Syllabus

Cryogenic Cryocooling and Liquefaction of gases

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Content/Central topics

1. **Introduction.**
   The discipline of Cryogenics, and its chronology as "The Quest for Absolute Zero" (Paris, Geneva, Wroclaw, London, Leiden, Munich, Grenoble, Berlin, Oxford, and more).
   Applications: Air separation and gas production, natural gas supply, propulsion, defense, transportation, superconductivity, physics (CERN), super fluidity, magnetic levitation, medicine and cryosurgery and cryopreservation, space applications, nuclear fusion.

2. **Joule-Thomson cryocooling**:
   The integral JT effect, real gas properties, miniature and MEMS cryocoolers for IR sensors, open cycle with high pressure vessel, closed cycle, pure coolants, staging, mixed coolants and the associated synergy, Linde-Hampson cycle, Kleemenko-Missimer cycle, cryocooling by atmospheric air, cryosurgical devices.

3. **Cryocoolers and their unified perspective**:
   The "interchanging" process of cryocooling, recuperative versus regenerative "interchanging", Siemens-the inventor of cryocoolers, Joule-Thomson, reverse Brayton, Stirling, Solvay, Gifford-McMahon, Vuilleumier, Active Magnetic Regenerative Refrigerator (AMRR), sub Kelvin single shotadiabatic demagnetization, the deep sub-Kelvin dilution refrigerator (for 5 mK).
   Crryocooling versus Vapor Compression Refrigeration.

4. **Liquefaction of gases**:
   Linde-Hampson (single and dual pressure), Claude and its optimization, reverse Brayton (ideal and real), Kapitza, Heylandt, Collins.
   Liquefaction of quantum gases (helium, hydrogen, neon) and natural gas.
   Simon's single shot liquefaction of helium.
   Satellite helium liquefaction.

5. **Cryocoolers: general issues**.
Achievable temperatures, cascades of serial and parallel staging and the associated COP, FOM, hybrid cryocoolers, cooldown, compression ratio, reliability.
Case study: comparison of Stirling and Gifford-McMahon cryocoolers.
Case study: the non viability vortex tube cryocooler.

6. **Special topics**: the Third Law, space applications of cryocoolers, supefluid helium, thermal/mechanical/electrical properties of materials at cryogenic temperatures, mixtures of He-3 and He-4, sorption cryocoolers, Equations of State and real gas properties, Pulse Tube cryocoolers, superconductivity, **Choked flow rates** of real gases at low temperatures.

Text books

1. ***Miniature Joule-Thomson Cryocooling****,*
Ben-Zion Maytal and John Pfotenhauer,
Springer Publication, New York, **2012**.

2. ***Cryogenic Engineering,***
Thomas Flyn,
Marcel Dekker Press, New York, 2005.

3. ***Cryogenic process Engineering,***
Klaus Timmerhaus and Thomas Flynn,
Plenum Press, 1989.

4. ***Cryocoolers,***
Milind D. Atrey,
Springer Press, **2020**.

Grading / Assignments

1/ Homework, 4 weekly assignments, 10%.

2/ A final project, prepared along the semester, groups of 3 students.

2.1/ Presentation, in class at the end of semester, 20%,

2.2/ Final report submission, 2 weeks after the end of the semester, 70%.