OXYGEN - PRESSURE SWING ADSORPTION

Oxygen needs to be produced in large volumes for many applications. Perhaps the commonest of these are in medicine and in the pulp and paper industry. There are two methods used for doing this: cryogenic and pressure swing adsorption. Pressure swing adsorption, which is outlined in this article, is most useful for small applications such as oxygen production in the home for asthma sufferers.

Pressure swing adsorption relies on air being filtered through aluminosilicate minerals known as zeolites. The one used for PSA oxygen has been specially designed so that nitrogen gas is adsorbed onto it while oxygen (and argon) pass straight through. The zeolite is quickly saturated with nitrogen, so two zeolite beds are usually used together, one filtering air while the other is regenerated.

This process is very environmentally friendly and the technique is also potentially able to be used to remove other gases (such as CO_2) from industrial waste gas streams.

INTRODUCTION

Pressure Swing Adsorption (PSA) is one of the most popular methods used for the commercial production of oxygen gas. Whilst cryogenic manufacture by the Joule-Thompson method (fractional distillation of air at low temperature and pressure) is suited to large scale operations (over 200 tonne of oxygen per day), PSA technology is suited to small and medium sized productions needs. A comparison between the two methods of oxygen manufacture is given in **Table 1**.

Table 1 - The relative advantages of PSA and cryogenic oxygen production

	PSA	**Cryogenic production**
Temperature	ambient	low
Pressure*	maximum is 150 kPa	maximum is 13,000 kPa
Purity	95%	near 100%

* The usual car tyre pressure is 200 kPa

Micro (suitcase sized) PSA plants have replaced heavy high pressure oxygen cylinders in the homes of many asthma sufferers. Small PSA plants have been built to replace large numbers of oxygen cylinders used in some industrial situations. Large PSA plants are often located alongside pulp mills where the oxygen produced is used directly in the mill process. The Kinleith plant of IChem Limited provides up to forty tonne per day of high quality oxygen to the neighbouring pulp mill. The oxygen has replaced chlorine as the primary chemical used to de-lignify wood pulp.

THE PSA PROCESS

The PSA process (shown in **Figure 2**) consists of pumping air through a bed containing a filter medium that preferentially adsorbs nitrogen, while allowing oxygen to pass through unrestricted. Eventually, the filter bed becomes saturated with nitrogen and must be regenerated. It is the feature of the filter media that nitrogen is adsorbed at pressures above 150 kPa and is desorbed at atmospheric pressures. The desorbed nitrogen is then flushed away by a proportion of the purified oxygen. It is this cyclic pressurisation and depressurisation that gives the PSA process its name.

The filter medium is a type of zeolite. The properties of zeolites in general and this zeolite in particular are discussed below.

Zeolite
Scientists have known for many years the special properties of naturally occurring zeolites. Natural Zeolites Limited, based in Tokoroa, produces some of the highest quality zeolite in the world.

Naturally occurring zeolite was not selective enough for oxygen separation and it was not until the 1950's that scientists at Union Carbide in the USA developed synthetic zeolites. PSA technology experienced rapid growth during the 1980's with over five hundred patents being issued between 1985 and 1990.

Zeolites are aluminosilicate minerals with complex crystal structures made up of interlocking rings of silicon, aluminium and oxygen ions. The chemical composition of the zeolite used for oxygen separation is $Na_{12}[(AlO_2)_{12}((SiO_2)_{12}].27H_2O$. It is the zeolite's shape which provides most of the ability to selectively adsorb nitrogen. The zeolite used for oxygen production is shaped like a die with holes drilled on each face to form an internal cage. The corners of the die (providing the framework) are SiO_2 and AlO_2 units. Cations (either Na or Ca) are exposed throughout the crystal lattice. This zeolite is shown in **Figure 1**.

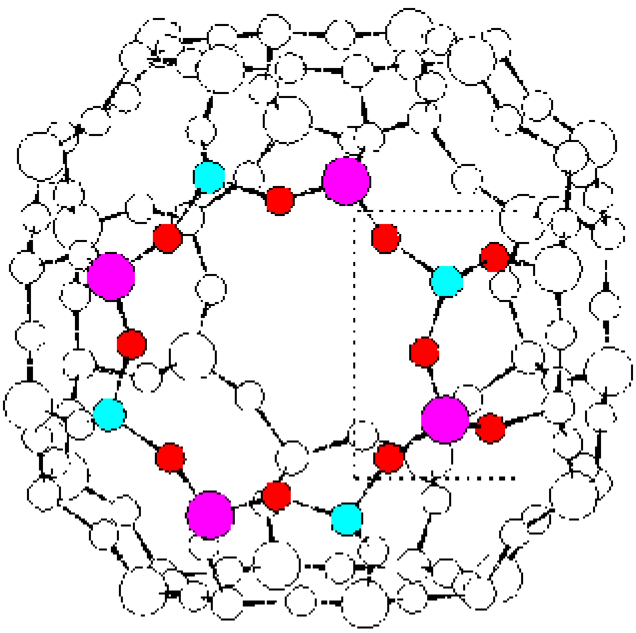

Figure 1 - Structure of the zeolite used in PSA oxygen production

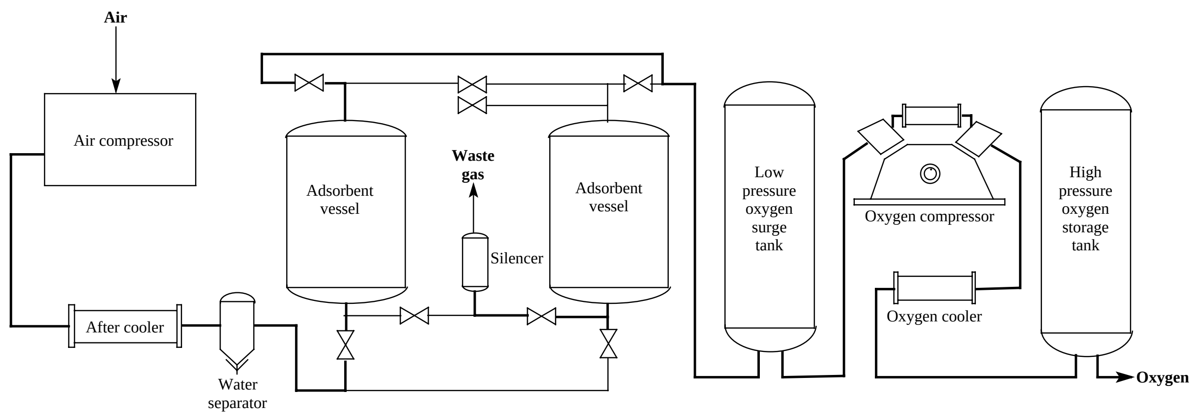

Figure 2 - Schematic representation of the PSA process

Zeolite is very efficient for two reasons.

Physical adsorption
When nitrogen is in close proximity to the exposed cations of the zeolite crystal, a charge induced dipole forms and the nitrogen is attracted into the zeolite crystal. Nitrogen is more polarisable than oxygen and the zeolite selectively adsorbs nitrogen allowing the oxygen gas to pass unrestricted. The internal surface area of zeolite is extremely large and so provides a high degree of adsorption per volume of zeolite.

Steric hindrance
The cage like structures of zeolite have been carefully designed to allow only nitrogen to pass to their inside and to exclude the larger oxygen molecules. That is, the holes in the side of the zeolite dice are large enough to allow nitrogen entry but small enough to exclude oxygen. They also exclude argon which makes up approximately one per cent of the input air. Argon comprises five per cent of the volume of gas produced by an oxygen PSA plant.

The uniformity of the micropores has been the major advantage of synthetically produced zeolites.

The PSA Cycle
Practical design of PSA oxygen plants depends on many factors, including bed length, diameter, zeolite bed packing, and rate of infeed air. In domestic medical oxygen PSA plants, power efficiency is sacrificed in favour of robustness, process stability and oxygen purity. In larger commercial oxygen plants, the process is only economic whilst operating at maximum oxygen separation efficiency. The control of the cycling is critical.

PSA zeolite beds are always built in pairs, so that a portion of the oxygen produced from one bed is used to regenerate the other bed. Clearly, the ratio of oxygen used for regenerating the other bed compared to that available for sale is critical. At the IChem Ltd plant, each zeolite bed is saturated after only twenty-two seconds, requiring the pressurisation and regeneration (i.e. depressurisation and flushing with oxygen) sequence to be precisely computer controlled.

The plant computer controls all aspects of running a large PSA plant. If there is a problem, the plant computer pages an operator. Apart from routine maintenance, the plant does not require the presence of an operator.

FURTHER APPLICATIONS OF PSA TECHNOLOGY

The principles of PSA technology have been applied to separation of many mixed gas streams. Plants are available to produce nitrogen for uses like blanketing fuel tanks at airports. “Designer” zeolites have been produced to remove hydrogen from waste gas streams.

Currently, PSA technology is used to remove CO_2 from the flue streams of the steel and lime industries. In the future, PSA plants may be used to extract the greenhouse gas CO_2 from the flue streams of coal fired power stations.

ENVIRONMENTAL IMPLICATIONS

The PSA process is an extremely clean operation. The only “raw material” is air, and the only other input is electricity to pump the air through the filters. The process removes approximately one third of the oxygen from the air. Larger PSA plants are computer controlled and run unattended. Their reliability is demonstrated by the thirty thousand PSA units in the USA providing medical oxygen in critical applications.

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- Whiting, R. *Chemistry in New Zealand*; Vol 55, No 2, 1991.

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