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Ph.D., Mechanical Engineering

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THESIS:

"Modeling the ITER Cryogenic Fore Pump"

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BACKGROUND & OBJECTIVE

BACKGROUND

- ITER
  - One of the largest scientific projects
  - Commercial use of fusion energy
  - Cryogenics extensively used
- The Cryogenic Fore Pump
  - First part in the roughing pump system
  - Collect and compress hydrogen
  - Cooled by supercritical/liquid helium

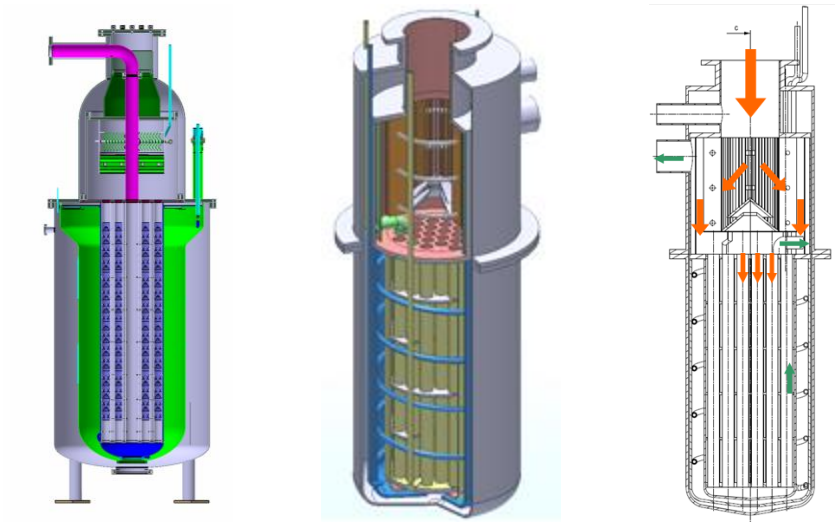


Fig. 2*. The initial design of the cryogenic fore pump

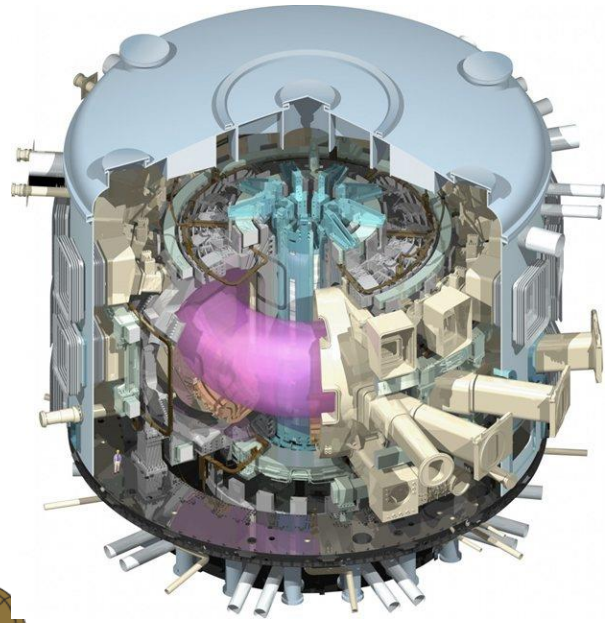


Fig. 1*. The ITER Tokamak

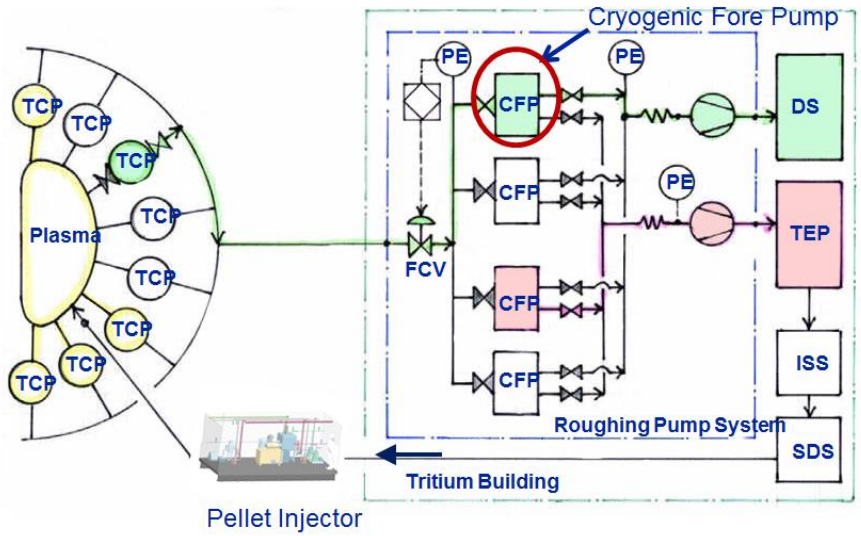


Fig. 3*. The simplified ITER fuel cycle flow diagram

OBJECTIVE

- Physics
  - Adsorption of hydrogen
  - Simultaneous transport process (species, momentum, and energy)
  - Hydrogen-helium gas mixture at cryogenic temperature
- Engineering
  - Explain experimental data
  - Identify key variables
  - Develop numerical models and solve highly coupled non-linear equations
  - Design and predict pump performance

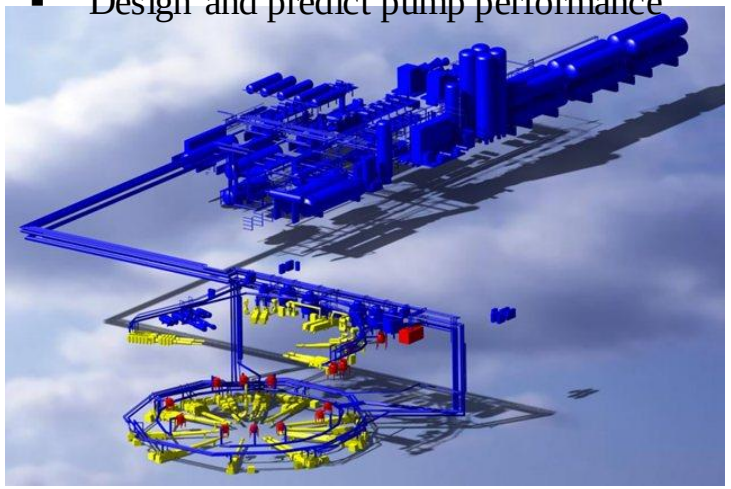


Fig. 4*. The ITER cryogenic system

INVESTIGATION

INVESTIGATION

- The adsorption
  - Deposition of hydrogen molecule
  - Adsorption energy & rate
- The transport phenomena
  - Gaseous mixture
  - Radial adsorption
  - Simultaneous transport process
- The numerical model
  - Five variables (Temperature, pressure, density, velocity, and composition)
  - Changing parameters (e.g. thermal conductivity)
  - Highly coupled non-linear equations

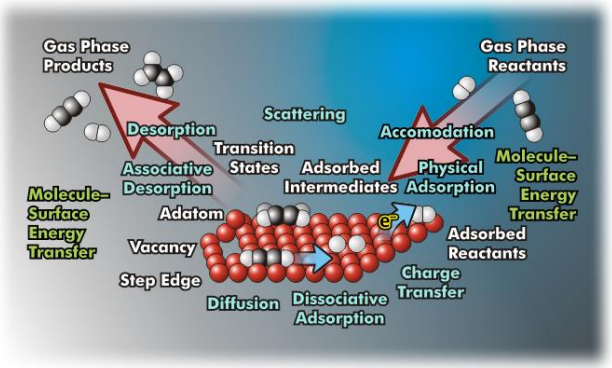


Fig. 5*. A illustration of Gas-surface interaction

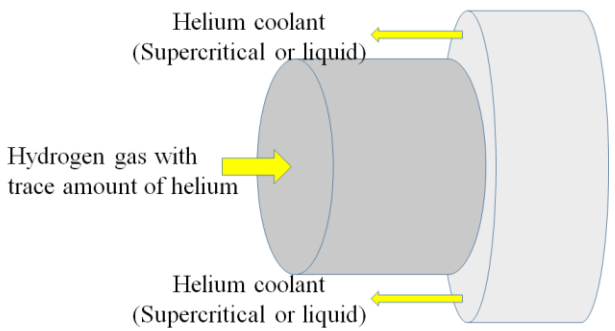


Fig. 6. A drawing of the pump configuration

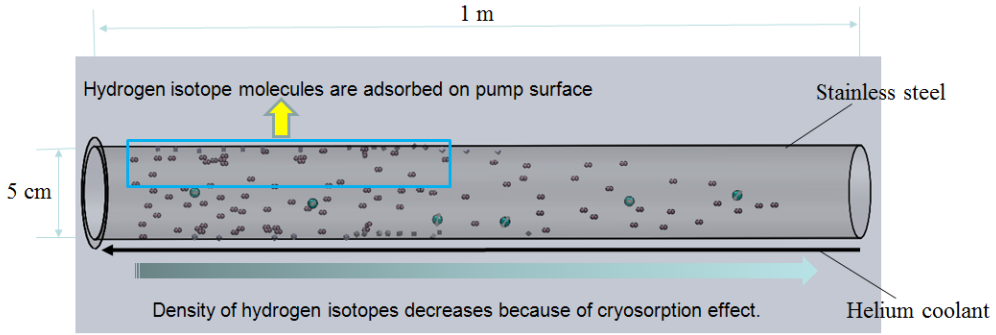
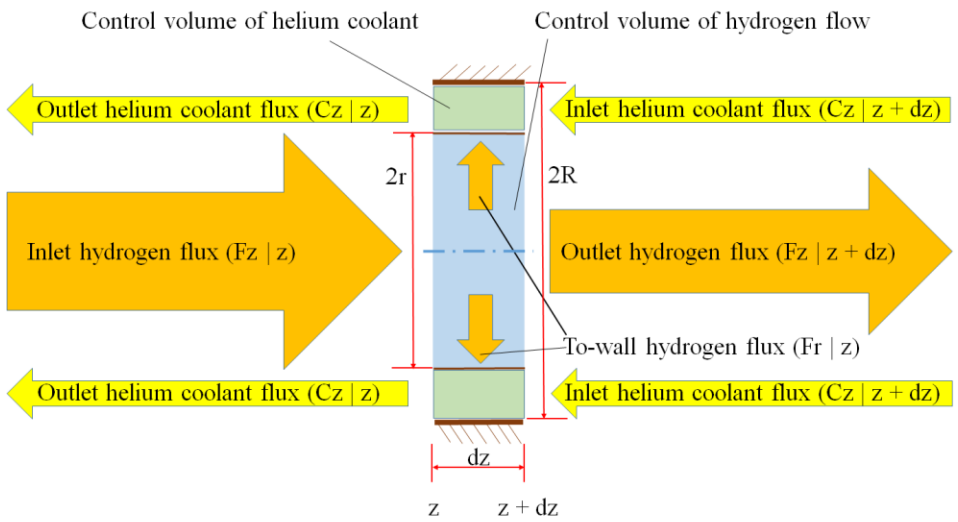


Fig. 8. The first intuition of the pump



$$\begin{cases} r\dfrac{d[M_{z,H_2}]}{dz} + 2M_{r,H_2} = 0. \\ \dfrac{d[M_{z,He}]}{dz} = 0. \\ r\dfrac{d[\Phi_{zz}]}{dz} + 2\Phi_{rz} = 0. \\ r\dfrac{d[E_z]}{dz} + 2E_r = 0. \end{cases}$$

Fig. 7. A differential control volume and analysis

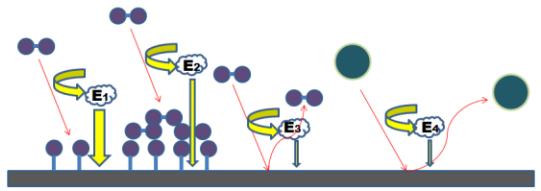


Fig. 9. The interaction of H_2 and He with a cold surface

RESULTS & FUTURE PLAN

RESULTS

- Understood & modeled
  - Adsorption mechanism for cryopumps working in viscous regime
  - H_2 & He cryogenic properties
  - Simultaneous transport process with adsorption
- Developed
  - Numerical models to predict temperature, pressure, density, velocity, and composition profile for the ITER cryogenic fore pump without the assumptions of constant parameters
  - The "Group-Member" numerical technique to solve highly coupled equations

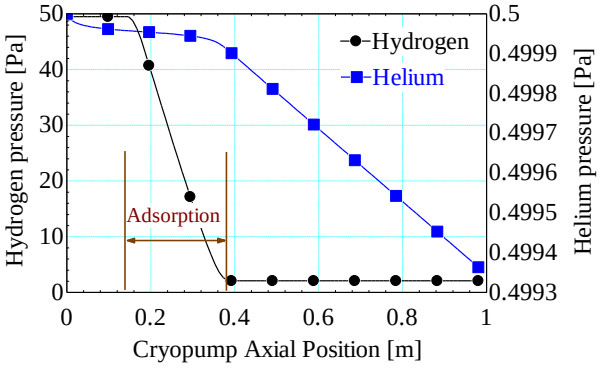


Fig. 10. Pressures as a function of axial position

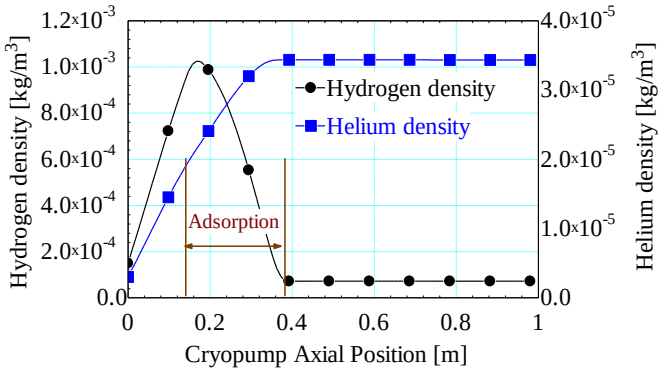


Fig. 11. Densities as a function of axial position

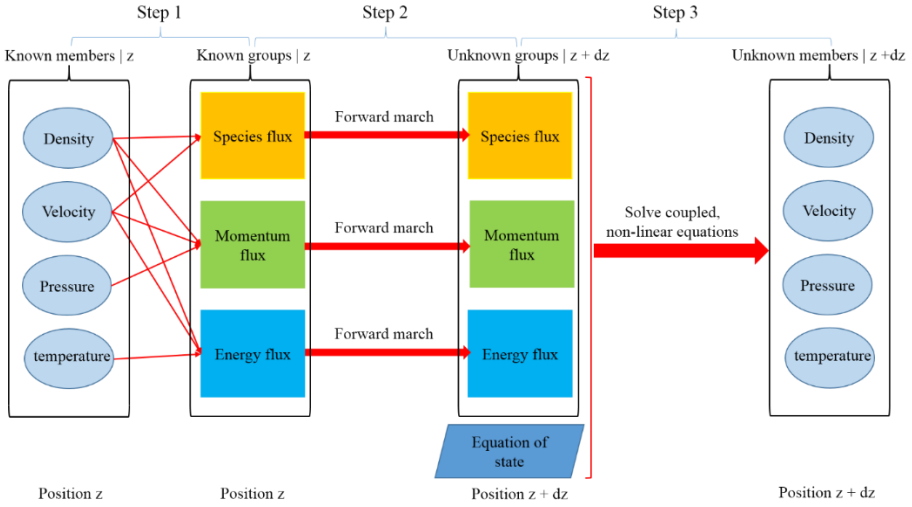


Fig. 12. A flow chart of the Group-Member numerical technique

FUTURE PLAN

- Improve the models
  - To explain the time dependence of the experimental date
  - To provide guide for the cryogenic fore pump design

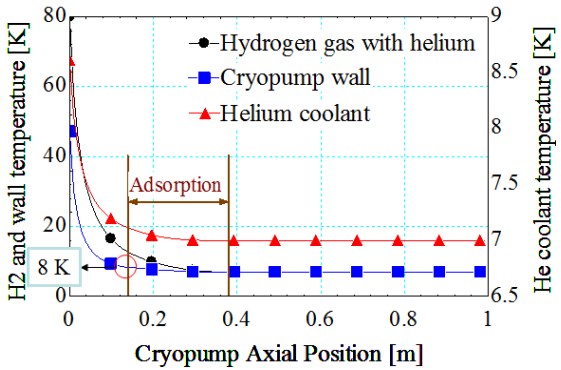


Fig. 13. Temperatures as a function of axial position

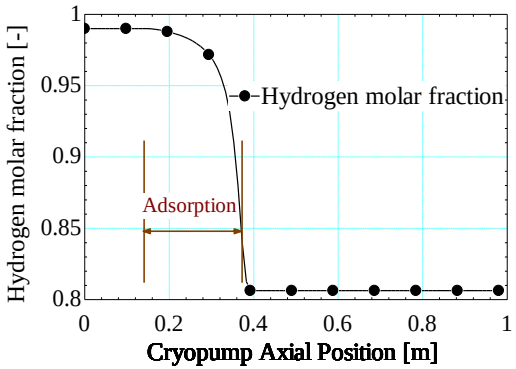


Fig. 14. H_2 molar fraction as a function of axial position

* Courtesy of ITER, the Oak Ridge National Lab, and the Brookhaven National Lab