Vacuum Technology
Room 205 ABCD W - Session VT1-MoA

Vacuum for Fusion and Large Systems I

Moderators: Sol Omolayo, Lawrence Berkeley National Laboratory, **Charles Smith**, Oak Ridge Natinal Laboratory

1:30pm **VT1-MoA-1 Advanced Roots Pumping Solutions for Demanding Applications in Fusion and Nuclear Research: The New Okta 1500 GM*, Nico Völker,*** Pfeiffer Vacuum GmbH, Germany **INVITED**

Abstract:

Fusion and nuclear research facilities impose stringent requirements on vacuum technology, including high pumping speeds, reliability, and contamination-free operation under extreme conditions. Pfeiffer Vacuum's latest addition to its high-performance Roots pump portfolio, the **Okta 1500 GM**, addresses these challenges with enhanced efficiency and flexibility tailored for scientific and industrial applications.

The Okta 1500 GM combines a robust design with an integrated magnetic coupling, ensuring absolute gas-tightness. This feature eliminates the risk of cross-contamination and significantly reduces maintenance, making the pump ideal for radioactive and toxic media handling.

This presentation will highlight key technical innovations, such as the mechanical seals and advanced thermal management, as well as application examples from recent fusion and nuclear research projects. Special emphasis will be placed on the pump's contribution to operational safety, system uptime, and reduced lifecycle costs in demanding R&D and pilot-scale environments.

2:00pm **VT1-MoA-3 Neutron Resistant Vacuum Systems for Fusion Energy Applications*, J.R. Gaines,*** Kurt J. Lesker Company

Fusion energy, the process that powers the stars, offers unique potential for sustainable, clean electricity without many of the harmful by-products of fission reactors. But nuclear fusion is not without issues, specifically the high-energy neutron fluxes and associated radiation damage threaten the integrity, performance, and longevity of critical components of these complex systems through deformation, swelling, embrittlement, and the loss of mechanical integrity.

The presentation will explore the intersection of fusion energy and vacuum technology with special attention to strategies to mitigate radiation damage in vacuum systems. Topis reviewed include specialized vacuum system metal alloys engineered for improved radiation resistance, modular system designs, shielding approaches using multi-layered thin films and neutron reflectors.

Attendees may gain insights into material science, design considerations and innovative, multi-disciplinary, approaches that will shape the future of commercial fusion energy technology.

2:15pm **VT1-MoA-4 Vacuum Roughing Pump System's Role in ITER's Fuel Cycle*, Jared Tippens,*** Oak Ridge National Laboratory

The ITER Torus Cryopumps (TCPs) are located adjacent to the machine and allow the 1,400 m^3 vacuum vessel to reach the high vacuum pressures needed for operation. They also allow for the high throughput of the hydrogen isotopes via cryopumping. The TCPs themselves have a high surface area and are cooled via supercritical helium at 4 K in order to condense the hydrogen isotopes. The six TCPs are positioned in parallel and will operate in cycles, where they are regenerated at elevated temperatures one at a time after the capacity of each cryopump is filled.

The RPS located at an adjacent building, consists of a series of tritium compatible pumps and supporting equipment to remove the regenerated process gas from the TCPs and deliver them downstream to tritium processing where the helium ash is separated from the hydrogen isotopes (Tokamak Exhaust Processing), and eventually the hydrogen isotopes are separated and prepared again to fuel the fusion reaction.

The RPS used for the ITER fuel cycle consists of a total of 15 tritium compatible scroll pumps and 3 roots pumps. These are evenly divided into 3 different cells, called the Torus Cryopump Regeneration System (TCRS) cells. Each cell consists of 3 pumping stages. The first stage consists of an all-metal roots pump, the second stage of four scroll pumps in parallel, and the third stage a single scroll pump that backs the other four. The process gas regenerated from the TCPs is pumped through the TCRS cells into a buffer tank, where the process gas then flows to Tokamak Exhaust Processing at a controlled rate.

An overview of the RPS and its role in the ITER fuel cycle will be provided, as well as insight to the pumping performance of the system. Additionally, several of the key operational scenarios of the system are outlined, showing the flexibility of this type of pumping arrangement in a complex fusion machine such as ITER.

Note: This work was supported by the U.S. Department of Energy contract DE-AC05-00OR22725. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

The ITER project has the goal to demonstrate the feasibility of fusion and to advance the scientific and engineering understanding of fusion for future commercial reactors. In the reactor, heat is created through the fusion of hydrogen isotopes, primarily Deuterium and Tritium. To maintain the reaction, the fuel needs to be continuously supplied to and removed from the tokamak at a high rate. ITER's Roughing Pump System (RPS) drives this flow of fuel that makes the continuous fusion reaction possible.

2:30pm **VT1-MoA-5 Advanced UHV Sealing Solutions with HELICOFLEX® TEXEAL®*, Ryan Widejko,*** Technetics Group - An Enpro Company **INVITED**

As a leader in high-performance sealing for demanding environments, Technetics Group is consistently pushing the boundaries of Ultra High Vacuum (UHV) sealing technology. This presentation focuses on the development and application of HELICOFLEX® TEXEAL®, a patented texturized technology integrated into metallic seals, designed to lower the required seating load and enhance UHV performance. By applying TEXEAL® technology to its HELICOFLEX® metal seals, Technetics has achieved a significant reduction in clamping load while maintaining superior sealing integrity, even under extreme conditions.The HELICOFLEX® TEXEAL® solution minimizes the contact area without reducing the seal track width, promoting optimal conformity to flange roughness. This approach eliminates the need for softer sealing materials by selecting materials with better thermomechanical properties. Comparative test data indicate that the texturized seal exhibits lower linear loads (lbs/inch) and improved sealing rates compared to non-texturized and traditional seals. Additional benefits include improved reusability, lower sensitivity to surface defects, and minimal requirement for flange redesign, resulting in increased equipment uptime and simplified assembly processes. These innovations render the HELICOFLEX® TEXEAL® ideal for applications in semiconductor manufacturing, accelerator and fusion research, and other areas that demand ultra-high vacuum stability and reliability.This discussion will detail design principles, test methodologies, and performance metrics associated with HELICOFLEX® TEXEAL®, while outlining manufacturing capabilities and real-world applications. The session aims to provide UHV professionals with novel insights into reducing hardware stresses and operational costs, thereby advancing the state-of-the-art in UHV sealing technologies—a critical component in today's increasingly demanding vacuum systems.

3:00pm **VT1-MoA-7 Space Simulator – Thermal-Vacuum Chambers*, Juan Pablo Romero,*** INOVOAL Corp, Argentina **INVITED**

Satellites and systems orbiting the Earth are affected by the extreme conditions of space, where vacuum and sudden thermal amplitude affect materials and hardware systems. To ensure their correct performance, in INOVOAL we are specialists in design and manufacturing Space Simulators, Thermal Vacuum Chamber systems for testing satellites and space components that validate the resistance and functionality of systems under controlled conditions prior to their launch. This equipment allows engineers to identify and correct potential failures, thus maximizing the lifespan and performance of space missions.

Vacuum System: The vacuum system includes Dry Mechanical Pump for the first stage and a turbo-molecular pump for the second stage. Optionally, the equipment is prepared to add a cryogenic pump as a third vacuum stage. Throughout the vacuum system and chamber sections, there are control points to sense the performance and allow the opening and closing of vacuum valves and the start of thermal sequences. Turbo and Cryogenic pumps are directly connected to the chamber through gate valves. Electrically operated right-angle valves are configured to control the approximate vacuum and the counter-vacuum of the turbo (and cryogenic) valves.

Mechanical Sub-System: Most of the SP vessels are based on a horizontal cylindrical design, with a cylinder central body and two semi-elliptical caps, one rear and one front as a door. The design is based on and verified according to ASME Sec. VIII Div. I standards.

Shroud: The Shroud is of the 304L stainless steel pillow plate type. The Shroud is divided into three sections: The main cylinder (located along the central axis of the Simulator's main vessel) and rear cover, the front cover or door, and the cold table.

INTERIOR SURFACE: The interior surface of the Shroud has an Emissivity higher than 0.9. It is internally painted with black polyurethane with thermal and optical characteristics suitable for thermo-vacuum tests. The painting is MAP PU1 or similar with equal or better characteristics. The paint is tested and certified to ensure that it does not out gas in high vacuum and thermal cycles.

EXTERIOR SURFACE: The external side of the Shroud is mirror polished with "Electropolish" or a similar process and has an emissivity rate lower than 0.15. Optional for the interior surface of the chamber: Shot peening with glass bead blasting.

3:30pm **VT1-MoA-9 Alternative Method for Large Vacuum Systems Bake-Out***, **Freek Molkenboer**, Han Veldhuis, Herman Bekman, Andrey Ushakov, Veronique De Rooij, Thom Oosterveen, Michael Dekker, Corne Rijnsent, Willem van Werkhoven, Dirk van Baarle,* TNO Science and Industry, the Netherlands

Thermal bake-out is a well-known and commonly used method for removing contaminants from the inner surface of a vacuum system. However, the economic and practical scalability of this method for very large systems or systems with a high thermal mass poses quite some challenges.

The Einstein Telescope will be the largest vacuum system on Earth and will require the removal of water and hydrocarbons after installation underground. The currently foreseen method is thermal bake-out using Joule heating of the beam tube. The beam-pipes have a diameter of 1 meter, and due to the layout of the Einstein Telescope, a total of 120 kilometers of beam-pipe is needed.

In a dedicated study, TNO will investigate the technical feasibility of using plasma techniques to remove water and hydrocarbons from the inner surface of the beam tube. For this study, a dedicated setup will be designed and built to assess whether plasma-assisted cleaning can achieve the low partial pressure specifications needed for the Einstein Telescope.

During the presentation, we will discuss the considerations and realization of the setup, as well as the first validation experiments.

Vacuum Technology
Room 205 ABCD W - Session VT2-MoA
Vacuum for Fusion and Large Systems II

Moderators: Freek Molkenboer, TNO Science and Industry, the Netherlands, **Marcy Stutzman**, Jefferson Lab

4:00pm **VT2-MoA-11 The Einstein Telescope Beam Pipe Vacuum System: The Pilot Sector***, **Ivo Wevers**, Giuseppe Bregliozzi, Paolo Chiggiato, Manjunath Dakshinamurthy, Ana Teresa Perez Fontenla,* CERN, Switzerland*; Purnalingam Revathi,* university of Antwerp, Belgium*; Carlo Scarcia,* CERN, Switzerland **INVITED**

Gravitational waves were first detected in 2015 by LIGO, which has since measured several other events in collaboration with VIRGO. These groundbreaking discoveries have driven the development of next-generation gravitational wave observatories, including the Cosmic Explorer (CE) in the U.S. and the Einstein Telescope (ET) in Europe.

A key factor in enhancing detection performance is the length of the Fabry-Perot cavities, where high-power laser beams are stored in an ultrahigh vacuum. Both CE and ET require over 100 km of vacuum pipes, each approximately 1 meter in diameter. If built using the same materials and design as LIGO and VIRGO, these vacuum systems could account for an important fraction of the total budget for the new facilities. To reduce the cost impact of the vacuum system, unconventional materials, less expensive pipe manufacturing and different surface treatments were investigated.

Mild steels and ferritic stainless steels have emerged as promising, cost-efficient alternatives due to their inherently lower residual gas content. However, material selection must also consider availability, formability, weldability, strength, ductility, corrosion resistance in addition to cost. Based on these criteria, ferritic stainless steel AISI 441 (EN 1.4509) has been identified as the most suitable material for ET’s beam pipe vacuum system.

To validate this approach, a 40-meter-long pilot beam pipe is being constructed at CERN. This test sector will assess the vacuum layout, material performance, vibration transmission and operational strategies needed to achieve ultrahigh vacuum (UHV) in a dust-controlled environment at a lower cost. The results will play a crucial role in shaping the final design of the next-generation gravitational wave detectors.

4:45pm **VT2-MoA-14 Comparative Water and Hydrogen Outgassing Behavior of Bare vs. Magnetite-Coated AISI 1020 Low-Carbon Steel***, **Aiman Al-Allaq**,* ODU - Jefferson Lab*; Md Abdullah Al Mamun, Matthew Poelker,* Jefferson Lab*; Abdelmageed Elmustafa,* ODU

Building on our previous work on low-carbon steel's outgassing characteristics, this study presents a systematic comparison between bare and magnetite-coated AISI 1020 steel vacuum chambers. Room temperature pump-down curves for both chambers follow power-law behavior ($P \propto t^{-\alpha}$) with α values near 1.1, indicating diffusion-limited desorption. The magnetite coating initially provides 5.3× lower water outgassing rates (1.88×10^{-11} vs. 9.88×10^{-11} Torr·L/s·cm^2), but this advantage reverses after thermal treatment, with bare steel outperforming magnetite by 3.3× after 80°C and 1.4× after 150°C baking. More significantly, hydrogen outgassing measurements show bare steel achieving rates as low as 9.6×10^{-16} Torr·L/s·cm^2 compared to 2.4×10^{-14} Torr·L/s·cm^2 for magnetite-coated steel after intensive thermal conditioning. Comprehensive characterization through Sips isotherm modeling reveals higher binding energies for magnetite (1.12-1.24 eV) versus bare steel (0.9-0.97 eV), while Arrhenius analysis shows similar activation energies (0.33-0.68 eV). RGA measurements confirm hydrogen dominance (>99%) in the residual gas composition. These findings enhance our understanding of the fundamental outgassing mechanisms in low-carbon steel and provide quantitative data essential for vacuum system design.

5:15pm **VT2-MoA-16 VTD Business Meeting***,*

Vacuum Technology
Room 205 ABCD W - Session VT1-TuM

Measurement, Simulations and Accelerator Vacuum Systems

Moderators: Jacob Ricker, NIST, **Julia Scherschligt**, National Institute of Standards and Technology

8:00am **VT1-TuM-1 ORNL Second Target Station (STS) Vacuum System*, Austin Chaires,*** Oak Ridge National Laboratory, USA **INVITED**

The STS is a $2 Billion, Department of Energy project to be constructed at the ORNL Spallation Neutron Source (SNS).The STS will provide wholly new capabilities for the study of a broad range of materials with neutron scattering and support thousands of users from the physical, materials, and applied sciences industries. The science capabilities provided by the instrument suite at the STS will complement those of the two existing DOE Office of Science neutron scattering user facilities at ORNL, the First Accelerator Station (FTS) of the SNS and the High Flux Isotope Reactor (HFIR). The STS will deliver the highest peak brightness of cold neutrons in the world, which together with advances in neutron optics, instrumentation, and detectors, will ensure US leadership in neutron scattering for decades to come.

The STS Accelerator Systems group is responsible for the design, fabrication, installation, and testing of all hardware necessary to transport the 700 kW, 15 Hz proton beam to a rotating tungsten target, to create 22 beams of moderate neutrons.

The Ring to Target Beam Transport Beamline vacuum system branches off the existing RTBT's vacuum system and stretches ~230 meters until it ends at the STS's proton beam window (PBW) to the target. The RTST vacuum volumeis essentially an 8" diameter cylinder from beginning to end and mostly located concentrically about the beam axis. It is also pocketed with additional spaces at crosses and instrument & shielding housings. The RTST is divided into 7 isolatable sections using all-metal gate valves. All sections contain:magnet vacuum chambers (VC), drift VCs adaptors, bellows, beam instrumentation VCs, pumps, Pirani gauges (TCG), cold-cathode gauges (CCG), a pumpdown access location, an RGA, and various other valves. Additionally, several large detector vessels and a core vessel are in early design and require systems to obtain low to high vacuum. Positive pressure gas distribution and vacuum analysis capabilities are also required for these systems.

This talk will also offer a cursory glance at the following additional vacuum systems:

1. Proton Beam Window Inflatable Seal and Interstitial Space Vacuum Systems
2. Cryogenic Moderator Vacuum Systems
3. Neutron Guide Beamlines and In-Bunker Vacuum System

8:30am **VT1-TuM-3 Robotic Assembly of SRF Cavity Pair*, Adam Duzik,*** *Roger Ruber,* Jefferson Laboratory

Superconducting Radio Frequency (SRF) cavities for particle accelerators require tight tolerances, ultrahigh vacuum, and strict cleanliness during assembly. As in the semiconductor industry, defects such as particles and residues are deleterious to performance, possibly rendering a cavity unfit for use. This problem is addressed primarily through cleanroom assembly during sensitive steps and rigorous chemical processing to prevent and remove such defects. Human workers are often the largest source of contamination, even with proper gowning and practices. The semiconductor industry has long integrated robots in cleanroom operation, but this has not occurred for SRF cavity production; SRF cavities, unlike wafers, are complex shapes, require more hands-on mechanical assembly, and are low-volume production items.

At Jefferson Laboratory, a co-operative robot (cobot) has been setup to overcome these problems. Cobots are safe for use alongside human workers and can integrate new tools such as a 3D camera part detection and gripper for item manipulation. Therefore, cobots represent a promising avenue for reducing particulate generated during a variety of assembly tasks. A mockup of a cavity pair and coupler was setup and the cobot programmed to automatically pick up the coupler and place on the mating cavity flange. Particle counting methods were setup to measure human vs cobot assembly particulate generation inside a cavity mockup. Other potential uses will be discussed for further improving SRF cavity assembly steps, where a cobot can replace or assist a human operator, and what potential gains are expected.

8:45am **VT1-TuM-4 Emergency Vacuum Repairs in an Aging Accelerator: Case Studies and Lessons Learned*, Marcy Stutzman,*** Jefferson Lab

Jefferson Lab operates the CEBAF electron accelerator at energies to 12 GeV for the Department of Energy Nuclear Physics program. The CEBAF injector beamline was designed and built in the early 1990s. Although many of the vacuum components have been upgraded and replaced, many unique, original components are still installed and operating daily. Over the past 3 years, several vacuum leaks have occurred in ageing components leading to emergency repairs on a tight timeline. These include an edge welded bellows and RF power ceramic feedthrough, both of which had been in use for at least 25 years. The nature of these vacuum component failures will be discussed, along with the difficulties in repair due to the age and availability of parts, lessons learned, and what steps are being taken to minimize similar failures going forward.

9:00am **VT1-TuM-5 Commissioning and Early Operations of the APS-Upgrade Storage Ring Vacuum System*, Jason Carter,*** Argonne National Laboratory, USA **INVITED**

The Advanced Photon Source's (APS) upgraded storage ring was brought online and began commissioning in April 2024. APS was rebuilt with a new 1100-meter length storage ring vacuum system, a complex assembly of over 2500 custom vacuum components. In 2024 and 2025 APS-U has successfully commissioned the vacuum system reach the designed pressure levels and allowing the machine to reach key performance parameters and for the facility to provide reliable beam to the users. This presentation will share results and analysis of the vacuum system commissioning along with lessons learned from the installation and operations phases.

9:30am **VT1-TuM-7 Design and Construction of a Vacuum End Station for Ion Irradiation in Magnetic Field Environments at the Tennessee Ion Beam Materials Laboratory*, Henry Osborne,*** University of Tennessee Knoxville*; Kendall Trellue,* University of New Mexico*; Miguel Crespillo,* University of Tennessee Knoxville*; Eric Lang,* University of New Mexico*; Khalid Hattar,* University of Tennessee Knoxville

As nuclear fusion reactors progress closer to becoming a reality, it is important to understand how materials that compose the heart of such reactors behave under the coupled extreme environments. Such intense temperatures, displacement damage, and magnetic field can have a significant impact on the thermal, mechanical, and radiation stability of most candidate alloys. It is essential to have this fundamental understanding for the development of physics-based models, however, this has been under studied due to lack of experimental capabilities. This presentation will detail the design and construction of a custom ion accelerator end station that will permit such experiments at the Tennessee Ion Beam Materials Laboratory (TIBML). This end station design will be compatible with either the MV tandem accelerator already at TIBML or the 300 kV implanter that is soon to arrive. The high vacuum design incorporated for this end station should permit vacuum pressures between 1×10^{-5} Pa and 1×10^{-6} Pa and easy transfers between beamlines. In addition, the end station achieves a maximum magnetic field strength of 1.44 Tesla by inserting the sample from the loading portion of the end station through the gate valve into the center of the large switching magnet of the ion accelerator using a 914 mm long linear translator. The exact magnetic field will be measured via hall probe at the sample location during the experiment. It similarly achieves cryogenic temperatures through liquid nitrogen cooling conducted to the sample via copper braids. Due to the extreme conditions created by the cryogenic, magnetic, and radiation environments, several precautions had to be taken in the design, material selection, and development of this end station. Initial results of this new end station design to study the microstructural evolution of materials will be presented. Finally, this presentation will highlight the varied and future potential fusion energy-related experiments that will be made possible through the utilization of this end station. The development of this magnetic end station at TIBML will allow the fusion materials community to better understand coupled extreme environments.

9:45am **VT1-TuM-8 Boosting Sticking-Dependent Transmission Studies to a Single TPMC Simulation*, Jan Beckmann,*** *Klaus Bergner, Stefan Kiesel,* VACOM, Germany

In the simulation of molecular flow through complex vacuum geometries, the transmission probability is a key parameter, particularly when modeling systems with surface adsorption or desorption effects, such as NEG-coated pipes or cryogenic beamlines. Traditionally, calculating the impact of varying sticking coefficients on transmission requires separate Test Particle Monte Carlo (TPMC) simulation runs for each coefficient, posing a significant computational burden often exceeding many hours of computation time in simulation frameworks like Molflow+.

We present a novel approach that enables the extraction of transmission probabilities for arbitrary sticking coefficients using only a single TPMC simulation conducted with zero sticking (s = 0). This method leverages the statistical distribution of particle bounces before exiting the system. By recording the number of wall interactions for each particle in a single simulation and applying a bounce-weighted exponential scaling factor of the form (1 - s)^N, we can reconstruct transmission probabilities for any s with high accuracy.

This methodology was validated using Molflow+ in an elbow-shaped vacuum geometry. The resulting predictions for various s-values closely matched full simulation results, confirming the reliability and computational efficiency of this approach. This technique enables rapid conductance analyses significantly reducing the total computation time to few minutes and supports more efficient vacuum system design across a wide range of applications.

Vacuum Technology
Room 205 ABCD W - Session VT2-TuM

Measurement, Simulations and Accelerator Vacuum Systems

Moderators: Freek Molkenboer, TNO Science and Industry, the Netherlands, **Sol Omolayo**, Lawrence Berkeley National Laboratory

11:00am **VT2-TuM-13 Enabling Vacuum Process Monitoring with Time-of-Flight Spectroscopy**, ***Marco John,*** *Klaus Bergner, Sebastian Hüttl, Kristian Kirsch, Andreas Trützschler,* VACOM Vakuum Komponenten & Messtechnik GmbH, Germany

The increasing complexity of industrial vacuum processes requires broader and deeper knowledge of the vacuum itself. A crucial aspect for increasing quality demands is the necessity of in-situ monitoring and control of pressure and residual gas composition within vacuum processes. A consequence of advanced process control is the reduction of production errors, prevention of failures or major damage in combination with increased operating time. Traditional monitoring devices like hot cathodes or quadrupole mass spectrometers are both only able to measure either pressure or residual gas composition. Therefore, these devices are only conditionally suited for complete process control of vacuum processes. With our novel wide-range vacuum monitor NOVION®, which combines the well-known technology of time-of-flight spectroscopy with our patented ion trap, industrially available pressure and gas analyzation is possible at the same time.

In this talk we present the fundamental principles of the novel vacuum monitor and explain the compact combination of well-known time-of-flight spectroscopy with our own patented ion trap. Within different application cases we discuss advantages and limits of this technology and demonstrate with one single device wide range gas analysis, simultaneous measurement of total and partial pressures, leak detection for Helium and detection of air leaks. With these combined capabilities the novel vacuum monitor is able to quickly capture the complete pressure and gas composition measurement at various stages of the vacuum process chain. In addition, we demonstrate a special signal enhancement method to improve the resolution in the near signal-to-noise range.

11:15am **VT2-TuM-14 Update on Fixed Length Optical Cavity (FLOC) Pressure Calibration Standard for Calibration of Military and Commercial Aircraft**, ***Jacob Ricker****, Kevin Douglass, Thinh Bui, Jay Hendricks, Jay H. (Fed) <jay.hendricks@nist.gov>,* NIST

NIST has constructed several Fixed Length Optical Cavity (FLOC) pressure standards based on gas refractivity and shown that they are effective at measuring absolute pressure [1]. The US Air Force has recently funded development of these standards for the support of their Air Data Calibration Systems. These Air Data Systems provide calibration for altimeters and air speed indicators and traceability of these sensors is crucial for all operational military and commercial aircraft. NIST has been constructing a new portable FLOC constructed of an Invar material. This presentation will describe the assembly and testing of a new lower cost/robust/portable calibration system capable of calibrating gas pressure sensors over the entire range of 1 Pa to 10 MPa. The testing includes pressure performance and system stability.

References:

[1] https://doi.org/10.1016/j.measen.2021.100286.

11:30am **VT2-TuM-15 Single-Laser Optical Pressure Measurements to Support Air Data Calibration**, ***Kevin Douglass,*** *Thinh Bui, Jacob Ricker, Jay Hendricks,* National Institute of Standards & Technology

NIST is currently constructing a portable robust Fixed Length Optical Cavity (FLOC) pressure standard to be optimized for the calibration of aircraft altimeters, rate of climb indicators, and air speed indicators while also extending the operating pressure range close to 10 MPa.To reduce cost and help simplify the operation of the system we have tested an optical approach that only uses a single laser locked to the reference cavity with a portion of that light being modulated to generate a sideband which is locked to the sample cavity.The tradeoffs and advantages of this technique will be discussed.

11:45am **VT2-TuM-16 Radiometric Force Due to Accommodation Coefficient of Gas-Surface Interaction**, ***Felix Sharipov,*** Universidade Federal do Paraná, Physics Department, Brazil; *Benjamin Schafer,* Harvard University

The radiometric force arises when a body heated non-uniformly by some radiation is immersed in a gas at a low pressure. This phenomenon results from gas-surface interactions, which are characterized by the accommodation coefficients. In turn, these coefficients depend on the gas species and surface properties such as roughness and chemical composition. When the accommodation coefficients are not constant over the body surface, the radiometric phenomenon arises when the body is a different temperature than the surrounding gas, even if the body temperature is uniform. In the present study, we calculate the force exerted on a thin membrane with different accommodation coefficients on its top and bottom surfaces. The membrane temperature is assumed to be higher than that of the surrounding gas. The direct simulation Monte Carlo method is used to span a wide range of the Knudsen number including the free-molecular, transitional, and viscous flow regimes. The force reaches its maximum value when the mean-free-path is close to the membrane diameter. Thus, if the membrane diameter is about 1 cm, then the force is maximum at the pressure about 1 Pa. We show that perforations in the membrane increase the radiometric force for higher pressures. The obtained results allow to optimize the membrane geometrical parameters to reach significant radiometric force. Analysis shows that the radiometric force caused by the accommodation coefficient difference can levitate a lightweight membrane that is a few centimeters wide in near-space conditions.

12:00pm **VT2-TuM-17 Thermal Transpiration: Beyond Takaishi and Sensuiλ**, ***Robert Berg,*** National Institute of Standards and Technology (NIST)

Thermal transpiration, also known as the thermomolecular effect, applies when a pressure gauge at temperature T_2 is used to measure the pressure of a gas held at temperature T_1. Examples include gas thermometry (say T_1 = 10 K) and temperature-controlled gauges (say T_2 = 318 K). When the temperature difference is large and the gas mean free path is comparable to the diameter of the tube connecting the two volumes, thermal transpiration can make the pressure ratio P_1/P_2 much less than 1.

Thermal transpiration has been described by physically motivated empirical functions, physics-based numerical models, and a physics-based analytical model. The most common empirical function is that of Takaishi and Sensui (T-S) [1]. Numerical models are rarely used because they rely on details of geometry and surface accommodation that restrict the model's use to a specific scenario.

There is only one physics-based analytical model, the "dusty gas" model [2], which employs the concept of a gas composed of infinitely heavy "dust" molecules. The dust molecules scatter the ordinary gas molecules, so that the flow in the connecting tube has a viscous component and an opposing rarified-gas component. The dusty gas model was used during the 1960s and 1970s to describe experimental measurements, most notably by Malinauskas and co-workers. Despite that success, it has not been widely used because the model's core equation requires a numerical solution.

The dusty gas model is superior to the T-S empirical function. The T-S function assumes perfect surface accommodation, while the dusty-gas model does not. Also, the T-S function has three free parameters of obscure meaning, and fitting those parameters to experimental data can hide an error in the data. In contrast, the dusty gas model has only two free parameters with clear physical meaning. The first parameter accounts for imperfect accommodation, and the second accounts for an error in the ratio λ/d, where λ is the mean free path and d is the tube diameter. A re-analysis of literature data found good agreement with the dusty gas model.

1. T. Takaishi, Y. Sensui, *Trans. Faraday Soc.* **59**, 2503-2514 (1963).
2. A.P. Malinauskas, J.W. Gooch, B.K. Annis, R.E. Fuson, *J. Chem. Phys.* **53**, 1317-1324 (1970).

Vacuum Technology
Room Ballroom BC - Session VT-ThP

Vacuum Technology Poster Session

VT-ThP-1 Deposition and Sublimation of Argon Sphere Immersed in a Non-Condensable Gas Over an Wide Range of the Knudsen Number*, Felix Sharipov,* Universidade Federal do Paraná, Physics Department, Brazil*; Denize Kalempa,* Universidade de Sao Paulo, Brazil*; Irina Graur,* Aix-Marseille University, France

Rarefied gas flows involving phase transitions on solid surfaces are of both scientific and practical interest, particularly, for the development and optimization of vacuum systems, heat exchangers, and chemical reactors, etc. For example, heat and mass transfer driven by the sublimation of solid particles plays a crucial role in advancing technologies based on chemical vapor deposition in vacuum chambers. In the kinetic theory of gases, evaporation and condensation, analogous to sublimation and deposition, have been extensively studied using the Boltzmann equation and the Direct Simulation Monte Carlo method. However, most existing studies rely on simplified models with hypothetical molecular masses and the hard-sphere potential for intermolecular interactions. In this work, we consider a solid argon sphere surrounded by its vapor and helium as a background gas. The temperature and pressure of the mixture are set such that argon undergoes sublimation or deposition, while helium solely reflects off the solid surface. To capture flow regimes ranging from free-molecular to transitional and viscous, we employ a kinetic model for the linearized Boltzmann equation to compute mass and heat transfer from the argon sphere to the surrounding gas mixture. To assess the influence of interatomic interactions on the flow dynamics, calculations are performed using both the hard-sphere model and ab initio potentials. The results demonstrate that the partial pressure of helium significantly impacts the mass and energy transfer rates from the particle due to phase transitions occurring on its surface.

VT-ThP-2 Experimental Characterization of Water Outgassing Energetics on Bare and Magnetite-Coated Low-Carbon Steel Surfaces*, Aiman Al-Allaq,* ODU - Jefferson Lab*; Md Abdullah Al Mamun, Matthew Poelker,* Jefferson Lab*; Abdelmageed Elmustafa,* ODU

This work presents a detailed experimental setup and methodology for comparative outgassing analysis between bare and magnetite-coated AISI 1020 low-carbon steel chambers. Using a custom-built throughput apparatus, we measured outgassing rates under various thermal conditions. Binding energies obtained through Sips isotherm modeling (0.9-0.97 eV for bare steel, 1.12-1.24 eV for magnetite) and activation energies derived from rate-of-rise accumulation measurements (0.33-0.68 eV for both surfaces) provide complementary perspectives on the energy landscape governing water interactions with these surfaces. The difference between these energy parameters offers insight into the shape of the potential energy diagram, revealing the height of the desorption barrier relative to the adsorption well depth. This comprehensive energetic picture helps explain the counterintuitive finding that magnetite, despite its higher binding energy, exhibits worse outgassing performance after thermal treatment. Our analysis demonstrates how the combination of throughput measurements and multiple energy characterization techniques creates a more complete understanding of surface-gas interactions critical for vacuum system optimization. This approach provides both fundamental insights into desorption processes and practical guidance for thermal treatment protocols in vacuum applications requiring extremely low outgassing rates.

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