

Gas Separation using Continuous Gas Centrifuge.

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The principle of the gas centrifuge was first demonstrated by James Clerk Maxwell in the mid-19th Century; his demonstration used a batch centrifuge rather than a continuous one. Currently, continuous liquid centrifuges are used in the dairy industry for separating cream from milk; they are also used in the pharmaceutical industry. Continuous gas centrifuges are only used for isotope separation in the nuclear industry. The principle of operation of a gas centrifuge is no different from that for liquids. This document relates to the industrial and domestic uses of continuous gas centrifuges for separation of gases of differing molecular weights.

I could find only a small number of academic reference to the use of continuous gas centrifuge technology other than for the nuclear industry, see References below.

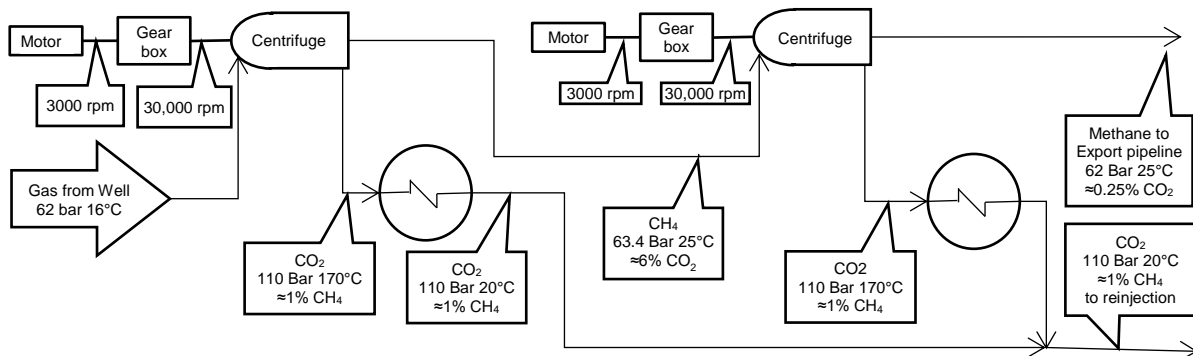
Ralph van Wissen, Michael Golombok, J.J.H. Brouwers: Separation of carbon dioxide and methane in continuous countercurrent gas centrifuges. This article concludes that using this technology in large-scale hydrocarbon processes is not feasible. The authors talk about countercurrent centrifuges, and this is not explained. They seem to be using large hollow rotating cylinders without any internal structure. The other references are more positive.

The most successful liquid centrifuges use a stack of perforated discs rotating within a cylinder. Our initial results show that a stack of perforated discs rotating at high speed within a fixed cylinder can perform a continuous separation efficiently; that the bigger the molecular weight difference, the easier the separation; and that high pressure, low temperature and thus high density improves the efficiency of separation. We intend to perform further physical tests of this technology. Meanwhile, we have developed a theory, from fundamental fluid mechanical and thermodynamic principles.

Oil and gas wells produce methane, natural gas, which comes out of the ground mixed with CO₂. Typically, every tonne of methane is accompanied by between 8 and 12 tonnes of CO₂. Separating methane from CO₂ is done at present by solvent absorption or cold distillation. Solvent absorption is a process with a huge capital cost and high running costs: for a unit handling 1000 tonnes a day of methane this is typically \$US 30 million capital cost and 22 to 33 MW of energy consumed. This energy is generated by burning methane or other fossil fuels, about 1.6 to 2.4 tonnes per tonne of methane exported to consumers; this represents 9 to 17 tonnes of CO₂ going into the atmosphere. Cold distillation is even more costly in both capital installation and energy consumed. The CO₂ from either process is generated at low pressures, which means that sequestering it in the oil or gas well is very costly, so it is generally put out into the atmosphere through a flare stack. Thus for every tonne of methane sent out to the customer, (which generates 2.75 tonnes of CO₂ when burnt), a further 17 to 29 tonnes of CO₂ goes into the atmosphere from the production process.

This separation could easily be accomplished with a gas centrifuge. Here the capital cost is about \$US 9 million with an energy consumption of 250 to 400 kW depending on the amount of CO₂ present in the mixture. Moreover the CO₂ is produced at about 110 bar and is a liquid after cooling, which means that it can be sequestered in the oil or gas well underground with minimal pumping costs.

Separating Methane from CO₂, a typical application:



Reinjecting the CO₂ into the deepest parts of an oil or gas well will displace the hydrocarbons upwards, increasing the well-head pressure and thus improving production rates.

Similar processes may be used for other gas separations where the molecular weights are significantly different. Commonly required separations include:

- Hydrogen from Methane:** A hydrocracker unit in a refinery typically needs about 20 tonnes/day of 90% hydrogen. This is generated at present by a cold fractionation unit with a capital cost of \$US 200 million and consumes about 60 MW. The same separation using a gas centrifuge requires a centrifuge costing less than \$US 65,000 and consuming 120 kW to generate the same 20 tonnes/day of 90% hydrogen.
- Ethane from Ethylene:** At present this is done by cold distillation. The capital cost of the installation for 2400 tonnes/day of 99% ethylene is about \$US 180 million and consumes about 600 MW of power, generated by burning fuel oil or gas. The same 2400 tonnes/day of 99% ethylene would require a series connected set of three gas centrifuges with intercoolers costing about \$US 8 million and consuming about 4 MW.
- Oxygen from air for domestic medical use:** Typical ventilators provide the patient with air containing about 40-50% oxygen. A typical patient will need about 20 litres per minute of oxygen-enriched air. At present, this is provided by bottles of compressed oxygen, a cylinder will last 2-3 days with a manufacturing cost of about 36 kWh of electricity per cylinder plus transportation costs. A small gas centrifuge in the patient's home or at his bedside could provide this from the air in the room. The centrifuge requires about 90W to operate, or about 2 kWh per day. There is some noise, slightly more than a typical fan heater. The cost of such a unit would be about \$US 65 assuming quantity manufacture. Ideally the enriched air would be bubbled through water to cool and humidify it; this water should be changed regularly. Patients storing oxygen in the home suffer a substantially increased home insurance cost; using this system would mean that there was no stored oxygen.
- Oxygen from air for hospital use:** at present a 1000 bed hospital will receive a refrigerated tanker with 17 tonnes of liquid oxygen every 15-20 days at a cost

of \$US 1.2 million per year. Bottled CO₂ is also required because pure oxygen causes health problems unless some CO₂ is added. The equipment in the hospital for storage and distribution costs about \$US 22 million, occupies 70 cubic metres of utility space and requires specially trained staff to be available on site at all times. The use of gas centrifuges for this purpose is possible. There are two concentrations of oxygen commonly used in hospitals: 96% and 42%. For the 42% oxygen, distributed to every bed, there is a demand maximum of about 1200 litres a minute, which can be provided by a centrifuge consuming 120 kW. To ensure a reliable and uninterrupted supply, it is proposed that three units are installed, with one operating in normal circumstances, the others in automatic standby. No CO₂ handling equipment is required as this is already present in the incoming air and leaves the centrifuge with the oxygen stream.

96% oxygen is only used in operating theatres and intensive care units. Demand varies, but to cope with the maximum demand of about 60 litres per minute, a centrifuge is installed downstream of the 42% units. Again three systems are used to ensure continuity of supply.

The total installation cost is about \$US 1.2 million and occupies about 10 cubic metres. No specialist staff are required as the skills needed are those required for any heating and ventilation system.

- **High altitude oxygen enrichment for mountain climbers:** on Everest and other high mountains, mountain climbers take bottles of oxygen with them. A typical Everest climber carries anything from 5 to 12 kg of oxygen bottles, a considerable burden at that altitude. A centrifuge kit consisting of about 1.0 square metres of flexible solar panels on helmet, back-pack and sleeves, generates about 40w at that altitude. A small gas centrifuge made of aluminium and weighing less than 200 g, would raise the concentration of oxygen in his breathing air to double the local concentration and a temperature of perhaps 20°C. The total weight penalty would be about 600 g.
- **High altitude oxygen enrichment for passenger aircraft:** All passenger aircraft carry a chemical oxygen generator in case of depressurisation of the passenger cabin. There is a substantial weight penalty and huge cost to this and it only provides about 30 minutes of oxygen. If the cabin air were to be supplied through a gas centrifuge, the passengers and crew could receive air throughout the flight at double the external oxygen concentration and at a comfortable pressure and temperature, (0.9 bar and 20°C). Assuming a dual redundant system (for reliability), the equipment weight for a wide-bodied jet, (500 passengers), would be about 120 kg, consuming about 40 kW of electrical power and would occupy about 1.2 cubic metres. For a military or cargo aircraft with up to 10 crew, the equipment would be 0.2 cu m, 6 kg and about 1 kW of power.
- **Oxygen for welding and cutting:** A gas centrifuge can be used for separating oxygen from air, which saves the need for oxygen bottles and the high insurance cost of having stored oxygen in a building. A system for a single welder would require a 3-stage separation with intercoolers and would cost not much more than the price of the first oxygen bottle, (i.e. including the bottle deposit). The daily electricity cost for an average welder's usage would be

around \$US 40. For larger workshops with several welders working, a piped system could be used from a single centrifuge installation.

- **Inert gas blanketing of flammable liquid storage:** Oxygen can be removed from air using a gas centrifuge and the remaining gases do not support combustion. These inert gases can be used for making the storage of flammable liquids safer by filling the vapour space of storage vessels with inert gas.
- **Separating CO₂ from oxygen for carbon sequestration:** see the document: “Carbon Capture and Sequestration” by the same author for more details.
- **Concentrating Oxygen from air to improve internal combustion engine efficiency:** see the document: “Internal Combustion Engine Water Injection” by the same author for more details.

In general, gas centrifuge separation is more efficient if the gas at inlet is at a high pressure and low temperature, i.e. the greatest gas density that can be economically achieved. Thus, for multi-stage separations, the use of intercoolers will significantly improve efficiency.

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