A Review of TOKAMAK Fuelling Systems

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Abstract— In today's world, the electricity production and its optimum usage are one of the biggest issues. Because of depleting conventional energy resources and harmful waste from nuclear fission reactor, a group of technical people across the globe is focussing on fusion reaction process and plasma technology. Tokamak is a plasma confinement which needs to be fed hydrogen continuously to ensure continuous fusion process and hence continuous energy generation. The main technical challenge incorporate here is that we need to feed the fuel in the form of solid only. And in this paper we are going to review some methods or techniques as a TOKAMAK fuelling solution.

Keywords: Tokamak Fuelling, Extrusion, Pellet Injection System, Screw Extruder, Fusion Reaction

I. INTRODUCTION

As far as the engineering and technology is concerned, the biggest issue for entire "Human Being" is to generate POWER with eco-friendly way. Because in current conditions the conventional energy resources are being depleted very quickly and after few decades it may happen that there will be no sufficient conventional energy resources for further use. And simultaneously there is a huge problem of pollution which is created by the conventional energy sources, which now a days is a biggest worldwide issue. And we have a hope to solve this issue permanently by means of fusion reaction of hydrogen isotopes. Fusion is the process in which there is no harmful product to spread pollution and even we have large ocean to have almost infinite amount of hydrogen to be fused, so by means of fusion process and plasma technology we can generate almost CLEAN, GREEN and INFINITE source of energy. So we are trying to develop plasma technology and fusion to be optimized so that we will be able to provide the necessary energy sources for upcoming generation.

II. INTRODUCTION TO TOKAMAK

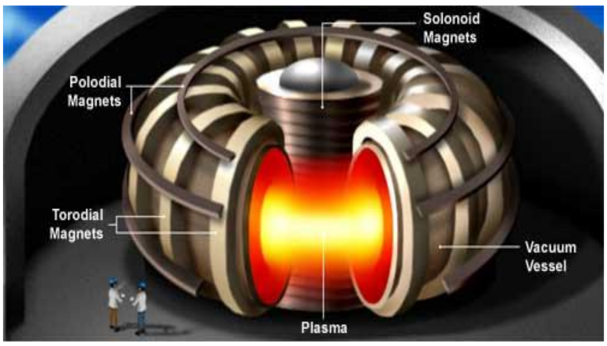

Fig. 1: Tokamak Illustrations (I)

A tokamak is a device using a magnetic field to confine plasma in the shape of a torus. Achieving a stable plasma equilibrium requires magnetic field lines that move around the torus in a helical shape. Such a helical field can be generated by adding a toroidal field (traveling around the torus in circles) and a poloidal field (traveling in circles orthogonal to the toroidal field). In a tokamak, the toroidal field is produced by electromagnets that surround the torus, and the poloidal field is the result of a toroidal electric current that flows inside the plasma. This current is induced inside the plasma with a second set of electromagnets.

The toroidal shaped TOKAMAK is the control volume where the matter would remain in PLASM state-a fourth state of matter. Inside the tokamak the fusion reaction takes place and generates great amount of energy which would be extracted by coolant as heat and supplied to turbine generator and thus Electricity is generated. As soon as hydrogen nucleus gets fussed and helium nucleus formatted and simultaneously heat is produced, we need to pump out helium particles and feed the fresh hydrogen to the tokamak. The feeding of hydrogen is must be in the form of solid because of some magnetic field limitations in tokamak. Therefore we need one equipment or a system which can provide enough solid hydrogen in desired dimensions.

First the material inside is heated to very high temperature so that it can be converted to the plasma. And then continuous feeding of hydrogen is required and simultaneously the helium gas is to be drawn out side

III. INTRODUCTION TO THE HYDROGEN FEEDING SYSTEM

The hydrogen gas comes inside and gets cooled by cryocooler and then phase change takes place from liquid to solid. After that the solid hydrogen is pressed against the die through piston cylinder arrangement and hydrogen is extruded throughout with continuous cross section as per the die.

Then a cutting mechanism comes in picture. By means of shear failure the continuous fibre is formed in the shape of pre decided pellets in particular frequency. The pellets get accelerated by the pressurized helium gas flow. And so the pellets are injected to thetokamak.

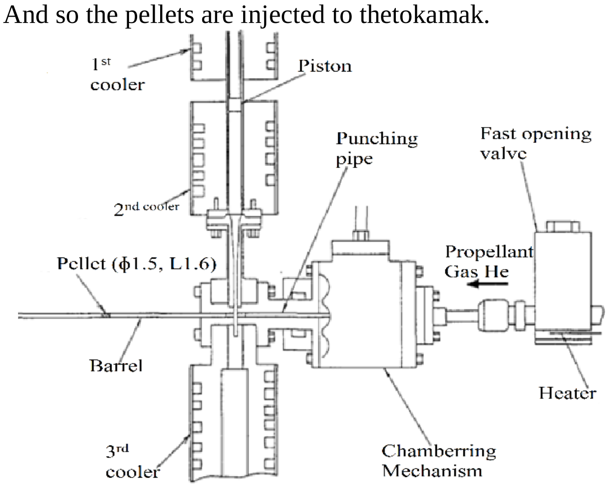

Fig. 2: Basic Arrangement of Hydrogen Feeding System (1)

IV. TASK AND CHALLENGE

The main task of injection system is to fulfil the requirement of the fuel inside the tokamak by optimizing

- Shape and size
- Frequency
- Density

Simultaneously we need to take care of

- Total volume that the system can handle
- Nature of the extrusion (continuous or pulsative)
- Total heat load on the system etc.

V. THE ATTEMPT TO FULFIL THE REQUIREMENT OF SOLID PELLET

To fulfil the requirement of fuelling of solid hydrogen to the tokamak some serious efforts has been made. The hydrogen pallet injection system has been developed (2).

The scientists from the University of California, USA, have developed the hydrogen pellet injector system. It was the basic setup shawn in figure below to provide solid hydrogen pellets which has successfully delivered the required output.

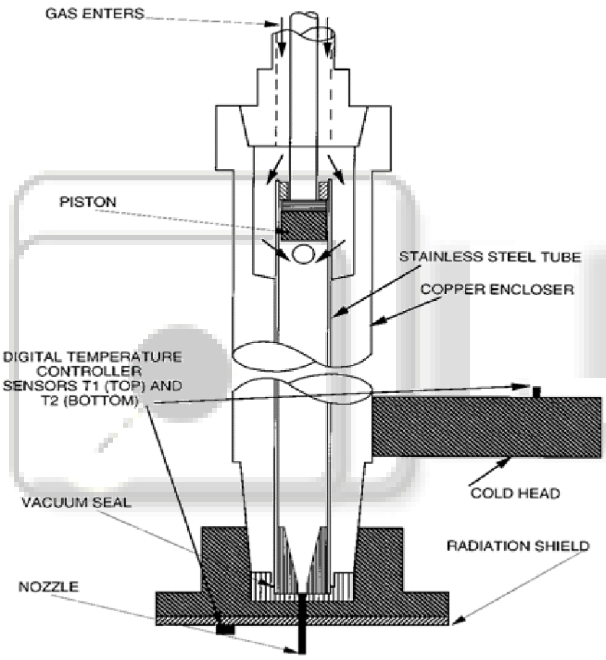

Fig. 3: Piston Cylinder Extrusion (2)

The main drawback of this type of extruder is pulsative or non-continuous output, which is not preferable for the task of tokamak feeding. So we need to go for an option that can provide a continuous output.

VI. SCREW EXTRUSION

For continuous extrusion process a screw type of extruder which is generally used in polymer industry is taken as a solution for continuity.

A technique for continuous production of solid hydrogen and its isotopes by a screw extruder is suggested for the production of an unlimited number of pellets. The idea was developed and patented by PELIN laboratories, Inc. (Canada)(3).

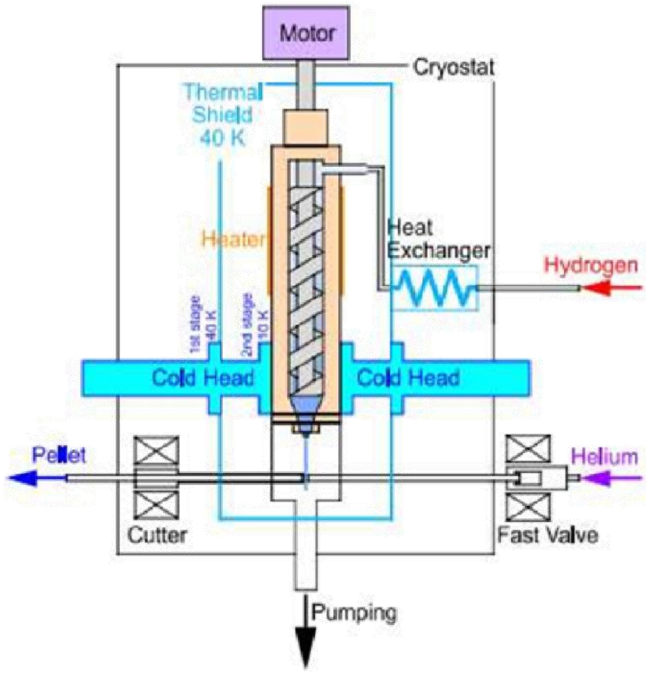

Fig. 4: Conceptual Screw Extruder (3)

A Gifford McMahon cryocooler is the better option for the generation of solid hydrogen fluid pellets (3).

VII. SENSITIVITY ANALYSIS

A sincere effort was carried out to measure the sensitivity of different parameters on the screw performance (4).

The parameters observed are Liquid specific heat, Solid specific heat, Latent heat of solidification, viscous dissipation, Solid enthalpy, Liquid enthalpy and Two-phase enthalpy.

This paper discusses the modelling of a twin-screw extruder, cooled by a GM cryocooler is developed, in order to simulate the solidification of deuterium over a range of operating conditions and extruder design parameters. The numerical model integrates a set of governing differential equations in the flow direction and includes variations in the thermodynamic and transport properties of the deuterium and extruder material as well as the effect of viscous energy dissipation and the latent heat of solidification. The model is used to evaluate the sensitivity of the extruder performance to the various parameters and processes in order to identify the critical areas for future experimental efforts.

The result is given in the form of charts below.

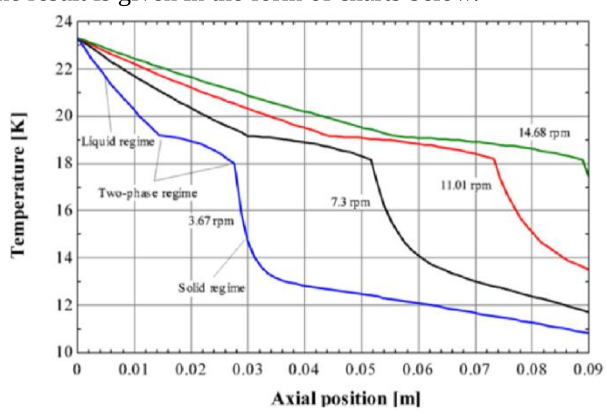

Fig. 5: Axial Temperature Distribution of The Wall & Fluid (4)

Here it is the chart for sensitivity comparison

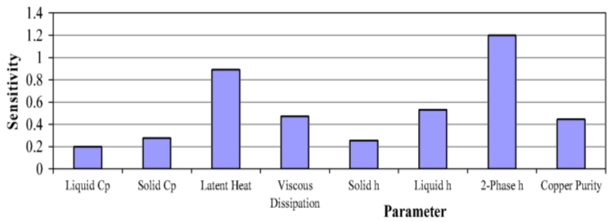

Fig. 6: Sensitivity of The Extrusion Performance to Several Parameters (4)

So we can conclude that the 2- phase behaviour of material and its enthalpy is the most sensitive parameter to influence the performance of the screw extruder.

VIII. Configuration of the Screw

There are mainly two types of arrangement, single screw and twin screw.After analysing the benefits and limitations of single and twine screw extruder, we conclude some points to be considered by referring one technical paper which shows that twin screw arrangement is better for extrusion purpose. (5).

Parameter	Single screw extruder	Twin-screw extruder
Main energy supply	Viscous dissipation	Heat transfer to barrel
Transport mechanism	Friction between metal and material	Positive displacement
Through-put capacity	Depended on material properties	Independent
Heat distribution	Large temperature Differences	Small temperature Differences
Mechanical power Dissipation	Large shear forces	Small shear forces
Capital costs	Law	High
Preferability	Moderate	Good

Table 1: Comparison of Single & Twin Screw Extruder Arrangement (5).

IX. Development of Screw Extruder at ITER

A sincere effort was given at Oak Ridge National Laboratory for twin screw extruder development for ITER (International Thermonuclear Experimental Reactor) pellet injection system. (6)

They have suggested the new improved liquefier design for elimination of transfer tubes from crossing the vacuum space.

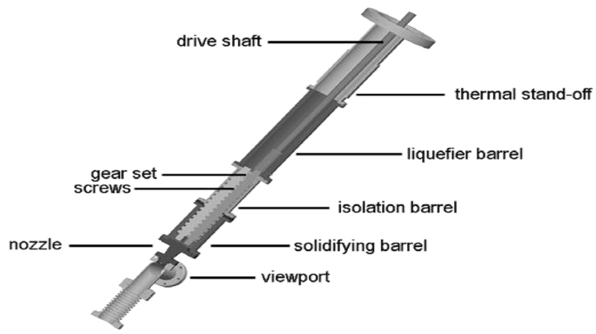

Fig. 7: Twin Screw Extruder with Co-Axial Mounted Liquefier (6)

The flow through their prototype extruder was calculated as a function of leakage as shown by the Q_{net} curve shows that a gap size of ~ 0.127 mm (0.005 in) is desired for the efficient extrusion of D_2

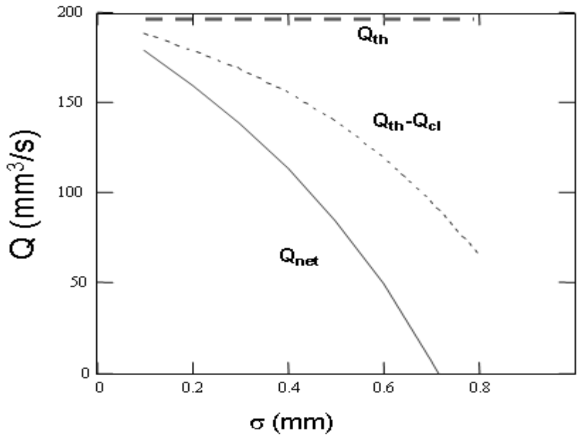

Fig. 8: Extrusion Losses Due to Leakage (6)

Gap sizes smaller than 0.127 mm are difficult to achieve with allowable assembly tolerances.

X. Viscosity, Shear Stress and RPM Variation

The viscosity is very important for extrusion performance and therefore I. V. Vinyar& A. YA. Lukin has carried out experiment to find temperature dependence of viscosity of hydrogen (7).

It may be calculated the variation of the shear stressτ_0 and the viscosityμ as functions of the temperature. The initial approximation for was determined by the pressure corresponding to a zero extrusion velocity, and the initial $\mu_0$and $\tau_0$value was estimated from the maximum flow rate. The iterative process leads to the following approximate Relationships (7).

$$\tau_0 = 0.026 * \exp[0.28(T_S - T)]$$
$$\mu = 0.0027 * \exp[0.44(T_S - T)]$$

Solid curves in Figure below shows the plots of calculated extrusion velocity versus temperature for various pressures.

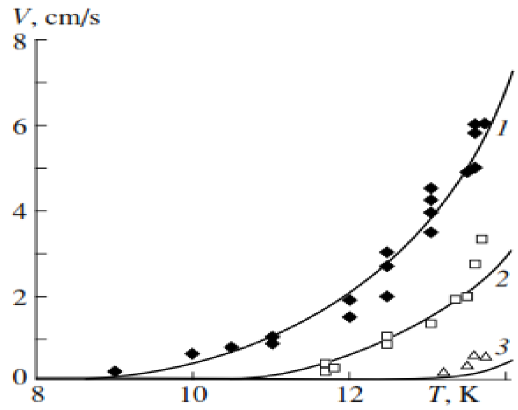

Fig. 9: The Plots of Hydrogen Extrusion Velocity Versus Temperature at Various Pressures (Mpa): (*1*) 10, (*2*) 5.5, (3)2.5 (7)

Also there is an analysis of extrusion velocity vs. screw rotation speed. (6)

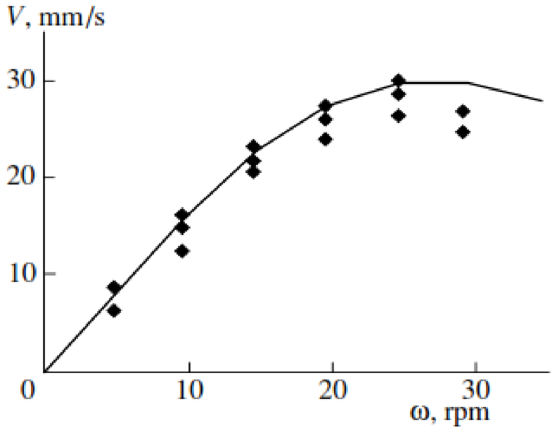

Fig. 10: Graph Of Extrusion Vs. Screw Rotation Speed (7)

XI. Conclusion

- There is a requirement of fuelling hydrogen isotopes in Tokamak in only solid form.
- The fuelling requirement can be solved by hydrogen feeding system, but the drawback is pulsative non-continuous output.
- Screw extrusion can be used for continuous output.
- GM cryo-cooler is the better option for cooling and freezing purpose.
- With increase in RPM the length required for freezing also increases.
- 2-phase behaviour of the fluid is the most sensitive parameter which influence the performance of the extruder.
- Twin screw extruder is better than single screw extruder system.
- Twin screw extruder with co-axial mounted liquefier is better option for compatibility.
- The extrusion rate decreases with increase in leakage.
- The extrusion velocity increases with increase in pressure and temperature.
- The extrusion velocity increases with increase in RPM up to a certain limit than it decreases with RPM increases.

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