Study on PSA Oxygen producing process under plateau region: Effect of purging flow rate on oxygen concentration and recovery

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Abstract. The effect of purging flow rate and oxygen product concentration and recovery rate under different altitude conditions (50 m-4540 m) was studied on the PSA oxygen production platform. The results show that the higher the altitude, the less the purging flow rate consumption in PAS process. Product oxygen recovery rate at altitudes of 50 m, 2810 m, 3080 m, 3550 m, 4140 m and 4540 m is 39.6%~42%, 42%~47%, 43%~46%, 43.4%~45.5%, 42%~46% and 48%~52.5% respectively. At the same altitude, the oxygen recovery first increases and then decreases with the increase of purging flow rate, and there is an optimal balance between oxygen recovery and purging flow rate. This study can provide reference for the regulation of oxygen production process of PSA at high altitude.

Keywords: pressure swing adsorption, purging flow rate, oxygen concentration, recovery, plateau region

1. Introduction

The method of oxygen production by pressure swing adsorption is a commonly used technique for achieving oxygen enrichment by using different adsorbent selective adsorbents for different gas components in the air. The technology has the advantages of short start-up time, convenient start and stop, low energy consumption, and operating cost. Low and high degree of automation. This technology has the advantages of short start-up time, convenient start and stop, low energy consumption, low operating cost and high degree of automation. In response to the special needs of high-altitude areas such as plateaus, John B. West, an expert in the field of plateau medicine in the United States, has studied and studied for a long time and most of the plateau regions including the Tibetan Plateau in China have pointed out that the pressure swing adsorption method is the most economical and One of the suitable oxygen production technologies [1-2]. However, the plateau region is featured with a large temperature difference between day and night and low atmospheric pressure; the atmospheric pressure is only half of the plain area at an altitude of 5500 meters. Take the Qinghai-Tibet plateau volcanic region of China...
as an example, the extreme maximum temperature reaches 23.2°C, the lowest temperature is -37°C, and the annual average temperature is -3 to -5°C [3], which is quite different from the conventional conditions of the pressure swing adsorption producing oxygen in plain areas. In the past, the adsorption performance of pressure swing adsorption oxygen was mainly studied at a normal temperature of 0°C to 25°C and at a standard atmospheric pressure [4-6], and accordingly, the adsorption properties of pressure swing adsorption for oxygen production in the plateau region is the problem worth studying.

In this paper, a dual-tower PSA oxygen production experimental system is built with specific adjustable valves for precise control of operational variables. The influence of purging flow rate in PSA oxygen production on the energy consumption and product recovery of the oxygen generator at different altitudes (from 50m to 4540m above sea level) was studied. The research results will provide technical basis for the optimization of PSA oxygen production process and its practical application under plateau conditions.

2. Experimental Methods

2.1. Experimental setup

![Figure 1. Experimental apparatus for oxygen production by PSA](image)

1—Filter; 2—Air compressor; 3—Heat exchanger; 4—Buffer tank; 5—Hand valve; 6—Relief valve; 7—Mass flowmeter; 8—Solenoid valve; 9—Pressure transducer; 10—Adsorption tower; 11—Check valve; 12—O₂ storage tank; 13—O₂ concentration sampling port; 14—Pressure reducing valve; 15—PLC; 16—Computer

The experimental setup of the dual-tower PSA oxygen production system is shown in Fig.1, with parameters of the rig and adsorbents listed in Table 1. The feed air was pressurized by the compressor with the power of 1350W/h and a displacement of 200NL/min. After filtration, and feed gas flowed into adsorption tower 1 (T1) or 2 (T2) with the control by solenoid valves. The tower was filled with adsorbents including the activated alumina for water removal and the Li-LSX for oxygen enrichment. The O₂-rich product after the tower flowed into a storage tank, while N₂ and other components were discharged into the atmosphere during the desorption step[7]. The feed flow rate, the adsorption pressure,
the purging flow rate and the product flow rate were controlled by valve K1, K2, K3, and K4, respectively.

### Table 1. Parameters of experimental rig and adsorbents

| Experimental setup | Adsorption bed | Size |
|--------------------|----------------|------|
|                    | Column length  | 600.0mm |
|                    | Internal column diameter | 125.0mm |
|                    | External column diameter  | 133.0mm |

| Adsorbents          |                   |
|---------------------|-------------------|
| Mass of Li-LSX in each column | 3.85 kg |
| Mass of activated alumina in each column | 0.8 kg |
| Bed porosity, $\varepsilon$ | 0.4 |
| Density of Li-LSX | 630 kg/m³ |
| Density of activated alumina | 700 kg/m³ |

#### 2.2. PSA oxygen production process

The Skarstrom cycle considering the pressure equalization step was adopted in this study. The schematic diagram and the duration for each step are shown in Table 2.

### Table 2. The technological process and time parameters of each step

| Items | Step 1 | Step 2 | Step 3 | Step 4 | Step 5 | Step 6 |
|-------|--------|--------|--------|--------|--------|--------|
| Duration | 12s | 5s | 0.5s | 12s | 5s | 0.5s |
| T1     | adsorption | adsorption | pressure equalization | desorption | purge | pressure equalization |
| Schematic diagram | ![Diagram](image) |
| T2     | desorption | purge | pressure equalization | adsorption | adsorption | pressure equalization |

In step 1, T1 and T2 were in the stage of adsorption and desorption, respectively, and vice versa in step 4. For step 1 with E1, E4, and E7 opened, the feed air entered into T1 through E1 and the O₂ product was collected through E7, while N₂ is desorbed in T2 at low pressures. In step 2, T1 and T2 were in the stage of adsorption and purge, respectively, and vice versa in step 5. For step 2 with E1, E4, E6 and E7 opened, part of the O₂ product is collected through E7 and the other part continuous purging tower 2 through E6, while N₂ is further desorbed in T2 to obtain better bed regeneration [8]. In step 3, T1 and T2 are both in the stage of pressure equalization, and vice versa in step 6. For step 3 with E2 and E5 opened, the O₂-rich gas flows from T1 top at a higher pressure into T2 through E5. Meanwhile, the high-pressure air source in the buffer tank flows into tower 2 through E2 making T2 reach objective adsorption pressure instantly.

#### 2.3. Experimental conditions

The time of the plateau experiment was selected in summer from July to August. The experiment was conducted in Geermu city, Nanshankou, Nachitai, Xidantan and Tuotuo River, Qinghai Province, China. The altitude rises gradually from 2810 m to 4540 m, and the atmospheric pressure drops gradually from 70.4 kPa to 58.7 kPa. The gas performance of the product becomes stable gradually, which can be regarded as cycle steady state (hereinafter referred to as CSS). At this point, effective data starts to be recorded. When the oxygen generator reaches the CSS state, the data such as product gas concentration,
product gas flow rate, intake flow rate, adsorption pressure and energy consumption are recorded and saved.

3. Results and discussion

3.1. Effect of purging flow rate on oxygen concentration

Figure 2. Effect of purging flow rate on product oxygen concentration at different altitudes

From figure 2, with the increase of purging flow rate in each cycle, the oxygen concentration of the product shows a trend of first increasing and then decreasing. The oxygen concentration of products at altitudes of 50 m, 2810 m, 3080 m, 3550 m, 4140 m and 4540 m is 86.9%~92.6%, 87.6%~92.1%, 89.1%~92.3%, 87.4%~93%, 91.9%~93.0% and 88.5%~92.8% respectively, and the optimal purging flow rate is 8 L/cycle, 7.8 L/cycle, 6 L/cycle, 4.5 L/cycle, 4.5 L/cycle and 3.8 L/cycle respectively. In this case, each cycle refers to the time it takes for the two adsorption towers of the PSA oxygen production system to complete one adsorption, purging, and pressure equalization.

As the purging flow rate increases, the oxygen concentration of the product increases first and then decreases. The main factors affecting the purging flow rate are the purging time and the opening of the purging valve. When the purging flow rate is small, increasing the cleaning flow rate can make more purging gas purge the adsorption column bed, more nitrogen come out from the molecular sieve from desorption, the effective adsorption capacity of the molecular sieve increases, and the bed regeneration effect is improved. This enables the raw gas in the next cycle in the adsorption process to better complete the nitrogen and oxygen separation, the product gas oxygen concentration increased. When purging flow rate is larger, increasing the purging flow rate to a certain degree of improving adsorption bed regeneration effect, the improvement of the regeneration effect at this time has little effect for the working condition of oxygen generation system, and because of the clear traffic continues to increase, too much purging mass loss after the adsorption process of product gas output is reduced, affected the product gas oxygen concentration, which show the product gas oxygen concentration with the further increase of cleaning flow gradually decreases instead.
3.2. Effect of purging flow rate on recovery rate

From figure 3, with the increase of purging gas volume per cycle, the recovery rate presents a trend of first increasing and then decreasing and increases with the altitude. Product oxygen recovery rate at altitudes of 50 m, 2810 m, 3080 m, 3550 m, 4140 m and 4540 m is 39.6%~42%, 42%~47%, 43%~46%, 43.4%~45.5%, 42%~46% and 48%~52.5% respectively.

With the increase of purging gas volume, the recovery of product oxygen first rise and then down. When the purging gas flow is lower, increasing the purging gas improves the cleaning effect of zeolite. However, when the purging time is too long, the gas loss of the product increases, and the regeneration effect of the bed improves is not obvious. At this time, the oxygen concentration of the product decreases, and the recovery rate decreases accordingly. Therefore, there is an optimal purging gas volume to maximize the gas recovery of the product. In addition, the recovery rate increases with altitude. This is because the bed utilization rate is low due to insufficient air intake under the condition of plateau low pressure, the adsorption of molecular sieve is in the unsaturated state, and the recovery rate is increased.

4. Conclusion

In this paper, PSA oxygen generator was tested in the plateau area, which covers the altitude of most human activities in the plateau area. The influence of purging process on oxygen concentration and recovery of PSA under different altitude was studied. It was found that with the increase of the purging gas flow, the oxygen concentration of the product and the oxygen recovery of the product had a tendency of first increasing and then decreasing, and there was an optimal cleaning flow. It is necessary to consider the direct balance between the consumption of cleaning gas flow and the oxygen flow of the product. With the increase of altitude, the consumption of optimal cleaning flow decreases and the recovery rate increases. This paper is an important reference for the regulation of the plateau PSA oxygen production process.
References

[1] S.P. Reynolds, A.D. Ebner, J.A. Ritter, Enriching PSA Cycle for the Production of Nitrogen from Air, Ind. Eng. Chem. Res. 45 (2006) 3256-3264.

[2] J.C. Santos, P. Cruz, T. Regala, F.D. Magalhaes, A. Mendes, High-Purity Oxygen Production by Pressure Swing Adsorption, Ind. Eng. Chem. Res. 46 (2007) 591-599.

[3] Liu Y., 2010. Oxygen supply technology in anoxic environment. Beijing.

[4] P.E. Jahromi, S. Fatemi, A. Vatani, J.A. Ritter, A.D. Ebner, Purification of helium from a cryogenic natural gas nitrogen rejection unit by pressure swing adsorption, Sep. Purif. Technol. 193 (2018) 91-102.

[5] M. Shi, J. Kim, A. Sawada, J. Lam, S. Sarabadan, M.T. Kuznicki, et al, Production of Argon Free Oxygen by Adsorptive Air Separation on Ag-ETS-10, Aiche J. 59 (2013) 982-987.

[6] J.C. Santos, A.F. Portugal, F.D. Magalhães, A. Mendes, Optimization of Medical PSA Units for Oxygen Production, Ind. Eng. Chem. Res. 45 (2006) 1085-1096.

[7] A.A. Bhat, H. Mang, S. Rajkumar, T.M. Kotresh, U.K. Singh. On-Board Oxygen Generation Using High Performance Molecular Sieve, Defence Life Science Journal. 2 (2017) 380-384.

[8] J.L. Liow, C.N. Kenney, The backfill cycle of the pressure swing adsorption process, Aiche J. 36 (1990) 53.