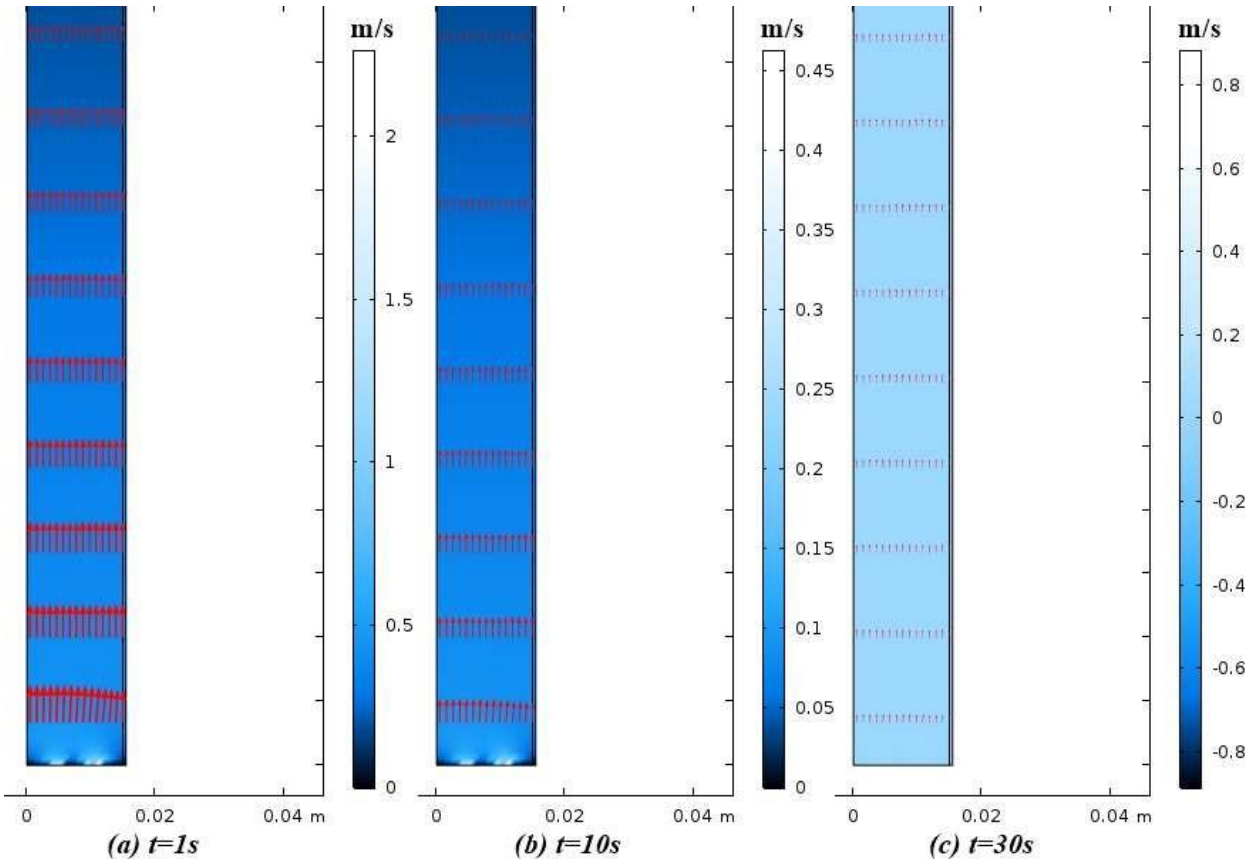

5.2 Pressure profile

Figure 5.2.1 shows the outlet pressure profile at different times during the adsorption step in the Free and Porous Media Flow Interface. The difference of the simulation results and the experimental data is negligible which is significant to the adsorption function in the Transport of Diluted Species in Porous Media Interface. According to the outlet pressure and flowrate profile in Fig. 5.1.1 and Fig.5.2.1 the model is able to represent the pressurization step flow condition of a portable oxygen concentrator with an air compressor instead of a constant flowrate simulation.

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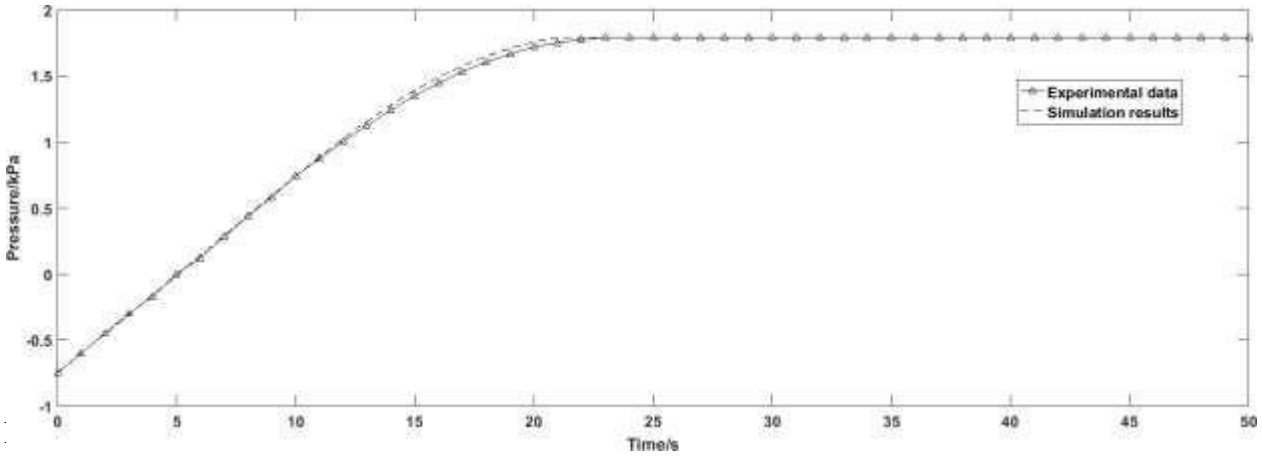

5.3 Oxygen concentration profile

Figure 5.3.1 shows the experimental and the simulation results of the outlet oxygen concentration at adsorption pressure =1.79 barg and desorption pressure = -0.82 barg. The enriched oxygen product starts to flow out of the column at t = 21s and the outlet oxygen concentration in the product flow reaches the peak at t = 35s. The experimental data shows the same enriched tendency of oxygen in the outflow as the simulation output. Compared to the simulation results, a slight difference of the oxygen breakthrough curve is observed from the experimental oxygen sensor data. This could be explained by the inaccuracy of the multicomponent Sips adsorption equations due to the complexity of the heterogeneous zeolite porous surface.

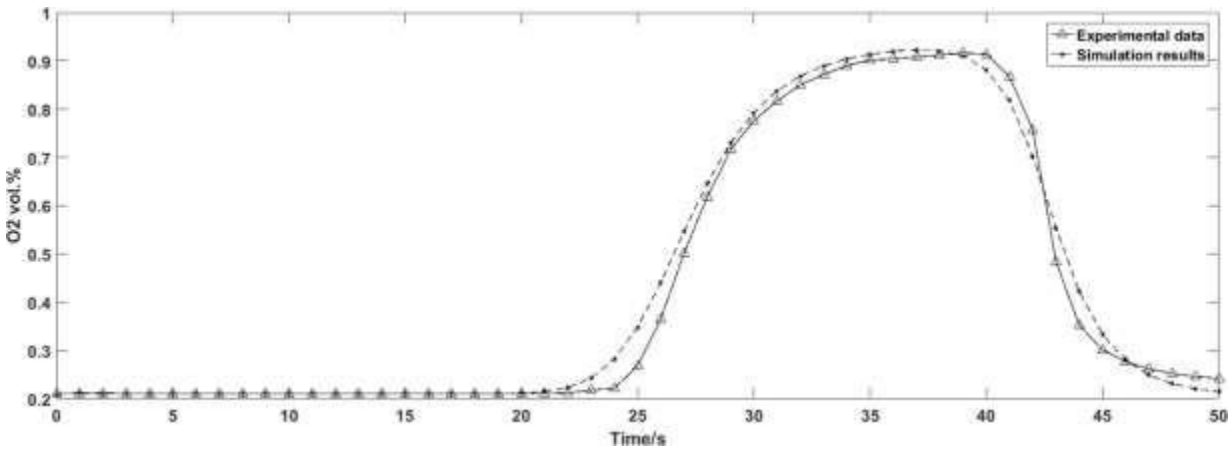

Fig 5.3.1 Experimental outflow oxygen concentration with simulation results

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5.4 Adsorbed component (N_2/O_2) profile

Figure 5.4.1 shows the average surface excess of the zeolite surface at the adsorption and desorption stage. The amount of N_2 and O_2 adsorbed to the zeolite particle gradually decreases when the adsorption column is connected to the suction port of the air compressor to create vacuum desorption condition inside the column. The adsorbed N_2 and O_2 are released from the zeolite at blowdown and purge stages which generates a clean bed for the next adsorption cycle

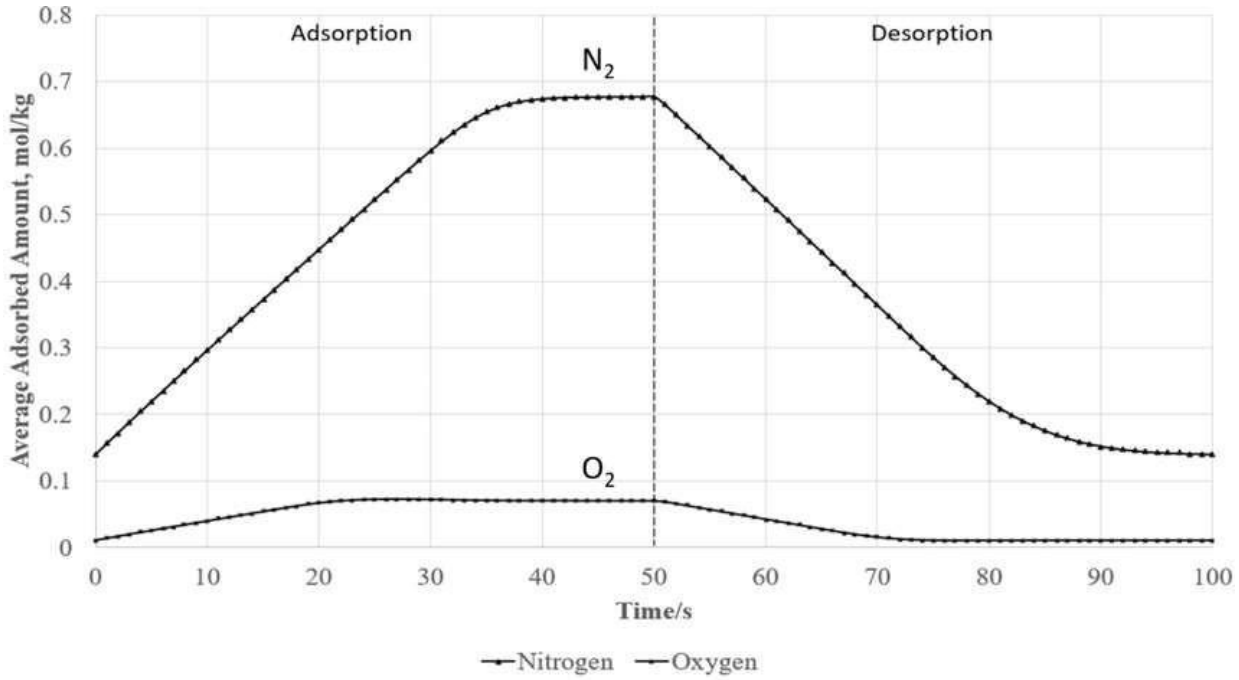

Fig 5.4.1 Simulation results of average adsorbed nitrogen and oxygen amount to thezeolite particles

Figure 5.4.2, Figure 5.4.3 and Figure 5.4.4 show the adsorbed N_2 and O_2 concentration profiles at t=1s, 10s and 30s during the adsorption step. The high-pressure flow is introduced from the inlet to pressurize the column at t=1s and adsorbed by the zeolite layers around the column inlet. The mass transfer zone is moving forward from the inlet to outlet of the column at t=10sand 30s which means the adsorption column is getting saturated with time. The mass transfer zone of the oxygen moves faster than that of the nitrogen at t=10s and 30s due to its lower surface excess onto the zeolite microporous area.

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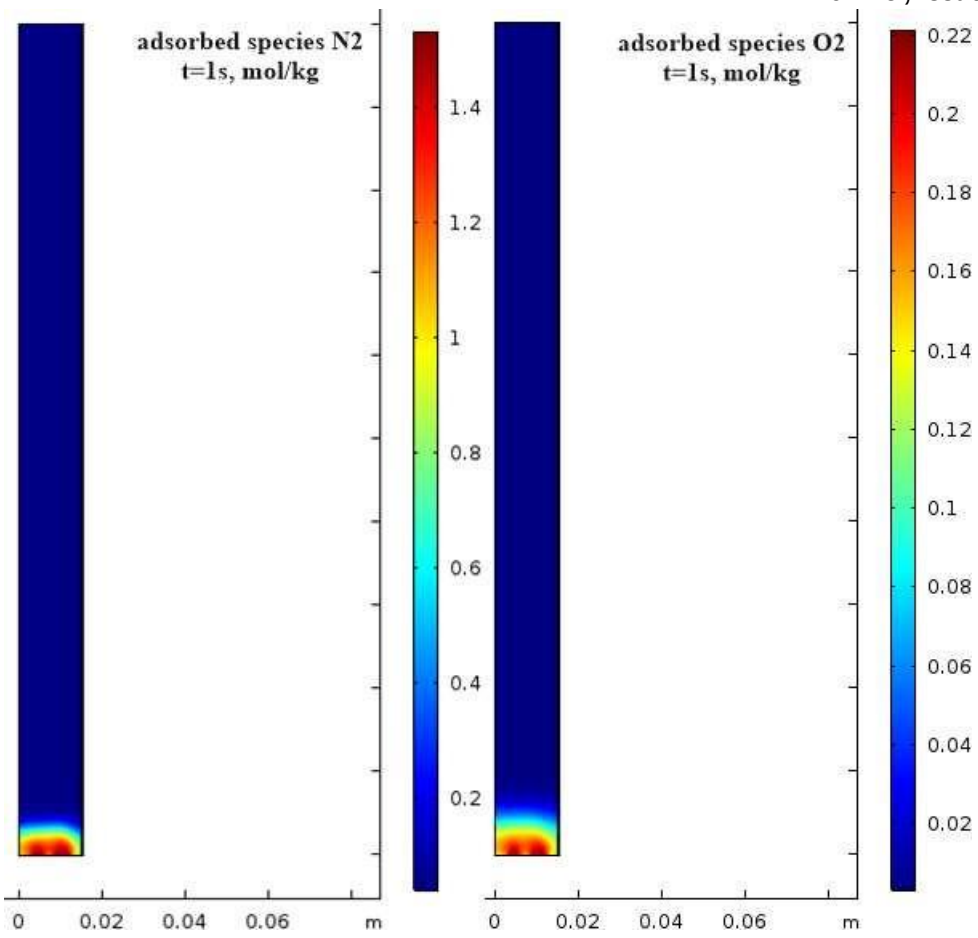

Fig 5.4.2 Adsorbed N_2 and O_2 concentration profiles at t=1s

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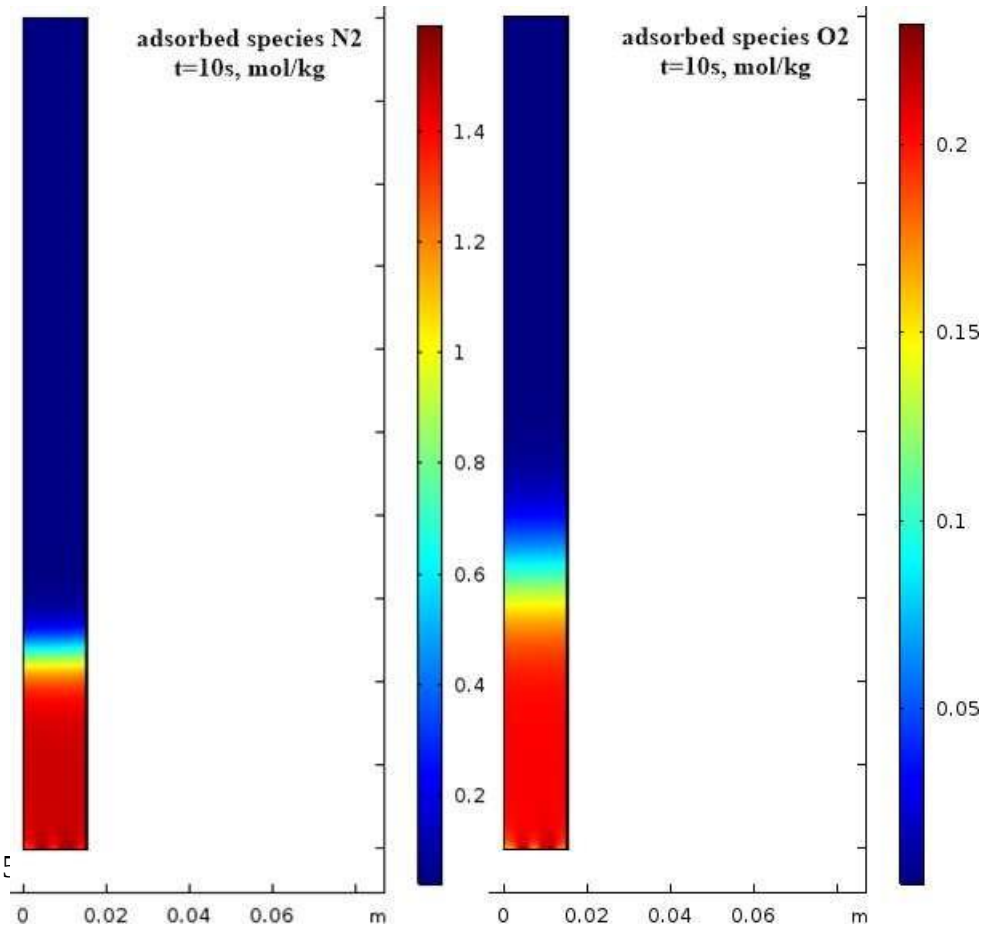

Fig 5

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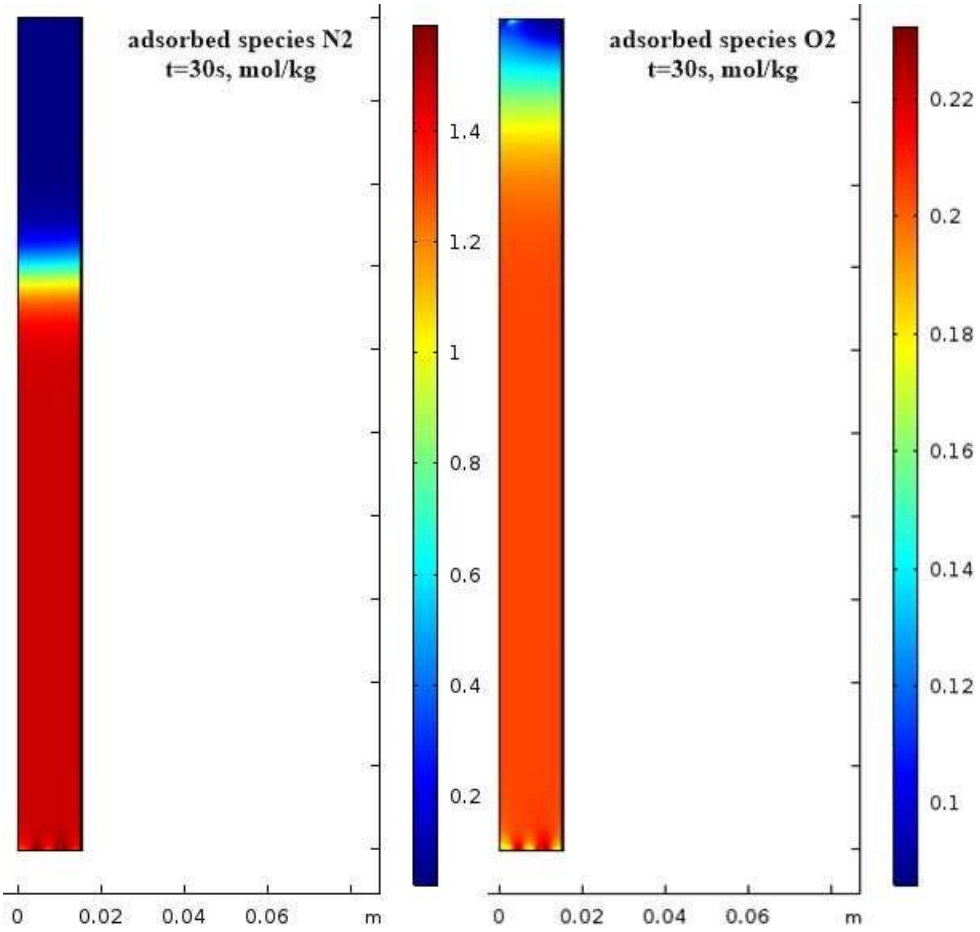

Fig 5.4.4 Adsorbed N_2 and O_2 concentration profiles at t=30s

5.5 Zeolite temperature profile

Figure 5.5.1 shows the mid column temperature simulation results of the zeolite particles at theadsorption and desorption stage with different column wall materials (glass and aluminum). The aluminum wall provides a higher boundary gas-wall thermal conductivity which benefits the cooling of the zeolite particles during the desorption stage. Considering the isosteric heat during the separation process, a material with relatively high thermal conductivity should be selected for the column manufacturing to maintain the nitrogen capacity of the zeolite during the adsorption step.

https://doi.org/10.26643/ijerst.2022.v15.i4.pp103-123
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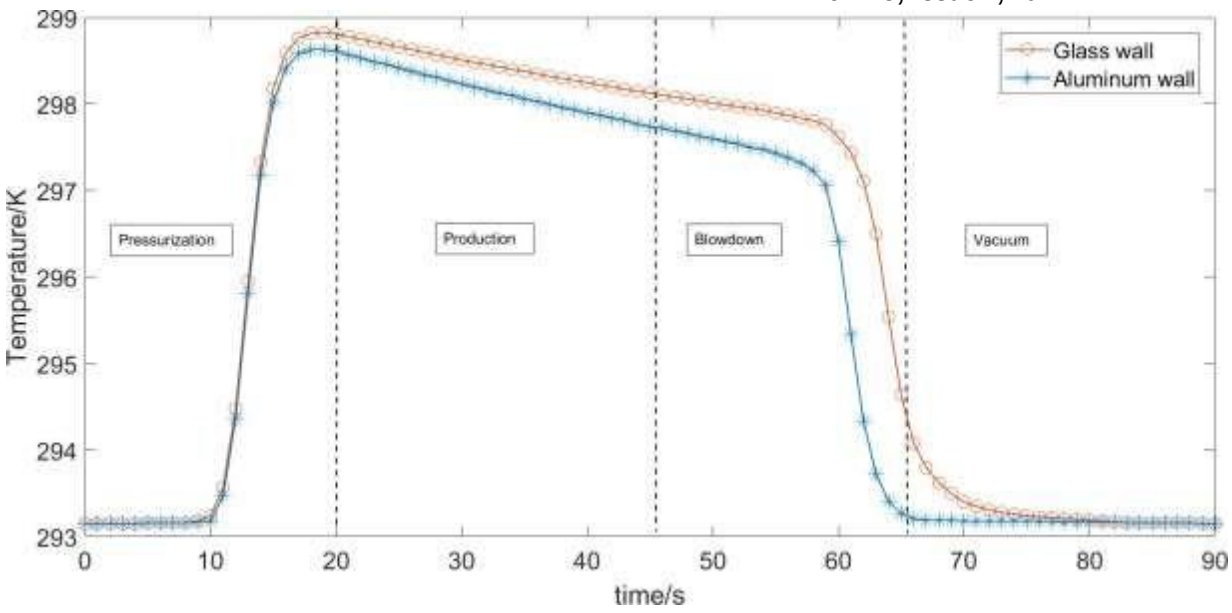

Fig 5.5.1 Mid-column temperature profile at adsorption and desorption stage with twocolumn wall materials

5.6 Miniaturization and Optimization of PSA oxygen concentration apparatus

5.6.1 Design of Inlet and outlet distribution column using COMSOLCFD module

Two types of inlet flow distribution were investigated for the column adsorption test. Figure 5.6.1 (a) illustrates the common central flow from a tubing to the column inlet without inlet distributor and Figure 5.6.1 (b) illustrates the distributed inflow with an inlet gas distributor. Figure 6.18 shows the N2 concentration profiles of two different inflow type at different times during the pressurization step. The distribution of the central flow is not uniform with a radial dispersion from column axis to the boundary while the distributed flow is closed to an ideal plug flow with negligible radial dispersion. Figure Fig 5.6.2compares the outflow concentration for distributed inflow and central flow. The results are in accord with the experimental data that pressurization time of the column with central inflow is 1.6s longer than that of the column with the distributed flow. The inlet gas distributor is significant for the inflow air and decreases the pressurization time for the adsorption cycle.

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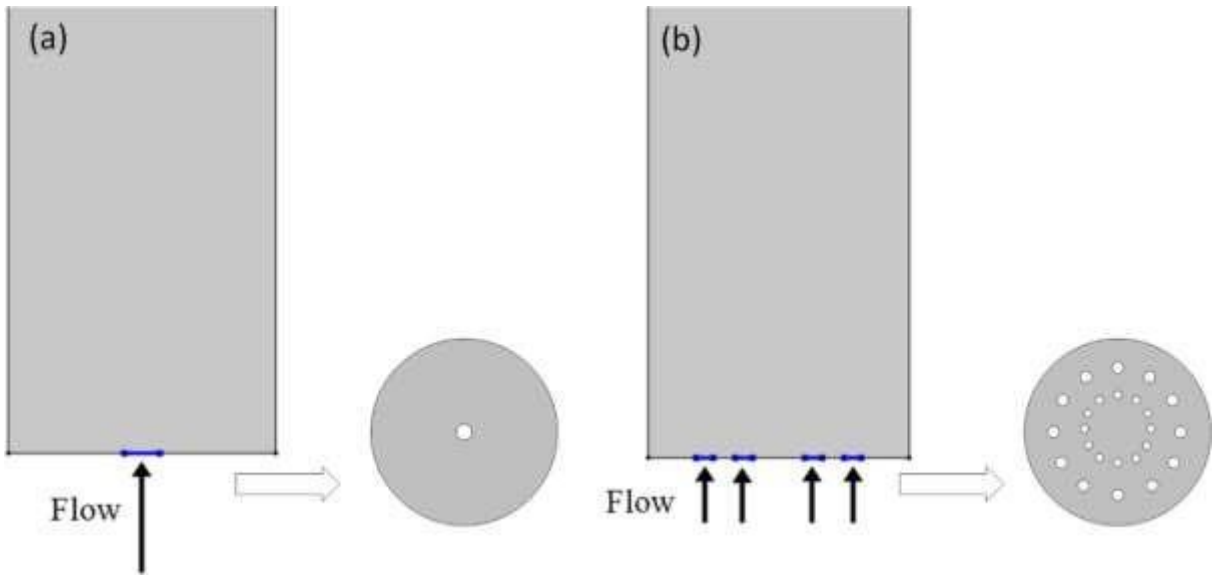

Fig 5.6.1 Schematics of inflow type at the inlet of the adsorption column (a) central flowwithout inlet distributor (b) distributed flow with inlet distributor

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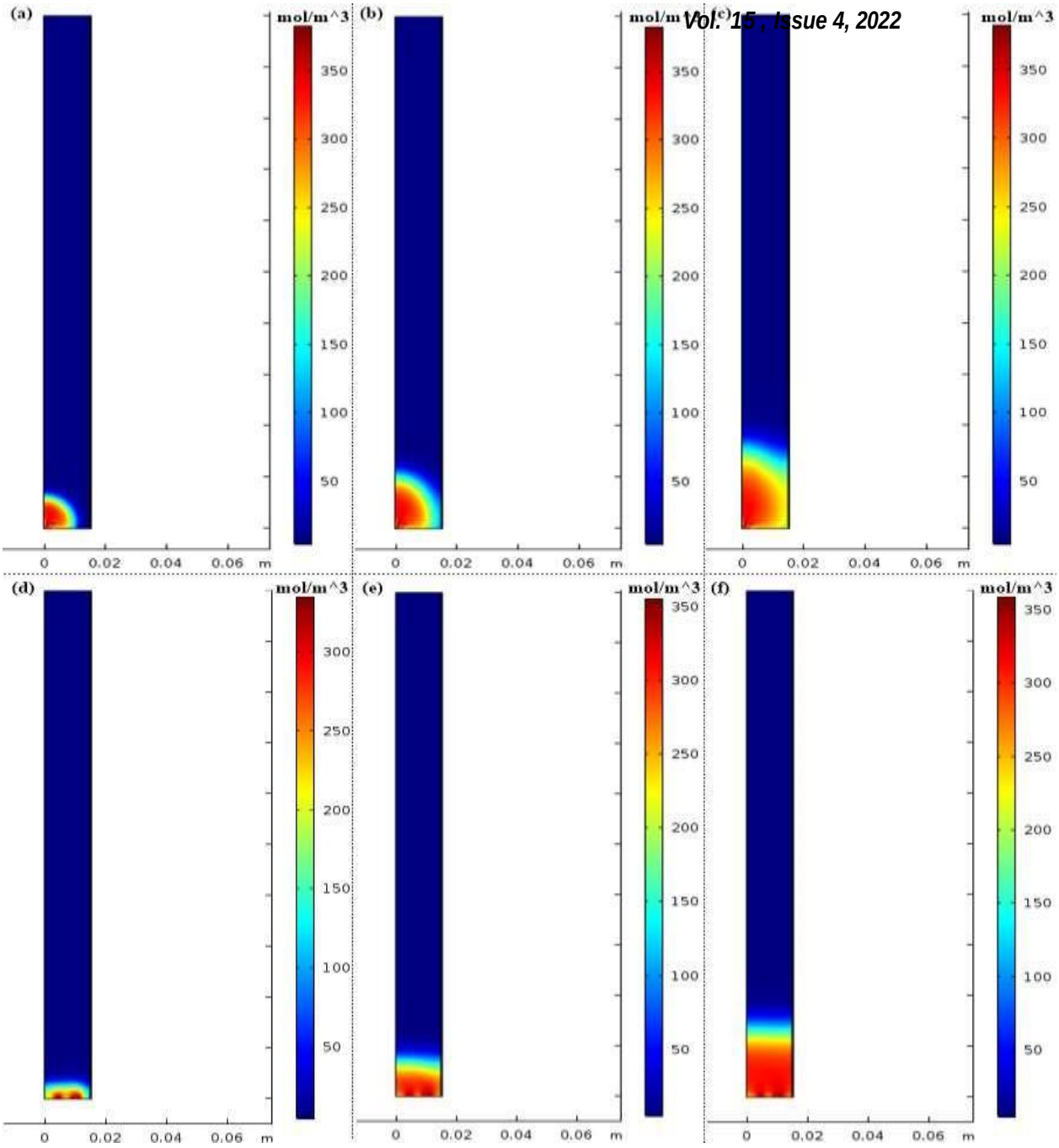

Fig 5.6.2 (a) N_2 concentration profile without inlet distributor at t=1s; (b) N_2 concentration profile without inlet distributor at t=3s; (c) N_2 concentration profile withoutinlet distributor at t=6s; (d) N_2 concentration profile with inlet distributor at t=1s; (e) N_2 concentration profile with inlet distributor at t=3s; (f) N_2 concentration profile with inlet distributor at t=6s

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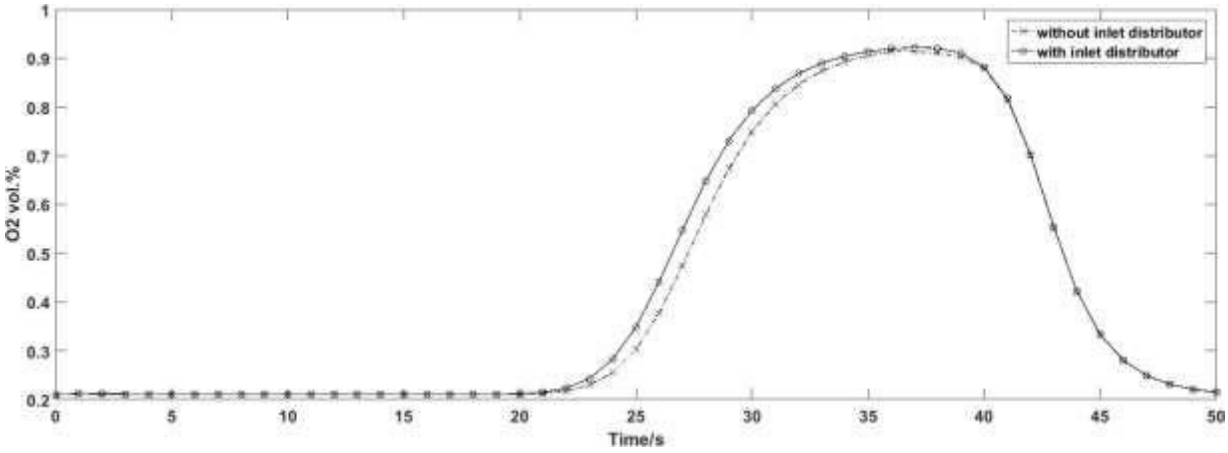

Fig 5.6.3 Simulation results of outflow oxygen concentration for different inflow type

6. CONCLUSIONS

The design of Oxygen Concentrator is a medical device used to deliver oxygen to those who require it. People may require it if they have a condition that causes or results in low levels of oxygen in their blood. Oxygen concentrators are powered by plugging in to an electrical outlet or by battery. If the concentrator is powered by an electric battery, that battery will need to be charged by plugging into an outlet. Several parts make up a concentrator, including a compressor, sieve bed filter, and circuit boards. An oxygen concentrator filters in air, compresses it, and delivers air continuously. The air supply will never run out. Instead of refilling compressed air, the concentrator just needs access to power. An oxygen concentrator works much like a window air conditioning unit. It takes in air, filters and modifies it and delivers it in a new form. An oxygen concentrator takes in air and purifies it for use by people requiring medical oxygen due to low oxygen levels in their blood It works by Taking in air from its surroundings then Compressing air, while the cooling mechanism keeps the concentrator from overheating. It then Removes nitrogen from the air via filter and sieve beds containing Zeolite material using the Pressure Swing Adsorption Technique. It adjusts the delivery settings with an electronic interface. Finally, delivering the purified oxygen via a nasal cannula or mask. Most patients will require a stationary source of oxygen which is usually provided by an oxygen concentrator. Since concentrators are relatively inexpensive and require less frequent home visits than liquid oxygen, they have become the system of choice for suppliers. These

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electrically powered devices utilize a molecular sieve to separate oxygen from air resulting in delivery of oxygen to the patient, while nitrogen is returned to the atmosphere. After detailed study we conclude that it is possible to design OC with 99% purity level.

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