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Production of Oxy-Rich Air by RPSA for Combustion Use

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Abstract. The capital and energy costs of production of oxygen enriched air by a rapid pressure swing adsorption (RPSA) process can be reduced by decoupling the air drying and the air separation duties of the process. Integration of the oxygen-RPSA process with an enhanced combustion application system allows thermal swing adsorption drying of air feed to the RPSA process. The air separation process then can be run using an ad(de)sorption pressure envelope of 2:1 atmospheres, which significantly reduces the cost and energy of operation of the air compressor.

Keywords: pressure swing adsorption, air separation, zeolite, rapid cycle, heat integration

Introduction

Use of oxygen enriched air containing 23–50 mole% O_2 (instead of ambient air) can result in a substantial fuel saving in many combustion operations like boilers, cupolas, ceramic and smelting furnaces, etc. (Stempo, 1980; Heffron et al., 1993; Saha et al., 1987). A rapid pressure swing adsorption (RPSA) process was recently described for the efficient production of such oxygen enriched air (Sircar, 1991; Sircar and Hanley, 1995). The process uses a single adsorber vessel containing a single or more pairs of shallow adsorbent layers separated by perforated metal plates as shown by Fig. 1. Each layer consists of a sublayer of a desiccant at the feed air inlet end and a sublayer of a zeolite for selective adsorption of nitrogen from the dry air. Each layer is cyclically subjected to sequential steps of (a) simultaneous pressurization with air and adsorption of nitrogen in order to produce the oxygen enriched air, and (b) simultaneous depressurization to near ambient pressure level and back purge with a part of the oxygen enriched gas in order to regenerate the adsorbents. A part of the oxygen enriched gas produced by step (a) is withdrawn as the product gas. A nitrogen enriched waste gas containing all of the water of the compressed feed air is also produced by the process. The compressed ambient air feed can be introduced into the adsorber at a constant super ambient pressure level (P_A) or it can be ramped from ambient pressure level to P_A during step (a) of the process.

A very short total cycle time of 8–12 seconds (4–6 seconds for steps a and b) is used by the RPSA. Consequently, the specific production rate of the oxygen enriched gas (volume/volume of total adsorbent/time) by the RPSA is increased by more than an order of magnitude compared to the conventional pressure or vacuum swing adsorption processes (Sircar and Hanley, 1995). This yields an order of magnitude reduction in the adsorbent inventory for a given oxygen production rate. The net oxygen recovery by the process (moles of O_2 in the product gas/moles of O_2 in the feed air/cycle) is fairly large. For example, the process can produce about 395 liters of O_2/liter of zeolite adsorbent/hour (40% O_2) at an oxygen recovery of 45.2% using NaX zeolite and a feed air pressure of 31 ($\pm$1.5) psig (3.1 atmosphere). The total cycle time for this case is 12 seconds. Figure 2 shows the O_2 productivity by the RPSA process at ambient temperature (expressed as lb moles of product gas/lb of zeolite/cycle) and the O_2 recovery as functions of product O_2 purity at a feed air pressure of 31 psig (P_A) using NaX zeolite and dry air feed (Sircar and Hanley, 1995). The novel concept of stacked adsorbent layers in a single adsorber vessel and the specific cycle design of the RPSA process

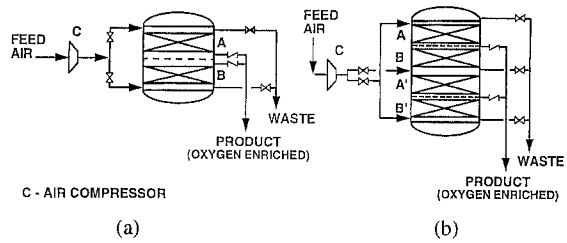

Figure 1. Schematic of two and four layered embodiments of the RPSA unit.

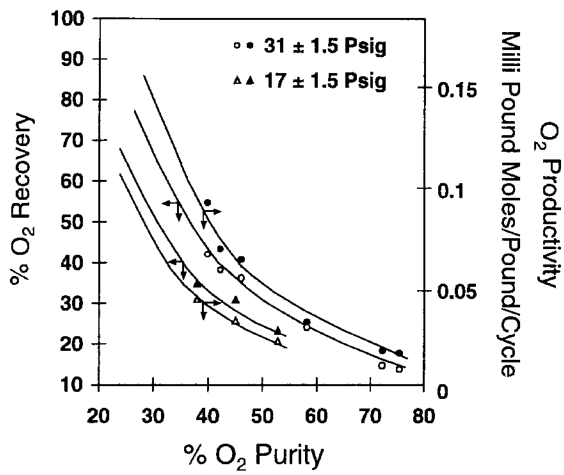

Figure 2. Specific oxygen production capacity and oxygen recovery as functions of oxygen product purity by the RPSA process using NaX zeolite (dry air feed, 12 seconds total cyclic time).

introduces design flexibility for large production rates and minimizes hardware requirements.

The purpose of the present work is integration of the above described RPSA process with an enhanced combustion application which can further reduce the capital and operating costs for the production of the O_2 enriched air.

Novel Mode of Operation of the RPSA Process

The original RPSA process simultaneously carries out two separations. It removes water from the compressed air by the desiccant sublayer in order to produce a dry air stream and it separates nitrogen from oxygen and argon by the zeolite sublayer in order to produce the O_2 enriched product gas. Activated alumina is often the preferred desiccant for gas drying. The weight ratio of alumina to zeolite layers is typically between 0.2–0.4. The drying operation is carried out by pressure swing adsorption (adsorption at a pressure level of P_A and desorption at ambient pressure). The adsorption/desorption pressure ratio must be kept at a moderate to high value ($\geq 3:1$) in order to reduce (a) the size of the desiccant layer and (b) the quantity of purge gas needed for desorption of water (Skarstrom, 1960). However, even a moderate pressure ratio of 3:1 ($P_A = 30$ psig; 3.04 atmospheres) requires the use of a two-stage air compressor. The size, cost and energy requirement for such a compressor for the production of 40% O_2 by the original RPSA process at a final adsorption pressure of 30 psig can be relatively large. For example, Table 1 shows the relative capital costs of various components of a RPSA system for producing 50 tons per day (0.4 m^3/s) of contained O_2 at an O_2 product purity of 40 mol% using NaX zeolite. These costs were estimated by using actually quoted equipment vendor prices. The corresponding schematic flow diagram for the process is given in Fig. 3. The capital cost of the air compressor is 57% of the total capital cost for the process. Table 2 shows the breakdown of relative capital and energy costs for the process. The energy cost is 29% of the total specific cost of the oxygen product.

Uncoupling the air drying and the air separation duties of the RPSA process permits the operation of the process at a lower ad(de)sorption pressure ratios. Figure 2 shows the performance of the RPSA process using dry air feed at a final adsorption pressure level (P_A) of 17 (±1.5) psig (2.1 atmosphere). It corresponds to an ad(de)sorption pressure ratio of 2:1. The experimental data reported in Fig. 2 were measured in a process development unit (Sircar and Hanley, 1995). It consisted of two layers of a commercial NaX zeolite (5.8 inches in diameter and 7.0 inches long containing

PROCESS FLOW DIAGRAM
RAPID PSA SYSTEM FOR O_2-ENHANCED AIR

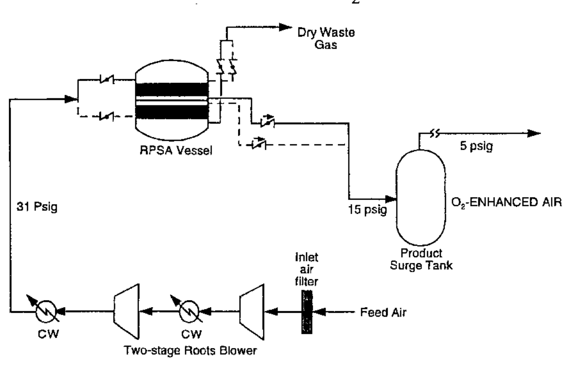

Figure 3. Schematic flow diagram for original RPSA system.

Table 1. Relative capital cost summary of RPSA processes producing 50 TPD contained oxygen at 40 mole% purity.

	Original RPSA process (Fig. 3)	Integrated RPSA process (Fig. 4)
Adsorbent	0.027	0.069
	(NaX + Alumina)	(NaX only)
Adsorber vessel and internals	0.074	0.102
Air compressor (roots blower) and after coolers	0.566	0.385
	(Two stage unit)	(Single stage unit)
Product storage tank:	0.015	0.016
Valves and actuators	0.033	0.036
Thermal swing drying system with adsorbent	—	0.123
Skid fabrication, piping controls, instruments and motors	0.160	0.130
Installation and engineering	0.128	0.139
	1.000	1.000

Table 2. Relative capital and power costs of RPSA processes producing 50 TPD contained oxygen at 40 mole% purity.

	Original RPSA process	Integrated RPSA process
Capital cost	0.71	0.73
Power cost	0.29	0.27

4.5 pounds of zeolite each). The adsorbent particles were 0.5 mm in diameter (30–50 mesh) and the total RPSA cycle time was 12 seconds (6 seconds for steps a and b each). Cyclic steady state was typically reached after 10–20 cycles of operation. Each data point of Fig. 2 was obtained by setting a specific feed air flow rate and a specific product O_2 withdrawal flow rate. A more detailed description of the experimental apparatus and the test procedure is given elsewhere (Sircar and Hanley, 1995).

Both the oxygen productivity and the recovery by the RPSA process are decreased for a given value of O_2 product purity at this lower value of P_A (compared to those at 31 psig), but the process can be successfully operated to make the oxygen enriched product gas when the air drying duty is removed. It may be seen from Fig. 2 that the specific oxygen production capacity and the oxygen recovery for the production of 40% oxygen product are decreased, respectively, by factors of 0.5 and 0.77 when the adsorption pressure is reduced from 31 to 17 psig. However, the lower pressure operation allows the use of a single stage compressor and the net energy of compression is significantly reduced. The increase in the size of zeolite layers due to lower oxygen production capacity does not add much to the overall capital cost because the cost of this component is minor (Table 1).

Compressed air can be dried in a conventional thermal swing adsorption (TSA) system before it is fed to the RPSA unit operating between the pressure levels of 17 and 0 psig. A portion of the dry nitrogen enriched desorbed gas from the RPSA unit can be used as the regeneration gas for the TSA unit. Since the RPSA system is coupled with an enhanced combustion system, the regenerating gas can be heated by recovering a part of the waste heat from the combustion operation using a gas-gas heat exchange system or a recuperator. Alternatively, the dry regenerating gas can be heated by other sources of waste heat such as steam. Figure 4 is a schematic flow sheet describing the integration of the RPSA, TSA and combustion units.

The relative capital costs of the components of the integrated RPSA process are also given in Table 1. These costs were also estimated by using actual quotes from the equipment manufacturers. It shows that the cost of the air compressor is only 38.5% of the total cost in this case. The cost of the TSA unit is only 12.3% of the total cost. Table 2 shows that the relative capital and energy costs for the integrated RPSA process are similar to those of the original process. However, Table 3 shows that the integrated RPSA process reduces the net capital cost and the net energy cost for production of 50TPD contained O_2 at 40 mole% purity by 8% and 24%, respectively. The net specific cost of oxygen enriched product gas is reduced by 18%. This demonstrates that the RPSA process for the production

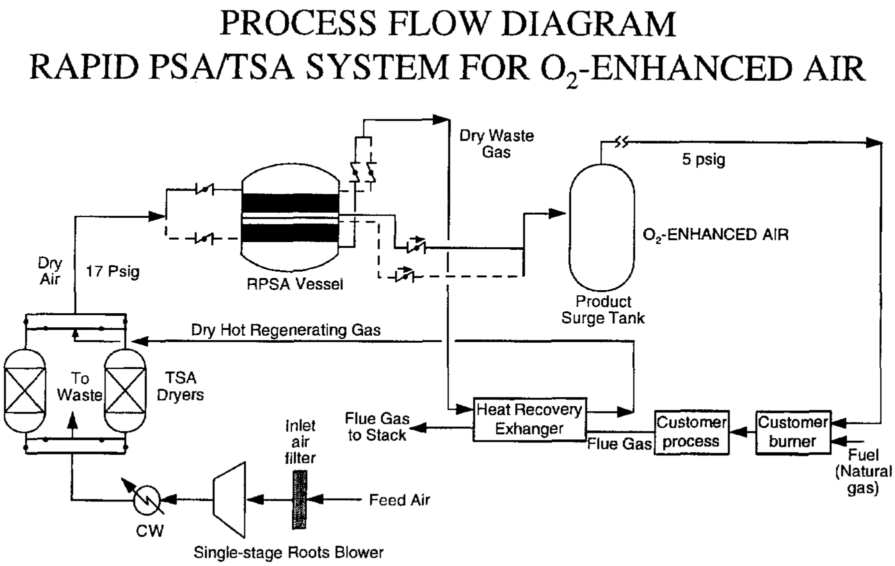

Figure 4. Schematic flow diagram for the integrated RPSA system for combustion use.

Table 3. Relative cost of thermally integrated RPSA process producing 50TPD contained oxygen at 40 mole% purity.

	% of original RPSA
Total capital	92%
Power	76%
Specific cost of contained O_2	82%

of low purity O_2 can be integrated with the enhanced combustion application in order to reduce the specific cost of the product gas.

Conclusions

Uncoupling of the air drying and air separation duties of a rapid pressure swing adsorption (RPSA) process for the production of oxygen enriched air can significantly reduce the product cost. Integration of the RPSA process with an enhanced combustion application or a source of waste heat such as steam permits this mode of operation. The process can then be operated using an ad(de)sorption pressure ratio of 2:1 which significantly reduces the capital and energy costs of the air compressor. Air drying for such a process can be carried out by using a thermal swing adsorption system (TSA). The dry desorbed gas from the RPSA unit can be used to regenerate the TSA driers. A part of the waste heat from the combustion operation or another source can be used to heat the TSA regenerating gas.

Acknowledgments

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