Vacuum Technology
Room: 14 - Session VT-TuM

Pumping, Gas Dynamics and Modeling
Moderator: L. Wang, Los Alamos National Laboratory

8:00am **VT-TuM1 Gas Dynamics Modelling for Particle Accelerators**, ***O.B. Malyshev***, STFC Daresbury Laboratory, UK **INVITED**

Design of accelerator vacuum chamber requires an input from different scientific disciplines such as surface science, material science, gas dynamics, particle beam dynamics, and many others. Although vacuum scientists work on the boundary field between these disciplines the gas dynamics is one that allows jointing all these to the vacuum science for particle accelerators.

The particle accelerator requirement to vacuum defined by beam gas interactions that should be negligible comparing to the other phenomena and effects limiting the quality of the beam, so these requirements are in free molecular regimes: HV, UHV or even XHV. At such low pressures the main source of gas in the vacuum chamber is molecular desorption from materials used for vacuum chamber and in-vacuum components.

The outgassing rates depends on material, its cleaning procedure, treatments (polishing, etching, coatings, bakeout, etc.), time in vacuum, irradiation or bombardment by particles (photons, electrons, ions, etc.) and accumulated irradiation dose. Therefore, the outgassing rates vary in very wide range.

The gas dynamic is used to design the research facilities to accurately measure and to study outgassing rates at different conditions, then it used for data analysis. By applying these data to the accelerator vacuum design one have to consider that outgassing is often non-uniform and changes with time with different functions. Full 3D modelling is possible with TPMC codes, however, it is time consuming work and not ideal for pumping and design optimization, so it is used for components or for finalized design. Meanwhile, during the optimization study the most time-efficient way is using 1D diffusion model where all parameters are defined as a function of longitudinal coordinate (along the beam path).

The examples accelerator vacuum chamber designer should also consider such effects as thermal outgassing, photon, electron and ion stimulated desorption, beam induced electron multipacting and ion induced pressure instability.

8:40am **VT-TuM3 Transient Flow of Rarefied Gas through a Short Tube**, ***F. Sharipov***, Federal University of Parana, Brazil

Steady flows of rarefied gases through orifices, slits, short tubes, and channels are well studied. In spite of the high practical interests to the transient flows of rarefied gases, the problem of short tube flow has not been studied from this viewpoint. The aim of the present work is to study transient rarefied gas flow through a short tube on the basis of the direct simulation Monte Carlo method. The mass flow rate and flow field are calculated as a function of the time in the transitional and hydrodynamic regimes with respect to the gas rarefaction. Two values of the pressure ratio, i.e., 0.1 and 0.5, and two values of the aspect ratio, i.e. 1 and 5, are considered. A characteristic time equal to that needed to cross the tube radius with the most probable molecular speed is introduced. The typical time to establish the stationary flow is calculated. The flow field past the tube reaches the steady state during the same time in the transitional regime and it takes a longer time in the hydrodynamic regime.

9:00am **VT-TuM4 Experimental Results and Direct Simulation Monte Carlo Modelling of a High-Performance Large-Scale Cryopump**, ***S. Varoutis****, Chr. Day, X. Luo, H. Haas,* Karlsruhe Institute of Technology, Germany, *F. Sharipov*, Federal University of Parana, Brazil

The main duty of the vacuum pumping system of fusion devices is to pump out the fusion exhaust gas. Due to the fact that very high throughputs have to be coped with, large pumping speeds are required. This is typically provided by cryogenic pumping, supplied with cryogen medium at 4 K and 80 K. The concept for the cryosorption vacuum system of ITER, the next generation fusion experiment currently being built in Europe, has been developed at the Karlsruhe Institute of Technology (KIT). As a result to the large gas flows, which are unusually high for a cryopump, the pumps are operated in the transitional regime. A further development and improvement of the system requires a corresponding numerical modelling of the gas flow inside the pump housing and near the cryopanel section.

The aim of the present work consists of the computational investigation of a 2D axisymmetric complex geometry of a model cryopump by the Direct Simulation Monte Carlo (DSMC) method. Since the flow close to the cryopanels can be assumed free molecular due to low pressure levels, the capture coefficient of the cryopanels can be estimated by applying the Test Particle Monte Carlo method. Then, this information can be used as input data to the corresponding DSMC simulations. The macroscopic parameters of practical interest as the bulk velocity, the pressure and the temperature in the whole flow field, have been calculated as a function of the incoming gas throughput and of the pump inlet valve position. Furthermore, the present numerical results have been thoroughly compared with corresponding experimental results obtained at KIT for the case of an ITER model cryopump.

The importance of these calculations is based on the fact that they can provide information for quantities which are not accessible for measurement during pump operation and that they can be used for prediction of the pump behavior. This paper describes a post-operational investigation of a built pump and is thought as a proof-of-principle test to include this approach in the design process of a future pump development.

9:20am **VT-TuM5 Development of a PhD-level course in Vacuum Science and Technology**, ***P. Eklund***, Linköping University, Sweden

There are many available courses in Vacuum Technology, including those offered by the AVS. They typically have an engineering-oriented approach aimed at the practical user of vacuum system. When I started teaching a PhD-level course in Vacuum Science and Technology, I was faced with a different – pedagogical and scientific – challenge. The attendees are PhD students who work, or will work, with vacuum in their PhD research and future careers, but most are not vacuum practitioners per se. Neither is the teacher. In such a course, the students need to achieve an in-depth understanding of the science of vacuum and how it can ultimately affect their research. Here, available textbooks on the topic of "Vacuum Technology" are not at PhD level – they tend to be "engineering user's guides" or similar.

In achieving this, a clear definition of the objectives is essential. In a PhD course, the aim is to give students a thorough understanding of how vacuum components and vacuum systems work, and the fundamental physics and chemistry behind them – emphasizing the latter part, in contrast to a more engineering-oriented course. Among others, this means that students should understand and be able to define the vacuum concepts (ideal, rough, low, high, ultrahigh, etc…), understand and be able to explain in own words the kinetic theory of gases, the principles for gas flow at low pressures, and physico-chemical phenomena in vacuum (evaporation, condensation, solubility, permeation, adsorption, absorption, desorption). They should also be able to apply the knowledge and understanding listed above to practically and theoretically relevant situations in vacuum science and technology, communicate this understanding orally and in writing, and be able to critically reflect on scientific articles relevant to vacuum science and technology.

Here, I will discuss my pedagogical and scientific approach to such a course and how to align the course activities for the PhD students to reach the above goals. I will also discuss the examination format, and why I have found it to be particularly suitable for this type of course. It is a combination of continuous examination in connection with the lectures and home examination, which also contains an assignment connecting the course content to the laboratory work of the students. The continuous examination is not mandatory, but gives credits for the home examination. The mandatory parts of the course are examined through peer review and an ending seminar.

10:40am **VT-TuM9 A Comparison between Numerical and Analytical Models of Turbomolecular Drag Pump's Stages**, ***I.F. Cozza***, Agilent Technologies, Italy, *M. Rose,* PI-DSMC, Germany, *R. Arpa, H. Telib*, Optimad Engineering S.R.L., Italy

The design and optimization of vacuum pumps requires a deep knowledge of the internal gas-dynamics, and a large trial-and-error process to fix the design parameters. A common practice in the TMDP's industry is to perform an experimental design of new pumps, by testing the global performances of prototypes. This approach has two drawbacks: it doesn't give indications on the details of the internal fluid dynamics of the problem, and the design and realization of prototypes has significant costs and requires long times, that could affect the time-to-market of new products.

In this framework, an accurate and efficient numerical analysis tool could meet these needs. This tool should model the tridimensional, local flow features, such as pump leakage and development of the rarefied gas flow along the curved channels, and take into account the inertial forces.

In this work, two approaches will be presented: a full 3D Direct Simulation Monte Carlo numerical analysis of the Siegbahn drag stages, and a semianalytical approach based on the numerical solution of the Linearized Boltzmann Equations.

The DSMC simulations have been performed using a DSMC software package called PI-DSMC. The sampling and collision cells were generated automatically from a triangular mesh describing the shape of the solid body. The reflection of molecules by the walls was investigated to choose the proper particle/surface interaction model. The temperature of the rotor, the stator and the gas at the inlet have a fixed value. The effect of rotor temperature on the performances of the stage has been investigated. The collisions between nitrogen and hydrogen molecules were modeled using the variable hard sphere model with the common parameters.

The semi-analytic model is developed for steady flows in spiral molecular drag stages, and it is based on the solution of the Boltzmann Equation (BE) with a BGK closure. The order of the original problem is reduced in the physical space to 2D, by introducing assumption of locally known flow development of the distribution function along the spiral channel. Thus, 2D-BE calculations of the flow rates and stresses will be performed in a finite number of sections, suitably positioned along the spiral channel, from the outlet to the inlet, in order to recover the integral performances of the pump. The original BGK equation is linearized in the most significant parameters (rotational speed and pressure gradients), and solved in the reference cross-section, by means of a DVM scheme. Maxwell diffuse boundary conditions and impermeability are provided at walls. The local values of pressure and torque are obtained consistently by enforcing the mass flow.

11:00am **VT-TuM10 Improved Modelling and Measurement of the Rotor Temperature of Turbo-Molecular Pumps in Magnetic Fields**, *A. Jansen,* KIT, IEKP, Germany*, N. Kernert,* KIT, IKP, Germany*,* ***J. Wolf***, KIT, IEKP, Germany

When designing a vacuum system with turbo-molecular pumps (TMP) in an external magnetic field, one needs to know the influence of eddy currents on the rotor temperature to ensure safe operating conditions. The KATRIN neutrino experiment will operate about 20 TMPs in the vicinity of super-conducting magnets, pumping out tritium gas from the electron beam-line of the experiment. In a dedicated test setup with Helmholtz coils systematic studies have been conducted, investigating the rotor temperature and stability for TMPs with magnetic and ceramic bearings at full speed. The rotor temperature was monitored with an infra-red pyrometer as a function of gas load, magnetic field strength and direction of the field. For interpretation of the data and predictions for different operating conditions an empirical model has been developed, describing the rotor temperature versus time as a function of gas flow and magnetic field, using 5 pump-specific parameters, which characterize heating effects of eddy currents and gas friction as well as cooling by radiation loss and convection. Since this approach assumes a homogeneous field, we extended the model, replacing the field and friction terms by the motor current of the pump, which compensates the retarding effects of eddy currents and gas flow. This new model can now be used for inhomogeneous magnetic fields.

KATRIN is supported by the German BMBF project 05A11VK3, the Helmholtz Alliance Astroparticle Physics and HGF.

11:20am **VT-TuM11 Test of Temperature-Dependent NEG Activation and Stability of Gold-Plating in the KATRIN Experiment**, ***W. Gil***, *L. Bornschein, J. Wolf*, Karlsruhe Institute of Technology, Germany

The Karlsruhe Tritium Neutrino (KATRIN) experiment will measure the neutrino mass with an unprecedented sensitivity of 0.2 eV/c^2 by investigating β-electrons from tritium decay. While the electrons are magnetically guided through a beam tube to the spectrometer by superconducting solenoids, the tritium flow rate from the source has to be reduced by at least 14 orders of magnitude by differential pumping and cryo-sorption. The last stage of the pumping section is the 7 m long cryogenic pumping section (CPS), using a pre-condensed argon-frost layer to capture tritium molecules. For reducing the adsorption of tritium on the wall of the beam line and for more efficient regeneration of the cryo-pump its inner surface has been gold-plated, using a standard industrial galvanic process. Non-evaporable getter (NEG) strips (SAES St707) will be installed inside the last meter of the beam tube of the CPS as a fallback system, protecting the spectrometer in case of a failure of the cryogenic system. The standard NEG activation temperature is 450°C for about 60 min, but can be reduced with prolonged activation time. However, the activation temperature in the CPS should be as low as possible with respect to the superconducting solenoids around the beam tube and the stability of the gold-plating. Therefore, a test has been set up, optimizing the activation temperature and time with regard to the NEG's pumping efficiency, the stability of the gold-plating, and the safety of the magnets. This paper presents results of the temperature-dependent NEG activation efficiency and the influence on the gold-plating.

11:40am **VT-TuM12 Improving the Pump Down of UHV Systems by the Additional Pumping Speed Provided by NEG Pumps**, ***F. Siviero***, *A. Bonucci, A. Conte, L. Caruso, L. Viale, P. Manini*, SAES Getters, Italy

The study of pump down processes is one of the basic topics of vacuum technology since its early days. Its relevance from the practical point of view is very high in a variety of systems including large machines like accelerators, surface science equipment, scanning/transmission electron microscopes and many other analytical systems and sealed off devices. At present the bake-out of these systems may require days to weeks, resulting in a considerable use of time and energy. Here we report on a series of experiments aimed at investigating how an increase of the total pumping speed during the pump down influences the behaviour of the main gases of interest, i.e. water and hydrogen. Several pumping configurations are compared, including turbo molecular pumps, large sputter ion pumps (SIP), Non Evaporable Getter (NEG) and a new SIP/NEG combination pump called NEXTorr® [1]. The most relevant desorption models and their predictions for the pump down processes are expressed in an explicit form and compared with the experiments.The results of the study confirm that water desorption can largely benefit from an increase of the available pumping speed, due to the reversible nature of its adsorption kinetics. As far as hydrogen is concerned, a higher pumping speed at the end of the bake provides a lower partial pressure. This translates into the possibility of either reducing the duration of the bake-out process or improving the ultimate achievable vacuum, both issues having practical interest in vacuum systems for research and industrial applications.

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[1] NEXTorr is an International Trademark registered by the "Madrid System" property of SAES Getters S.p.A.

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