EXPERIMENTAL AND NUMERICAL INVESTIGATION OF VACUUM GAS FLOWS IN FUSION VACUUM SYSTEMS

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Fusion devices typically feature very complex vacuum systems. A good example is the ITER divertor pumping system, which maintains the vacuum conditions inside the plasma chamber by pumping out the exhaust gas and provides a controlled neutral pressure in the divertor. The achievable net pumping speed and effective vacuum conductance of such a system is of major importance and therefore a thorough and complete study of the flow conditions is mandatory, in order to provide a fully optimized system.

Each vacuum system of the complexity typically found in nuclear fusion devices can be represented by a node network of various channels with different lengths and cross sections. The flow in such channels may vary from the free molecular regime, through the transition until the hydrodynamic limit. The basic parameter which defines the flow regime is the Knudsen number (*Kn*), which is the ratio of the mean free path over a characteristic length of the channel. For such a network representation of a vacuum system, the predicted quality of the performance is directly given by the quality with which the channel flow can be described. In the last decade, excellent progress has been made in modeling fully developed flows in long channels. However, a typical fusion vacuum system comprises mainly shorter channels in which the flow is characterized as developing and end effects may not be ignored.

The availability of any experimental and numerical results in order to validate the modeling is very limited. Hence, to provide a thorough basis for channel flow prediction, a parametric programme has been launched at Karlsruhe Institute of Technology focusing on the experimental and numerical investigation of gas flows through tubes at variable finite length. The flow rate and associated pressure difference measurements have been conducted in the dedicated TRANSFLOW (Transitional Flow Range Experiments) test facility. The flow through such tubes was simulated using the Direct Simulation Monte Carlo method (DSMC) which models gas flows by simulation of molecules and their interaction with other molecules. It is the first time that a dedicated parametric vacuum flow test program has been performed which allows to benchmark modeling and experiments in a unique way.

This paper will start with a general introduction in the current state-of-the-art of vacuum flow modeling. It then presents the computed and measured quantities of the mass flow rate and the conductance of various short circular tubes in the whole range of the Knudsen number. The results are compared with the free molecular and hydrodynamic limit solutions to illustrate the importance to have a good description over the full range of the *Kn* number. Finally, examples are given how the design of the ITER vacuum systems could be improved by these new results. It is also demonstrated for the first time that DSMC is a vital approach to be used for complex vacuum systems.

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