Energy Consumption of Pressure Swing Adsorption vs. Vacuum Swing Adsorption - A Thermodynamic Study

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Introduction

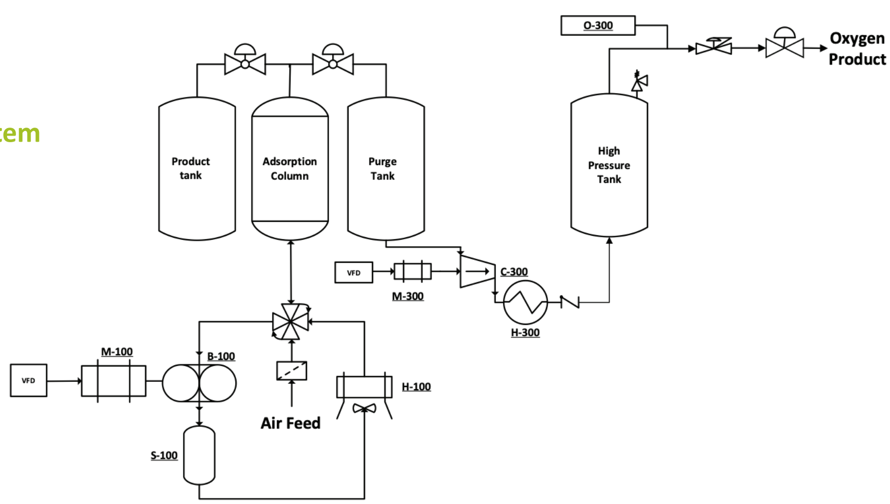
When comparing options for generating cost-efficient on-site Oxygen at a purity of 95% or less, Pressure Swing Adsorption (PSA) and Vacuum Swing Adsorption (VSA) are the two main competing technologies. One of the most important parameters to consider when choosing between these two systems is the energy that is required to produce Oxygen per unit mass, which is often expressed as kWh/kg O2 and is directly related to the operating expense of the system. The goal of this report is to estimate the power consumption of both a VSA and PSA system using a Thermodynamics analysis and determine which system is more energy efficient.

Discussion

Pressure Swing Adsorption vs. Vacuum Swing Adsorption

Figure 1 below shows a process flow diagram of a typical VSA system. Both PSA and VSA systems use a fluid mover to pressurize a column full of an adsorbent that separates Oxygen from the other constituents of air. One of the key differences between the two systems is that a PSA uses a compressor to fill the adsorption column from ambient pressure up to 90psig. In a VSA system, a blower is used to fill the adsorption column to low pressures (~8 psig) and is also used to empty the column and bring it to a vacuum (~-8 psig) to regenerate the adsorbent. A typical PSA system will operate between 0psig to 90psig, and a typical VSA system will operate between -8 psig to 8 psig. In a VSA system, the product oxygen is then compressed from 8psig up to the pressure that the end-user requires and is stored in a high-pressure tank. For ease of comparison, it will be assumed that the Oxygen booster compressor will operate at 90 psig.

Figure 1.
Schematic of a VSA system



Pressure Swing Adsorption vs. Vacuum Swing Adsorption

Table 1 and Table 2 below show the theoretical amount of energy that is required to compress gas from 0 psig to 90 psig in the case of a VSA system, and from -8psig to 8psig in a VSA system, respectively. The calculations for the VSA include the energy required to compress the product Oxygen from 8 psig up to 90 psig. This comparison is between an OSI-1000 and a competitor's equivalent unit that can produce up 1 tonne of Oxygen per day. The energy calculations assume that compressing the gas from one state (pressure) to another is an isentropic process. All state data was taken from NIST webbook .

OSI-1000 VSA		
	State 1	State 2
Pressure [psia]	6.00	21.00
Temperature [K]	293.15	402.00
Entropy [J/(g*K)]	7.04	7.04
Enthalpy [J/(g*K)]	303.92	417.50
Mass of Air Compressed in 1 hr [kg]	459.38	459.38
Heat Capacity of Air [J/(g*K)]	1.01	1.01
Energy change from state 1 to state 2 [kJ]	50303.09	
Average power consumption without Oxygen product recompression[kW]	13.97	
Additional power consumption of 5HP compressor to compress Oxygen Product @90psig [kW]	3.73	
Total average power consumption including Oxygen recompression to 90psig [kW]	17.70	
Cost of Electricity [$/kWh]	0.16	
Energy [kWh/kg O2]	**0.44**	

Table 1 - Energy Efficiency of a VSA System

1 https://webbook.nist.gov/cgi/fluid.cgi?ID=C7727379&TUnit=K&PUnit=psia&DUnit=kg%2Fm3&HUnit=kJ%2Fkg&WUnit=m%2Fs&VisUnit=uPa*s&STUnit=N%2Fm&Type=IsoBar&RefState=DEF&Action=Pag

Competitor PSA		
	State 1	State 2
Pressure [psia]	14.00	104.00
Temperature [K]	293.15	518.00
Entropy [J/(g*K)]	6.83	6.83
Enthalpy [J/(g*K)]	303.92	539.21
Mass of Air Compressed in 1 hr [kg]	563.19	563.19
Heat Capacity of Air [J/(g*K)]	1.01	1.01
Energy change from state 1 to state 2 [kJ]	127394.17	
Average Power [kW]	35.39	
Cost of Electricity [$/kWh]	0.16	
Energy [kWh/kg O2]	**0.68**	

Table 2 - Energy Efficiency of a PSA System

The overall energy consumption on a kWh/kg O2 basis for a VSA system capable of producing 1000 kg/day of Oxygen is 0.44 kWh/kg O2 and is 0.68kWh/kg O2 for an equivalent PSA system. This means that the operating expense of a VSA system is 1.5 times less than an equivalent PSA system. This leads to significantly lower operating expenses and a lower carbon footprint. Assuming a cost of electricity of $0.16/kWh and an Oxygen production of 1000kg/day, the use of a VSA system results in yearly savings of $14,000 from an operating expense standpoint. The reason for VSA systems being much more energy efficient comes down to the operating pressures of the systems. In a PSA system, ambient air is compressed from atmospheric pressure (0 psig) up to 90 psig in the adsorption column. The Oxygen product is taken directly from the top of adsorption column at 90 psig. Ambient air is made up of approximately 21% Oxygen, 78% Nitrogen, and 1% other trace gases. With the PSA system having such a high pressure in the adsorption column, the Nitrogen and trace gases, which make up 79% of the air by volume, are compressed up to 90 psig. Compressing the Nitrogen and trace gases up to 90psig wastes a significant amount of energy, as after every cycle in the PSA the Nitrogen and trace gases are discharged back into the atmosphere. In the case of a VSA, the adsorption column operates between -8psig to 8psig. This means that the Nitrogen and trace gases in the ambient air are compressed from -8psig to 8psig. In a VSA, the product Oxygen is removed from the top of the adsorption column and is the only gas that is compressed to high pressures, which is 90 psig for the sake of this comparison. The significant increase in energy efficiency is a result of compressing only the product Oxygen up to high pressures.

Conclusion

The goal of this report was to determine the energy consumption of a PSA and VSA system on a kWh/kg O2 basis that can produce 1000kg/day of Oxygen and determine which system is more energy efficient using thermodynamics. In this study it was found that the VSA system being studied used 1.5 times less energy than its PSA competitor.