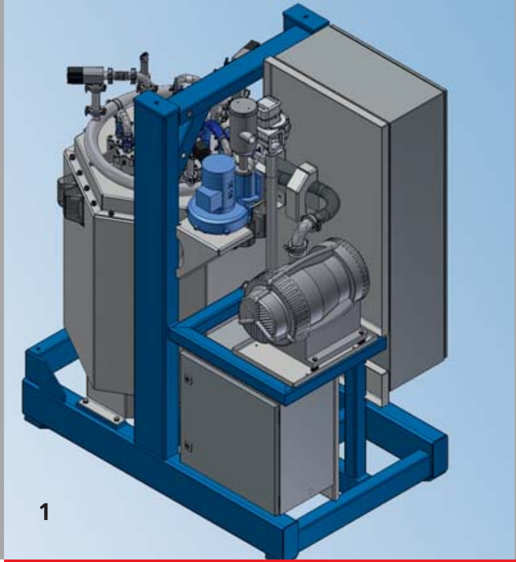


ENERGY DEMAND OF OXYGEN MEMBRANE PLANTS

Dr. Ralf Kriegel

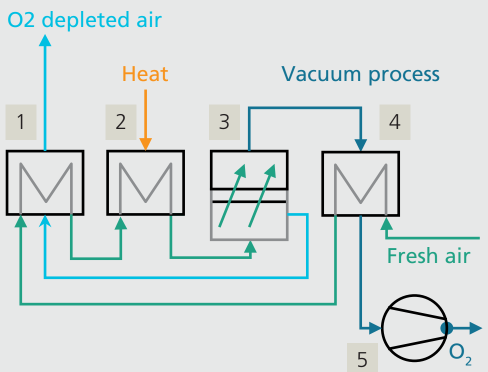
The production of pure oxygen (O_2) currently amounts to appr. 120 billion m^3 STP (standard pressure and temperature) per year at a growth rate of 5.5 % per year. Main consumers are steel and chemical industry (ethylene oxide, partial oxidation etc.). O_2 is locally used for sewage treatment plants, hospitals, for welding and flame cutting, fish breeding etc. Fruthermore, O_2 has a huge application potential for biomass gasification, for efficiency improvement in combustion processes and combustion engines as well as for oxyfuel processes. However, a reduction of the production costs is necessary for these applications.

Today, industrial O_2 production is carried out in cryogenic ASUs (air separation unit) using the so called Linde® process. A minimal energy demand of 0.36 $kWh_{el.}/m^3$ STP O_2 is possible for energetically optimized ASUs at high O_2 throughput. Plants with a production capacity below 1000 m^3 STP O_2/h are not built, as PSA and VPSA plants (pressure swing adsorption, VPSA – vacuum PSA) are more competitive at smaller production rates. Small PSA plants need approx. 0.9 $kWh_{el.}/m^3$ STP O_2 reaching a maximal O_2 content of approx. 95 vol% O_2. A decentralized O_2 production using PSA plants is not profitable for many potential applications for small and medium oxygen demand, since energy costs dominate the O_2 price. O_2 supply using gas flasks or liquid O_2 tanks is usually still more expensive.

An alternative process for production of pure O_2 is based on gas separation using mixed conducting ceramic membranes (MIEC – mixed ionic electronic conductor). The material, which is in fact gas-tight, transports O_2 as oxide ions and electronic charge carriers (electrons or holes) at sufficiently high temperature. Since the end of the 1980s, a variety of ceramic materials was investigated regarding their O_2 permeation and other relevant material properties. Promising materials like BSCF ($Ba_{0,5}Sr_{0,5}Co_{0,8}Fe_{0,2}O_{3-\delta}$) were used for first O_2 generators at Fraunhofer IKTS as shown in Figures 1 to 3.

The energy demand of O_2 membrane plants depends primarily on the process route. At Fraunhofer IKTS, the vacuum operation route depicted schematically in Figure 4 is being developed. The alternative overpressure process needs the compression of the total air amount, but the ratio of air throughput to O_2 flux is typically ≈ 10:1. Therefore, an efficient operation needs a recovery of the compression energy. However, this is not necessary for the vacuum process, since only the O_2 amount has to be compressed. In addition to the electrical energy needed for compression, thermal energy for air heating and O_2 cooling is required. As depicted in Figure 4, the process heat should be recovered as much as possible using heat exchangers so that only the heat losses have to be compensated.

Compression energy is determined by the specific energy demand of the vacuum pump (≈ 0.18 kWh/m^3) and increases with decreasing vacuum pressure. The thermal energy demand depends on the degree of heat recovery of the heat exchangers and on the air throughput. Oxygen recovery, an auxiliary value representing the oxygen share separated from the feed air, makes it possible to normalize the energy demand on the O_2 volume produced and to calculate the maximal vacuum pressure applicable for the process. These values



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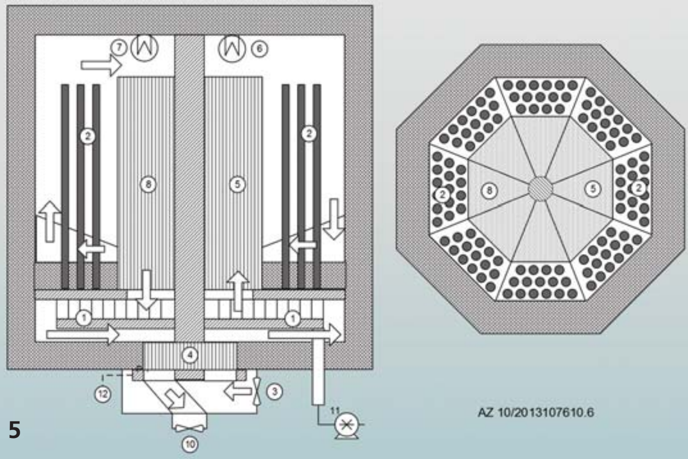

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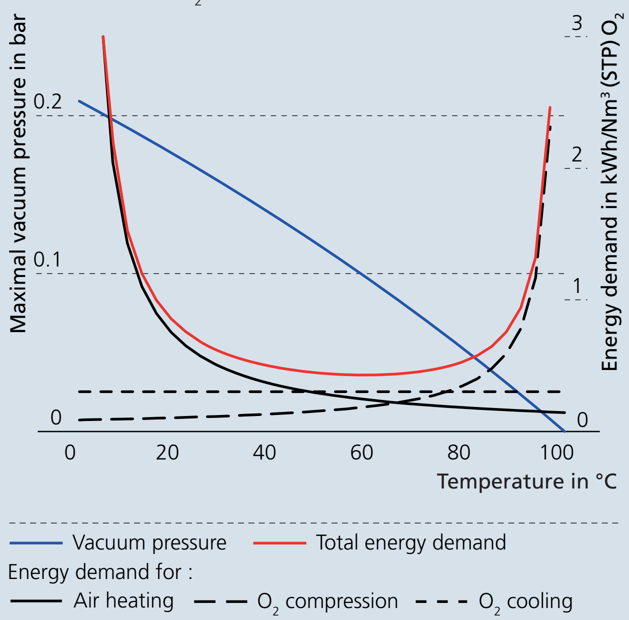
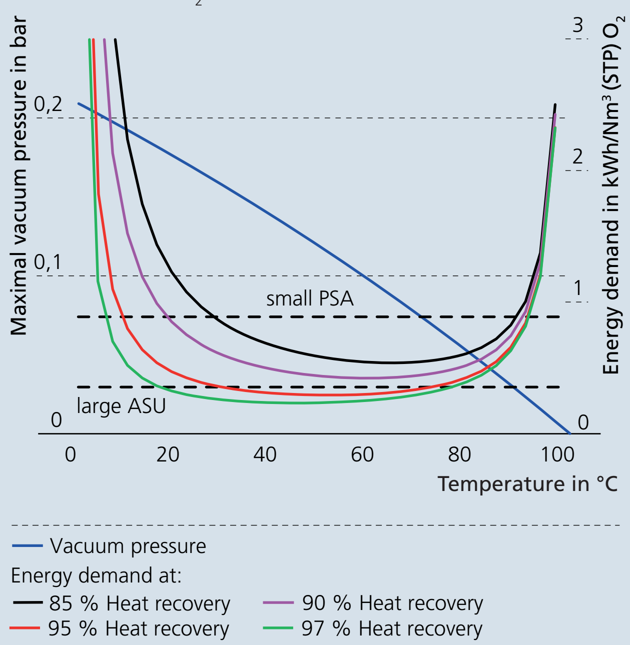
are shown as a function of O_2 recovery in the diagram on the left. The thermal energy demand was calculated for balancing the thermal losses at a heat recovery of 90 %.

significantly using such plants, especially for small and medium O_2 production rates.

Vacuum pressure and energy demand for O_2 membrane plant (90 % heat recovery)
Vacuum process using BSCF tubular membranes at 850 °C, cross flow of air/O_2



Energy demand and vacuum pressure depending on oxygen recovery and heat recovery
Vacuum process using BSCF tubular membranes at 850 °C, cross flow of air/O_2



Obviously, there is a broad minimum of total energy demand at medium O_2 recovery. In contrast to previous work, the energy demand does not depend on the O_2 permeation performance and, thus, not on the kind of material. In addition, the diagram on the right shows that the total energy demand depends essentially on the heat recovery of the heat exchangers. The membrane plant needs less energy than a cryogenic ASU if a heat exchanger with more than 92 % heat recovery is used. RTO plants (regenerative thermal oxidizer) with a heat recovery up to 98 % are state of the art. Therefore, a concept for an energy efficient O_2 generator a shown in Figures 5 and 6 was developed and patented. Compared to the state of the art, it should be possible to decrease the O_2 production costs

1 *CAD model of O_2 generator.*
2 *Membrane segment.*
3 *Prototype for 2kg O_2/h.*
4 *Scheme of vacuum process: 1) air/air heat exchanger, 2) air post heater, 3) membrane module, 4) O_2 cooler, 5) vacuum pump.*
5 *O_2 generator with regenerative heat exchangers.*

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