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INSIDE THIS ISSUE
(2 Pages)

Solid Hydrogen Extrusion for Fuelling Fusion Tokamaks

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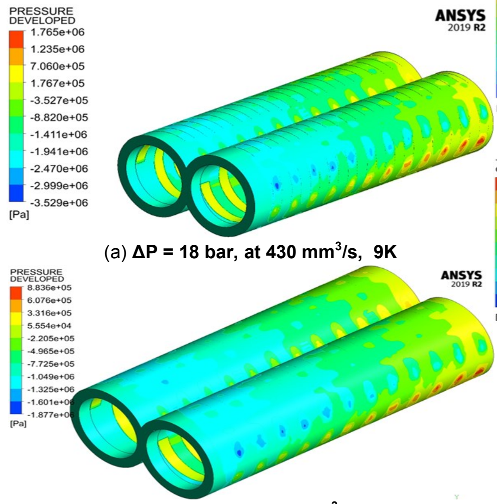
Extruding process is well known in the field of polymer and pharmaceutical industries. Day to day example is ice-cream serving in cones etc. On the high technology end, it is further extended to an extruder delivering hydrogen ice in the form of pellets and then accelerating the pellets to inject as fuel into plasma in a tokamak device. The extruder is a thermodynamic system, where most of the power needed to operate the screw is converted into heat. The parameters affecting the rate of extrusion include the requirement of minimum viscous dissipation rate with control on heat loads, control of rotation of screw because the tensile strength of extruded solid hydrogen is very low and in the range of 1×10^5 N/m^2. The challenge lies in computationally meshing the intermeshing zone of counter-rotating screws extruding solid hydrogen and the non-Newtonian and temperature-dependent properties of solid hydrogen which further complicates the analysis.

Cryogenics Twin Screw Extruder System [1] is a theoretically positive displacement pump; throughput increases linearly with screw speed. The solidified hydrogen pellet can be extruded in different ways such as a batch extruder, a single-screw extruder, and a twin screw extruder. A pellet can be a frozen deuterium or hydrogen isotope [2], cylindrical, and a few millimeters in size. The shear stress and heat transfer during the flow of solid hydrogen, deuterium, and neon was measured by a Couette type viscometer cell [3]. The torque and pressure had been measured with high accuracy and precision devices [4]. The viscous dissipation rate is found to be highly sensitive to the screw rotation speed [5]. Some basic calculations and throughput-pressure relationship had been reported [6] for the modelling of the screw based extruder system. A simplified 2D numerical model for the single screw extruder in the temperature range of 10 K to 13 K had been developed [7].

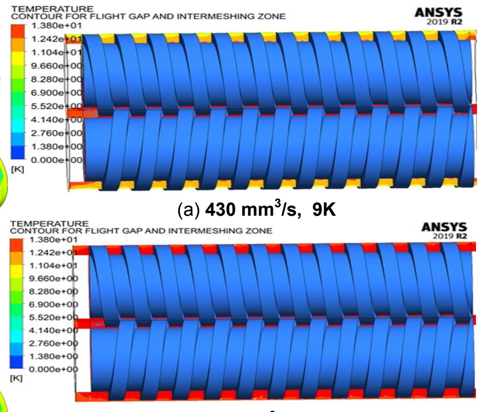
The development of an Extruder-Type Pellet Injector System (ETPIS) is necessary for a continuous supply of pellets of hydrogen isotopes to cater to the fueling needs of the future tokamaks [2] like ITER. Hypothesis governing the performance of these technologies has not been fully developed due to the intricate geometries, change of material phases, and cryogenic temperatures. Predictive models are necessary for the operation of cryogenic twin screw extruders. We have developed a CFD model to predict the performance of cryogenic twin screw extruders using *ANSYS POLYFLOW (ANSYS-2019R2 licensed version installed on ANTYA)*. The simulation results showed that the reduction of shear stress value leads to a drop in pressure developed along the extruder. Figure 1 shows the comparison of pressure developed along the extruder length for minimum and maximum barrel wall temperatures of 9 K and 13 K respectively for 15 rpm. The shear stress of solid hydrogen is higher at 9 K.



(a) **ΔP = 18 bar, at 430 mm^3/s, 9K**

(b) **ΔP = 10 bar, at 430 mm^3/s, 13K**

Figure 1: Comparisons of pressure developed along the extruder for different barrel temperatures at 15 rpm.



(a) **430 mm^3/s, 9K**

(b) **430 mm^3/s, 13K**

Figure 2: Comparisons of temperature distribution along the screw at various locations for different barrel temperatures.

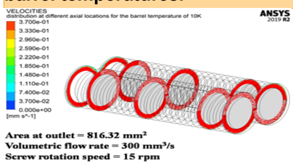


Figure 3: Extrusion velocities at different axial locations for 300 mm^3/ s at 15 rpm.

> ***"ANTYA compute resources had a key role in investigating the cryogenic process of solid hydrogen extrusion using a twin-screw extruder and developing the CFD model focusing on screw rotation speed affecting the extrusion rate and viscous dissipation"***

Prediction of hydrogen temperature at the intermeshing zone inside the extruder system plays a vital role to decide the barrel temperature. Figure 2 shows the comparisons of extrudate temperature, between the flight gap near the barrel wall and the intermeshing region for the different barrel temperatures. Due to more number of moving surfaces at the intermeshing region, the temperature is higher and increases above the melting point (T_m = 13.8 K) of the hydrogen. In this case, at a barrel temperature of approximately 11.5 K, the hydrogen temperature will reach the melting point. The extrudate is likely 2-phase with a low solid fraction over this barrel temperature of 11.5 K. Other parameters like viscous heating could be visualized with the help of contour plots, which are difficult to study experimentally or analytically. This study would help plan the experiments for the extrusion of hydrogen pellet in near future. At a barrel temperature of 13 K, the increase in viscous dissipation increases screw temperatures above the melting point (T_m) of hydrogen. All screw temperatures decrease with barrel temperature at a high rate of change. This is again due to the change in shear stress behaviour at a specific temperature below the melting point. Figure 3 shows the extrusion velocities inside the fluid domain. The simulations for this study were carried out using 2 HPC packs with 32 cores on ANTYA, taking ~10-12 hours significantly lower than the workstation (36 hours). Future investigation will be based on the simulation of liquid, liquid-solid and solid regimes of the hydrogen in the extruder.

References:

1. *Jacob Thomas Fisher, "Diagnostic Twin Screw Extruder for Characterizing Fusion Tokamak Fuel Production," Dissertation, Washington State University, 2015.*
2. *Shashi Kant Verma, et al., A Review of Pellet Injector Technology: Brief History and Recent Key Developments, Fusion Science and Technology, Volume 76 (770–785); August 2020.*
3. *J.W. Leachman, Thermophysical Properties and Modeling of a Hydrogenic Pellet Production System, Dissertation University of Wisconsin-Madison, 2010.*
4. *J. T. Fisher et al., Development of a Diagnostic Twin Screw Extruder to Characterize Fuel Production for Tokamaks, Fusion Science and Technology, 64:3, 525-529 (2013).*
5. *Shashi Kant Verma, et al., Development of CFD Model for the Analysis of a Cryogenic Twin-Screw Hydrogen Extruder System, Cryogenics 113 (2021) 103232.*
6. *L.P.B.M. Janssen, A Phenomenological Study on Twin Screw Extruders, PhD Thesis, Aerodynamics & Wind Energy, Applied Sciences (June 1976).*
7. *I.V. Vinyar and A. Ya. Lukin, Screw Extruder for Solid Hydrogen, Tech. Phys. 45 (1) (2000) 106–111.*

Compilers Available on ANTYA for Popular Programming Languages: C, C++ and Fortran

ANTYA has three sets of compilers namely GNU, Intel, and Portland Group, Inc. (PGI). Each set includes compilers for the most commonly used programming languages, C, C++, and FORTRAN. Intel compilers are part of the Intel Parallel Studio XE Cluster edition and are licensed. PGI Compilers can be used when doing GPU programming with OpenACC and are also licensed. These compilers suits are available through modules to set up the user environment in ANTYA. Open source GNU compilers will give reliable results but the Intel or PGI compilers may provide considerable performance improvements depending on your code and libraries being used.

Serial Compilation for Single Core Codes

Language	GNU Compilers	Intel Compilers	PG Compilers
C	gcc	icc	pgcc
C++	g++	icpc	pgc++
Fortran	gfortran	ifort	pgfortran, pg77, pg90

Parallel Compilation for MPI Codes

Language	GNU Compilers (openmpi, mpich)	Intel Compilers
C	mpicc	mpicc/mpiicc
C++	mpicxx/mpic++/mpiCC	mpiicpc/mpicxx
Fortran	mpif77/mpif90/mpifort	mpif77/mpif90/mpiifort

Syntax

Check the available versions for the GCC, Intel and PGI compiler suite

```
$ module avail gcc
$ module avail intel
$ module avail pgi
```

Check the available versions for the open source compiler suite for MPI

```
$ module avail openmpi
$ module avail mpich
```

Intel has its own MPI libraries and does not need any 3rd party software.

Example files are available in /scratch/compiles_examples.

ANTYA UPDATES AND NEWS

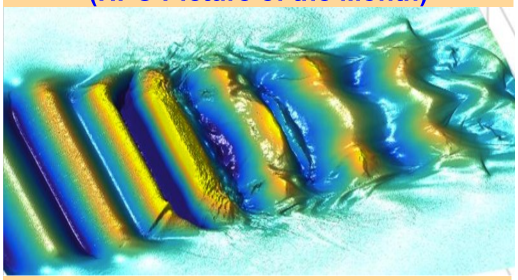
1. **New Software Installed**
   - ⇒ **Pluto-4.4 module**
   - ⇒ **RASPA2 module**
   - ⇒ **Paraview-5.7.0 and Ovito singularity container images now available**
   - ⇒ **Image Processing packages in python379 module**
2. **DDN Storage Controller issue identified and resolved**

AI Bootcamp for Science Series-II

Registrations will be open soon

Wakefield Production from Beam Plasma Interaction

(HPC Picture of the Month)



Pic Credit: **Ms. Devshree Mandal**

Wakefields are generated in a media when an object moves fast through it. In this image, longitudinal field of plasma is represented in a case when an electron beam is propagating with 0.9c velocity. Such wakefields are used in PWFA scheme to accelerate electrons upto GeV energies. The image was generated in Matlab with data obtained from OSIRIS 4.0 simulation run on ANTYA (OSIRIS 4.0 used under UCLA/IST-IPR OSIRIS Agreement, provided by Dr. Bhavesh G. Patel).

Other Recent Work on HPC

Numerical Simulation of Diesel Combustion Passing Through High Power Arc Region in a Plasma Fuel System	SUNIL BASSI
Cryogenic Vacuum Producing System	RANJANA GANGRADEY
Preliminary Estimation of Radionuclides generation in a fusion reactor environment for medical and industrial applications	SHRICHAND JAKHAR
Resonance heating at lower hybrid frequency via laser in a magnetised plasma	AYUSHI VASHISTHA
The study of unconventional boundary driven mechanism for generating magnetic field	DEVSHREE MANDAL
Landau damping in 1D periodic inhomogeneous collisionless plasmas	SANJEEV KUMAR PANDEY
Effect of ion population on a toroidal electron plasma	SWAPNALI KHAMARU
Can a small fraction of mass inhomogeneity decide the fate of Rayleigh-Bénard convection cells in 2D Yukawa liquids?	PAWANDEEP KAUR

Tip of the month

TO CHECK THE LIST OF HISTORICAL JOBS OF A USER

```
$ qstat -x -u username
```

Acknowledgement

The HPC Team, Computer Division IPR, would like to thank all Contributors who helped to make this newsletter available in time.

On Demand Online Tutorial Session on HPC Environment for New Users Available

Please send your request to ***hpcteam@ipr.res.in.***

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