Vacuum Technology
Room 201 - Session VT-WeA
Vacuum Gas Dynamics

Moderator: J.L. Provo, Sandia National Laboratories

2:00pm **VT-WeA1 A Test Problem for the Holweck Pump*, J.C. Helmer,*** AVS Fellow

The general principles of molecular drag pumping have been understood since since W. Gaede's work in 1913, but it is curious that approximate models have not existed to explain the operation of the Gaede and Holweck molecular pumps over the range of practical application. The laminar flow model for the one-dimensional Gaede pump is now complete. One would infer that the wide channel, Holweck pump model is a two dimensional generalization of the Gaede model. This generalization has not been achieved, although some specific CFD (computational fluid dynamics) solutions have been published.@footnote 1,2@ Our analytic investigation of the Holweck case shows that there is no solution with a parallel flow field, and that compressibility introduces rotation. An approximate solution at high flow rate has been obtained for wide Holweck channels, which illustrates how these issues are resolved. A major difference between the Gaede and Holweck pumps is in the form of the leakage, which is parallel to the channel in the former, and across the channel in the latter. The problem of leakage-limited operation will be discussed. In practical cases the channel depth is small, and the the solution in this dimension is known as a case of Couette-Poiseuille flow. The Holweck geometry may then be idealized in two-dimensions, as a parallelogram lying in a plane with a drag vector of arbitrary direction. @FootnoteText@ @footnote 1@ K. Nanbu & S. Igarashi, "Three-dimensional low-density flows in the spiral grooves of a turbo-molecular pump", Computers Fluids, 21(2), pp221-228, 1992 @footnote 2@ H-P Cheng, R-Y. Jou, F-Z. Chen, Y-W. Chang, "Flow investigation of Siegbahn vacuum pump by CFD methodology", Vacuum 53, pp 227-231, 1999. "Three-dimensional flow analysis of spiral-grooved turbo booster pump in slip and continuum flow", J. Vac. Sci.. Technol. A. 18(2), 543-551, Mar/Apr 2000 .

2:20pm **VT-WeA2 Significance of Bulk Flow Velocity for Turbopump Design*, M.H. Hablanian,*** Varian Inc.*; R. Cerruti,* Varian Inc., Italy

Initially, studies of many aspects of the pumping mechanism of turbomolecular pumps were approached from the high-vacuum side rather than from atmospheric pressure. Therefore, some significant parameters, well known from the discipline of fluid mechanics, have been neglected. One such parameter is bulk fluid stream velocity, which can be a significant engineering consideration for creating an optimized design. Due to the enormous densification ratios achieved in modern turbomolecular pumps, especially of the hybrid or compound variety, the flow velocity at the exit end of the pump is often near zero. This induces a stagnant condition, particularly when backing pumps are very small, allowing, for example, increased back-diffusion of light gases (hydrogen and helium). In addition, the presence of the nearly stagnant gas produces adverse effects on power consumption, which is very significant in newer hybrid turbopumps that can reach 100 mbar exhaust pressure. Attempts to create a single algorithm for a design using one type of impeller do not produce a scheme for a viable pump. The selection of appropriate different types of impellers for the entire pump structure seems to be the best method for optimizing overall performance.

2:40pm **VT-WeA3 A Quantitative Test of Slip-Flow Theory using the Spinning Rotor Gauge*, J.P. Looney,*** National Institute of Standards and Technology*; J. Setina,* Institute of Metals, Slovenia

Although a theory for gas slip flow has been in existence from the time of James Maxwell, no quantitative test of slip flow theory has been undertaken. Typically the slip flow theory of Maxwell is used to extract momentum accommodation coefficients from gas flow data. This is one method for 'measurement' of gas accommodation coefficients. However, this assumes that slip-flow theory is correct and that there is indeed proportionality between the magnitude of the momentum accommodation at the surface and the gas 'slip'. No test of this conjecture has been reported to the author's knowledge. In this talk I will report on the simultaneous and independent measurement of gas momentum accommodation and gas slip coefficients for a group of six spinning chrome steel spheres (spinning rotor gauges) and for four gases (H2, He, N2, and Ar). The results of these experiments clearly demonstrate the proportionality between the gas slip and momentum accommodation. A detailed comparison of these measurments with slip-flow theory will be made.

3:00pm **VT-WeA4 Power Dissipation in Gaede Stages of Turbomolecular-drag Pumps in Viscous High-pressure Regime*, R. Cerruti,*** *S. Giors, J.C. Helmer, A. Netti,* Varian Vacuum Technologies, Italy

Drag Gaede stages are used for extending the operating range of turbomolecular pumps to higher pressures. A practical limit to high pressure operation is set by the power dissipated by these stages, which comes mainly from the friction inside the gas boundary layer. The power has then a direct impact on the rotor temperature and the electrical consumption of the motor. In a previous paper we presented a transitional power consumption model, which allowed to predict the power consumption of a given drag stage up to about 10 mbar, correctly capturing the effect of the transition from molecular to viscous regime, but failing above a critical pressure. @footnote 1@ The present work is aimed to extend the model to higher pressures ranges, where turbulence and other instabilities can not be neglected: above a certain pressure the rotor and stator boundary layers get affected by the centrifugal force field, their structure becomes pressure dependent and eventually turbulent. The simple viscous model is extended in order to incorporate these effects through the definition of an "eddy viscosity", which is a pressure dependent parameter introduced by Prandtl turbulent mixing length theory. The model results, showing the power dissipation growing with pressure in the high pressure regime, are compared with experimental power consumption measurement up to 100 mbar, on single drag stages with different dimensions, different rotational speeds and different gases. The model is aimed to be used in the optimization of the multistage Gaede pumps at very high pressure. @FootnoteText@ @footnote 1@ R. Cerruti, M. Spagnol, J. C. Helmer, "Power dissipation in turbomolecular pumps at high pressure", J. Vac. Sci. Technol. A 17(5), 3096-3102, Sept/Oct 1999.

3:20pm **VT-WeA5 Modelling Micro-Channel Flows with DSMC and a Particle Continuum Method*, T.J. Bartel,*** *M.A. Gallis,* Sandia National Laboratories

Advances in micromachining technology have enabled fabrication of MEMS devices. Even at atmospheric pressures, flow through these devices can range from rarefied to transitional due to the length scale and the mean free path. The Direct Simulation Monte Carlo (DSMC) technique, a direct particle based simulation of the Boltzmann equation, is an appropriate and accurate simulation tool for these devices; however, the computational expense of determining subsonic flows is very large. The major issue is one of statistical resolution: the computational particle velocities are at their thermal speeds while the mean gas velocity is at M ~ 0.01. We will present a overview of the issues of using DSMC and show results for micro-channel flows obtained with our massively parallel version. We have developed a new strategy which accelerates convergence to the steady-state. In this method, we have define the computational particle as a mass per time quantity (rho*V*A). Now the computational phase space is not stochastic, but is deterministic based on the resonance time of each computational particle in a cell. This formulation greatly reduces the statistical noise and computational expense experienced in pure particle simulations. We use a Langevin formulation for the viscous and pressure forces. We use the DSMC method to obtain a spatial varying model for the transport properties (similar to a turbulence model) to extend the validity of the continuum method to non-continuum flows. We will compare results from this new method with DSMC and discuss future work. This strategy is more robust and computationally efficient than split domain methods: DSMC is used for a portion of the domain and a continuum solver for the remainder.

3:40pm **VT-WeA6 Flow of Moderately Rarefied Gases Through Short Circular Tubes*, S.A. Tison,*** Millipore Corporation

The conductance of vacuum geometries is very important for design of vacuum systems. In particular the conductance of cylinders has been exhaustively studied because of its predominant use in vacuum components. While the conductance is well established for these geometries under high rarefied conditions@footnote 1@ the conductance in the transition between rarefied flow and continuum flow is less understood. In particular, phenomena such as the Knudsen minimum identified in long tubes almost a century ago is still an active area for theoretical and experimental study. While long tubes are known to have mimimums in conductance, sometimes less than 20% of the free molecular value, sharp edged orifices do not exhibit this pattern. It is logical to assume that there must exist a relatively short tube which exhibits traits intermediate to long tubes and sharp edged orifices. A series of conductances with length to diameter ratios (L/D) from 100 to 2 have been experimentally studied and compared to transition flow models. Data includes Knudsen numbers from 0.01 to 10 for a variety of noncondensable gases. Results indicate reasonable agreement with models@footnote 2@ and show the disappearance of the Knudsen minimum for short tubes (L/D)=2. @FootnoteText@ @footnote 1@ Clausing, P., Ann. Physik (5) 12, 961 (1932) @footnote 2@ Arkillic, E., and Breuer, K.S., AIAA paper 93-3270, (1993).

4:00pm **VT-WeA7 A Method for Calculation of Gas Flow in the Whole Pressure Regime Through Ducts of Any Length***, **R.G. Livesey**,* BOC Edwards, UK

Useful approaches to the calculation of gas flows in the molecular-continuum transition region have been presented by a number of authors. These have covered particular conditions such as long ducts or orifices with a large pressure difference for example. There is, however, no generally applicable method which enables calculation under all conditions. A particular area of difficulty is the isentropic-molecular transition. The paper presents a simple model which enables calculation for all conditions of long or short ducts and large or small pressure differences. Results are found to agree well with published data.

4:20pm **VT-WeA8 Conic Peak/Dimple Roughness Model for Explaining the Reduction of Flow Rate through Passages with Rough Walls***, **T. Sawada**, W. Sugiyama, M. Yabuki,* Akita University, Japan

Passages with rough walls allow for smaller conductance for rarefied gas flow than passages with smooth walls. For the purpose of clarifying the effects of surface roughness on rarefied gas flow through passages, surface roughness is modeled by circular-conical peaks and dimples with the same base radius. Cones (peaks and dimples) are located in a statistical manner. Cone height and depth are also determined in a statistical manner from the measured angle distributions of actual surface roughness. The following are assumed in the model: (1). Cones are optional in contact with one another. (2). Cones higher than 1.2r(r: radius of base circle) are cut at the height of 1.2r and the upper parts are removed, but the top flat faces are not open for molecules to fly into. (3) The distance traveled by molecules between collisions with cone surfaces on the same macroscopic surface does not affect the macroscopic transfer of molecules. (4) Molecules do not collide with one another during their travel on a macroscopic surface. (5) Molecules are regarded as hard spheres and they scatter on cone surfaces according to cosine law. (6) The height of cone roughness is much smaller than the height of the passage. The calculated results predict well the measured reduction of free molecule and near free molecule flow conductance through channels composed of two flat plates.

4:40pm **VT-WeA9 Free Jets in Vacuum Technologies***, **A.K. Rebrov**,* Institute of Thermophysics, Russia **INVITED**

The knowledge on gas expansion into vacuum or a low density background was of a paramount importance for the development of vacuum technologies throughout their history. The variety of gas sources, of flow parameters in sources and parameters of background gas state sets the problem of jet flows as vast for the analysis. But the classification of flows is possible. The first step is division of gas expansion into vacuum and in a background. The expansion into vacuum can be considered separately for different types of sources (orifices, capillaries, flat slots, Laval nozzles) under different channel Knudsen numbers. The discharge coefficients, the plume of molecular flow, the structure of the free jet, relaxation processes in the jet, the gas mixture issue represent the main interest. By the expansion of gases into a background from some source the structure of jets in the regimes from free molecular to turbulent flow is defined by the source and state of the background gas. The available results of investigations allow to determine the location of different zones and character of flow, including the evaluation of relaxation of the internal energy and condensation effects. New problems of vacuum technologies are in need of determination of the flow parameter distribution with high accuracy. New computational methods can be used for this purpose. The direct simulation Monte Carlo (DSMC) method became a powerful instrument for study of jet flows. It has depreciated attempts to extend the continuum approach on cases of flows with effects of rarefaction. The hybrid DSMC / fluid methods raise the role of computational simulation, taking into account difficulties of experiments. New achievements in theory can provide not only optimization of technology but extraction of physical knowledge by industrial testing as well.

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