World Academy of Science, Engineering and Technology
International Journal of Chemical and Materials Engineering
Vol:11, No:05, 2017

H2/He and H2O/He Separation Experiments with Zeolite Membranes for Nuclear Fusion Applications

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Abstract : In future nuclear fusion reactors, tritium self-sufficiency will be ensured by tritium (3H) production via reactions between the fusion neutrons and lithium. To favor tritium breeding, a neutron multiplier must also be used. Both tritium breeder and neutron multiplier will be placed in the so-called Breeding Blanket (BB). For the European Helium-Cooled Pebble Bed (HCPB) BB concept, the tritium production and neutron multiplication will be ensured by neutron bombardment of Li4SiO4 and Be pebbles, respectively. The produced tritium is extracted from the pebbles by purging them with large flows of He (~ 104 Nm3h-1), doped with small amounts of H2 (~ 0.1 vol%) to promote tritium extraction via isotopic exchange (producing HT). Due to the presence of oxygen in the pebbles, production of tritiated water is unavoidable. Therefore, the purging gas downstream of the BB will be composed by Q2/Q2O/He (Q = 1H, 2H, 3H), with Q2/Q2O down to ppm levels, which must be further processed for tritium recovery. A two-stage continuous approach, where zeolite membranes (ZMs) are followed by a catalytic membrane reactor (CMR), has been recently proposed to fulfil this task. The tritium recovery from Q2/Q2O/He is ensured by the CMR, that requires a reduction of the gas flow coming from the BB and a pre-concentration of Q2 and Q2O to be efficient. For this reason, and to keep this stage with reasonable dimensions, ZMs are required upfront to reduce as much as possible the He flows and concentrate the Q2/Q2O species. Therefore, experimental activities have been carried out at the Tritium Laboratory Karlsruhe (TLK) to test the separation performances of different zeolite membranes for H2/H2O/He. First experiments have been performed with binary mixtures of H2/He and H2O/He with commercial MFI-ZSM5 and NaA zeolite-type membranes. Only the MFI-ZSM5 demonstrated selectivity towards H2, with a separation factor around 1.5, and H2 permeances around 0.72 µmolm-2s-1Pa-1, rather independent for feed concentrations in the range 0.1 vol%-10 vol% H2/He. The experiments with H2O/He have demonstrated that the separation factor towards H2O is highly dependent on the feed concentration and temperature. For instance, at 0.2 vol% H2O/He the separation factor with NaA is below 2 and around 1000 at 5 vol% H2O/He, at 30°C. Overall, both membranes demonstrated complementary results at equivalent temperatures. In fact, at low feed concentrations (≤ 1 vol% H2O/He) MFI-ZSM5 separates better than NaA, whereas the latter has higher separation factors for higher inlet water content (≥ 5 vol% H2O/He). In this contribution, the results obtained with both MFI-ZSM5 and NaA membranes for H2/He and H2O/H2 mixtures at different concentrations and temperatures are compared and discussed.

Keywords : nuclear fusion, gas separation, tritium processes, zeolite membranes
Conference Title : ICIMA 2017 : International Conference on Inorganic Membranes and Applications
Conference Location : Barcelona, Spain
Conference Dates : May 26-27, 2017