ΑΝΑΚΟΙΝΩΣΗ - ΠΡΟΣΚΛΗΣΗ
ΔΗΜΟΣΙΑ ΥΠΟΣΤΗΡΙΞΗ ΔΙΔΑΚΤΟΡΙΚΗΣ ΔΙΑΤΡΙΒΗΣ
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Προσκαλούμε τους μεταπτυχιακούς και προπτυχιακούς φοιτητές μας, τα μέλη Δ.Ε.Π., τους διδάσκοντες του Τμήματος και κάθε ενδιαφερόμενο, στη δημόσια υποστήριξη της Διδακτορικής Διατριβής του κ. Σεραφείμ Μισδανίτη με τίτλο:

RAREFIED GAS PIPE NETWORK ANALYSIS VIA KINETIC THEORY

In recent years, extensive investigation has been conducted in an attempt to simulate gas pipe networks in the hydrodynamic regime, based on the Navier-Stokes equations. Several in-house and commercial codes have been developed to model gas pipe networks appearing in various technological applications. The corresponding work in gas pipe networks operating under rarefied conditions, with applications related to vacuum pumping, metrology, industrial aerosol dispersion, porous media, and micro-fluidics is quite limited. This is mainly attributed to the increased complexity of the problem since kinetic modeling has to be combined with pipe networking.

The aim of the present thesis is to fill this gap and constitutes the first systematic and successful scientific effort in integrating gas flow modeling through channels of various lengths and cross sections under any vacuum conditions in a unified gas pipe network solver. In this framework, the developed Algorithm for Rarefied gas flow in Arbitrary Distribution Networks (ARIADNE), with its graphical interface, is a complete computational tool capable of simulating complex rarefied gas flow configurations operating at any pressure from the atmospheric down to ultra-high vacuum. The code is validated by comparisons with commercial and in-house developed algorithms and then is applied to solve various gas pipe networks including the neutral gas pipe network of the ITER divertor pumping system which is considered as one of the largest and most complex ones worldwide.

Three main setups, with respect to the channel length, namely flows through a) long, b) moderate long and c) short channels have been employed. Flows through long channels are treated based on the infinite capillary theory, while in channels with moderate length, the same theory, coupled with the so-called end effect correction approach is implemented. Flows through short channels are treated based on linear and nonlinear kinetic modeling, when the driving pressure difference along the channel is small and arbitrarily large respectively. Overall, it has been demonstrated that linear kinetic modeling, as described by suitable kinetic model equations, may take advantage of flow characteristics and yield very accurate results in the whole range of the Knudsen number with minimal computational effort. Accurate results based on nonlinear modeling are also acquired, but the computational cost in drastically increased. The corresponding kinetic equations along with the associated formulations are implemented to return adequate dense kinetic data to be integrated into the network code. The range of validity of each approach is also examined.

The detailed description of the core components of ARIADNE and their interconnection to form the integrated algorithm are provided. The kinetic data base is dense enough to allow accurate representation of the operational conditions of arbitrary gas pipe networks. Interpolation between the available flow rates is performed by cubic splines in the case of long channels, by high order curve fitting for the increment lengths in the case of channels of moderate length and by trilinear interpolation in terms of pressure, length and gas rarefaction in the case of short channels. The developed algorithm includes the drawing of the network in a graphical environment and then the formulation and solution of the governing equations describing the flow conditions of the distribution system. In the drawing process of the network, the user, through the developed graphical interface, may provide the input data including the coordinates of the nodes in a 3D space, the length and the diameter of the pipe elements, the pressure heads of the fixed-grade nodes and information for the type of the gas and its properties. Furthermore, the demands (if any) at the nodes may also be provided. Once the geometry of the network is fixed, an iterative process is initiated between the pressure drop equations and the system of mass and energy conservation equations in order to successfully handle gas pipe networks operating from the free molecular, through the transition up to the slip and hydrodynamic regimes.

Additionally, the in-house Matlab solver, employed for the simulation of gas pipe networks in the hydrodynamic regime has been upgraded, extending the range of its applicability in the slip regime. This is achieved by making use of the slip boundary conditions and accordingly correcting the the friction factor expressions.

The validation of the developed algorithm and its implementation in solving gas pipe networks of various complexity levels is provided. Various flow scenarios in sample networks consisting of long channels or channels of moderate length with circular, orthogonal and trapezoidal cross section channels, as well as of short channels are studied. The code validation and benchmarking are achieved by comparisons in the viscous regime with the in-house Matlab hydrodynamic solver and in a wide range of the Knudsen number with ITERVAC (a semi-empirical code developed at KIT). Simulations have been performed with respect to i) the network complexity, ii) the Knudsen number, iii) the piping elements cross-section, iv) the geometrical characteristics (length and diameter) and v) the applicability and effectiveness of the code in micro-geometries and vacuum conditions. In all cases very good agreement in terms of the mass flow rate and the conductance of the pipe elements, as well as the pressure heads at the nodes of the network is reported.

Furthermore, the advanced capabilities of ARIADNE are demonstrated by modeling the 2012 ITER torus primary pumping system. The ITER divertor and lower port schematics are translated into a network of piping elements of various lengths and cross sections. Results of the flow patterns and paths along the cassettes and the divertor for various operating scenarios, including the backflow and pumped throughputs, are provided. The code developed in the present Ph.D. thesis, coupled with the kinetic data base, may support the design and optimization of gaseous distribution networks operating under any rarefied conditions.

Τρίτη 21 Σεπτεμβρίου 2021, ώρα 10:00