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Different types of cryogenics Pellet injection systems (PIS) for fusion reactor

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Abstract
Fusion reactor is the one of the most capable option for generating the large amount of energy in future. Fusion means joining smaller nuclei (the plural of nucleus) to make a larger nucleus and release energy in the form of neutrons.The sun uses nuclear fusion of hydrogen atoms into helium atoms. This gives off heat and light and other radiation. Hydrogen is used as the fuel in the fusion reactor. We have to inject the solid hydrogen pellet into the tokamak as per the requirement. For injecting the pellet we use the pellet injection system. Pellet injection system (PIS) is the fuel injection system of the fusion reactor.
Keywords: Pellet injection, Comparison of different PIS

I. Introduction

Tokomak is the doughnut shape vessel (fusion reactor) in which the heat energy librates due to the fusion of the hydrogen take place inside the vessel. For this fusion process hydrogen is the fusion fuel. We have to inject hydrogen continuously inside the tokomak for getting heat energy continuously by the fusion process. The pellet injection systems are used to inject the solid hydrogen in the reactor. There are different types of pellet injection systems are available as below:

1) Gas gun type
2) Centrifugal type
3) Rail gun type
4) Extruder type
   i. Piston type
   ii. Single screw
   iii. Double screw

II. Different Pellet injection Systems

B. Plöckl, P.T. Lang(Plockl, Lang, Jehl, & Prechtl, 2010)In case of a **blower gun** (and a gas gun as well), acceleration of pellets is due to expanding gas which pushes or drags the pellet. The diameter of the pellet is smaller than the diameter of the barrel and the gas flows around the pellet. Acceleration force transfer follows the force closure principle (frictional connection), hence some slip is present. The thermal impact of the propellant gas influences the pellet as well. Both effects can cause a variation of the velocity and time scatter.

A shuttle in reciprocating motion cuts the ice rod and moves it in one of the two firing positions in front of the barrel. A short propellant gas pulse released by a fast valve accelerates the pellet.

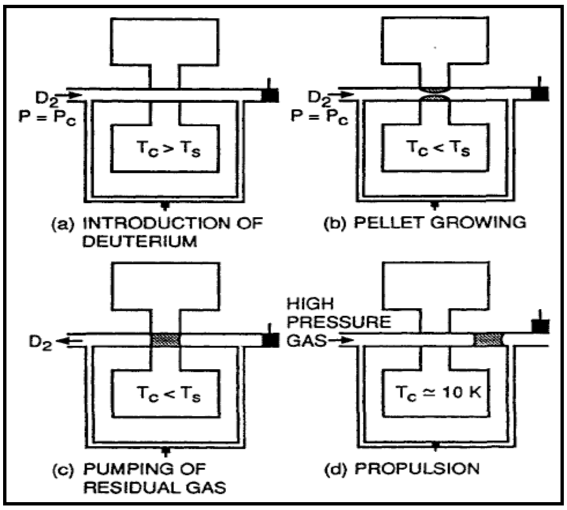


Figure 1 Gun type pellet injection system

B. Plöckl, P.T. Lang(Plockl, Lang, Jehl, & Prechtl, 2010)In the **centrifuge** the acceleration is due to the centrifugal force acting on a pellet sliding in the grooveof a rotating straight arm. Consequently there is no slip during acceleration. Hence the accelerationof pellets follows the form-closure principle (positive locking) and can be very precisely tunedprovided the onset conditions are sufficiently accurate. This requirement is attained by the stop cylinder technique. The generated pellet drops into the stop cylinder that is mounted adjustablebut not rotating above the centrifuge.

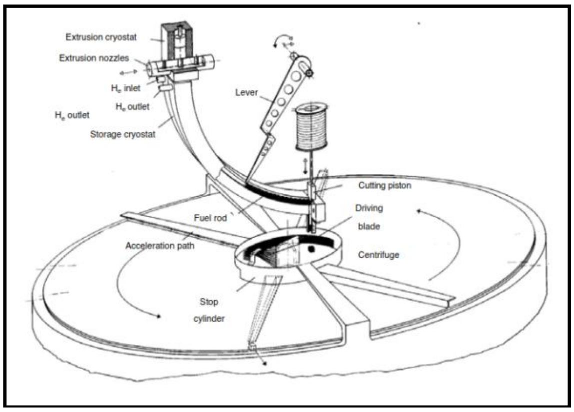


Figure 2 Centrifugal PIS

This stop cylinder ensures an accurate timing for the startof the acceleration since the pellet leaves the stop cylinder at a well defined radial position withzero speed. In the absence of any propellant gas and due to the Leidenfrost effect heat transfer andfriction are low. The centrifuge revolution frequency precisely prescribes the pellet velocity (speed
scatter at the exit < 0.25%); the repetition rate has to be an integer fraction of centrifuge frequency.

Upon request, the ice rod is shifted by a stepping motor driven mechanical lever; the number of steps determining the pellet length. The pellet is chopped from the rod using an electromechanical cutter.

The ice production is similar to the blower gun using an extrusion cryostat and a storage cryostat. Three different pellet sizes can be selected without any mechanical intervention into the system.

The transfer line guides the pellets to the High Field Side (HFS) of AUG. In order to achieve high pellet velocities a “looping” has been installed, a 17m long transfer line of elliptical shape avoiding changing curvature direction. Due to the Leidenfrost effect and good pumping, friction and the heat transfer are low. The maximum useful transfer velocity is 1000m/s.

Table 1 Comparison of relevant data

System	Pellet velocity [m/s]	Repetition rate [Hz]	Transfer: length / time	Time scatter [ms]
AUG Centrifuge	1000	62	17m 17ms	± 0.23
AUG Blower gun	100	60	5m 50ms	± 31
JET Centrifuge	160	5	12m 75ms	± 2.2
JET Blower gun	142	10	10m 70ms	± 9

S. K. Combs, S. L. Milora(S.K., S.L., & L.R., 2000) While great progress has been made in the area of pellet injector technology at Oak Ridge National Laboratory (ORNL) and around the world during the last decade [1–3], additional research and development are required to meet the fueling needs of the International Thermonuclear Experimental Reactor (ITER) and future fusion reactors. The base-line ITER pellet injector concept is the centrifuge acceleration device. Centrifuge pellet injection systems are currently in operation on ASDEX-U,Tore Supra, and the Joint European Torus (JET). Present devices operate at pellet frequencies of up to 5 to 80 Hz with nominal pellet diameters of 1 to 3 mm. Operation with Pellets >3 mm has yet to be demonstrated with the centrifuge accelerator.

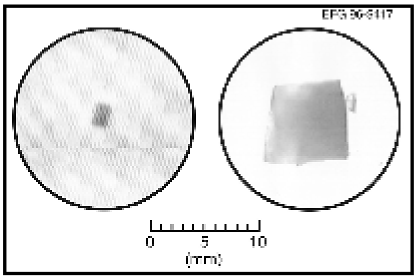


Figure 3 Photo of small duterium pellet

For the ITER application and future steady-state
fusion reactors, a feed system capable of providing a continuous supply of frozen isotopic hydrogen is required. A straightforward concept in which multiple extruder units of identical design operate in tandem was described briefly at the 1994 symposium.

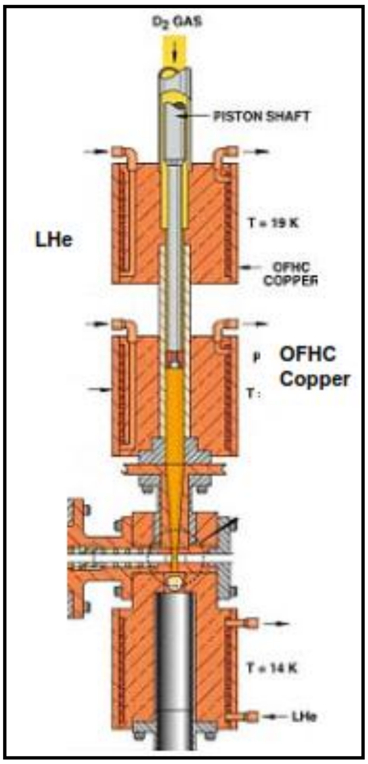


Figure 4 Piston type PIS

This approach applies a reliable ORNL technology that has been used on many pellet injection systems. The overall reliability of this technology is indicated by the performance record of the three-barrel repeating pneumatic injector, which includes three of the standard ORNL extruder units. Since its construction and initial testing in 1986, this system operated on JET from 1987 to 1992 and on DIII-D since 1994. Over a period of 10 years, the performance and reliability of the extruders have been outstanding; the three extruders have processed an estimated 5 to 10 kg of deuterium ice in that time period without any significant problems or mechanical failures.

S. J. Meitner and L. R. Baylor(S. & L., 2009) work on a**twin screw extruder** prototype for frozen deuterium pellet production, designed and constructed at Oak Ridge National Laboratory. This one-fifth ITER scale extruder is cooled by a combination of liquid nitrogen, and two cryo-coolers. Separate pre-cooler and liquefier sections reduce the room temperature deuterium gas to a 20K liquid before it is introduced into the extruder. Continuous extrusions in excess of 20 minutes have been made.

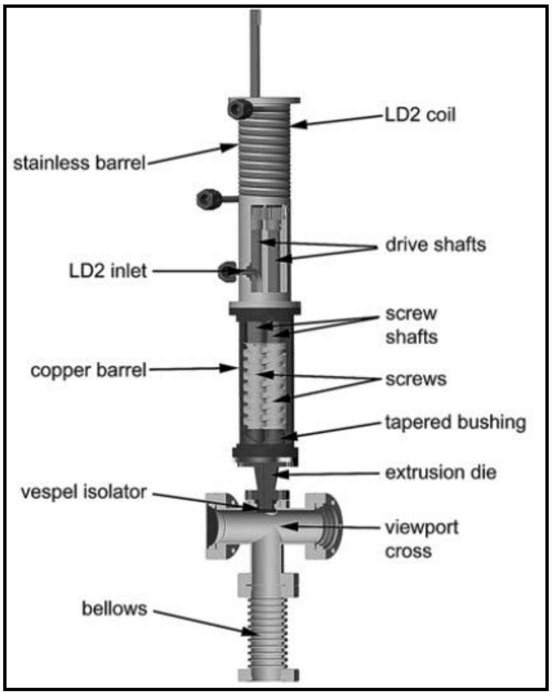


Figure 5 Twin screw extruder

Preliminary experiments have shown that initial extrusion start torque can be significant enough to damage the apparatus. The start torque is kept low by keeping a constant torque on the screws while heating the barrel with resistance heaters. Torque levels drop as viscous heating creates a slip layer between the deuterium and the screws.

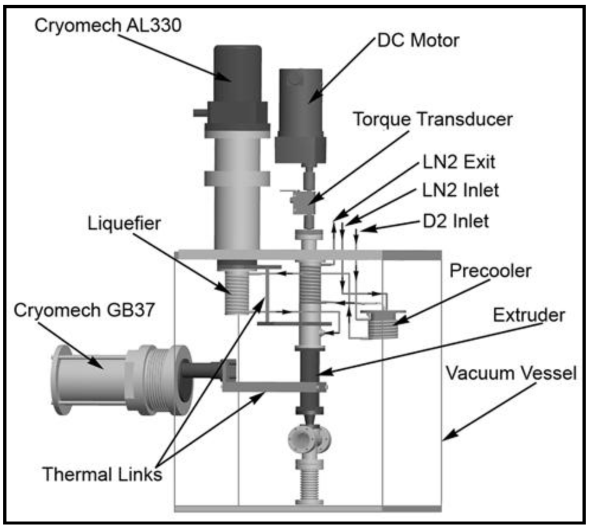


Figure 6 Deuterium flow path and cooling system

Experiment characterization tests were conducted at a constant rotation rate and a constant temperature. The extrusion rate increased from 7.4 to 8.6 mm^3/s as temperature was increased from 16.7 K to 17.6 K at a set 2 rpm. The extrusion rate increased from 8.6 to 11.5 mm^3/s as the rotation rate was increased from 2 to 7 rpm at a constant 17.6 K.

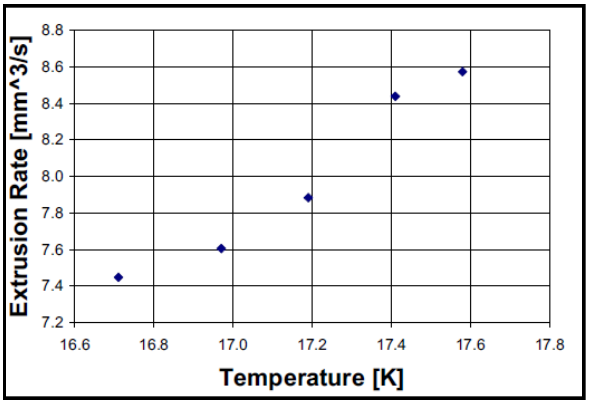


Figure 7 Deuterium Extrusion Rate at 2 RPM

These extrusion rates indicate that material is lost through the gaps in the screws and so a future iteration will be to reduce the gap size and increase the torque limit. Further optimization of the design tests for maximum extrusion rates will be conducted.

I. Viniar, S. Sudo, A. Geraud(Viniar, Sudo, & Geraud, 2001)works on the Pneumatic and centrifugal injectors for steady-state plasma refueling by solid hydrogen, deuterium and tritium pellets have been designed at the PELIN Laboratory to meet requirements.

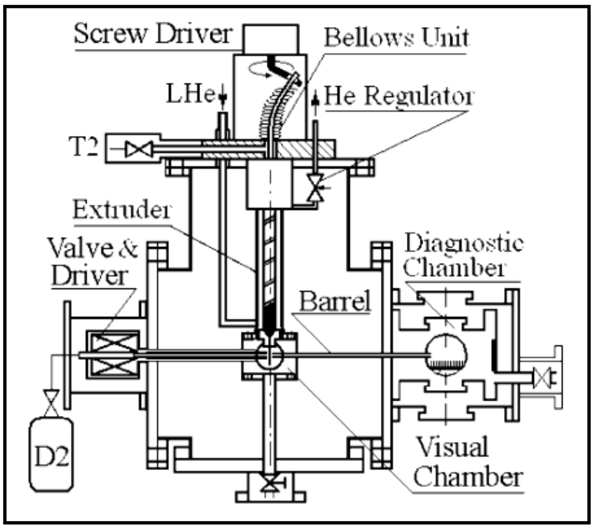


Figure 8 Schematic of a tritium pellet injector

Based on the screw extrusion concept, recent advances towards the development of a reliable plasma fuelling system for steady-state operation are encouraging. With a high reliability, over 1 million hydrogen and deuterium pellets, 2mm to 3mm in size, have been injected continuously by pneumatic injectors equipped with screw extruders at the repetitive rates of 1 Hz-15 Hz, during a lot of cycles of duration 100 s ~2000 s.

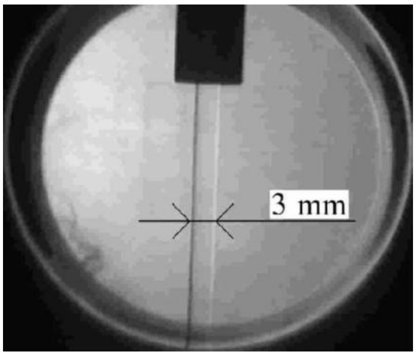
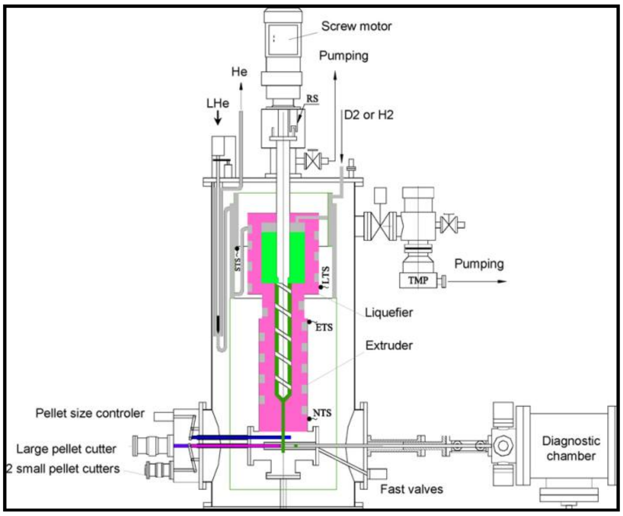


Figure 9 Solid hydrogen rod extruded at 11 K

A tritium injector with a screw extruder is also being prepared for tritium tests. Anew design of the centrifugal injector promises to provide an adequate level of pellet injection reliability.

Alain Geraud and M. Dentan(Geraud & Dentan, 2007) carried out their work on a new deuterium ice pellet injector is in preparation for JET. It is designed to inject both small pellets (variable volume within1–2mm3) at high frequency (up to 60 Hz) for ELM mitigation experiments and large pellets (volume within 35–70mm3) at moderate frequency (up to 15 Hz) for plasma fuelling. It is based on the screw extruder technology developed by PELIN and pneumatic acceleration. An injection line will connect the injector to the flight tubes already in place to convey the pellets toward the plasma either from the low field side or from the high field side of the torus. This injection line enables: (i) the pumping of the propellant gas, (ii) the provision of the vacuum interface with the torus and (iii) the selection of the flight tube to be used via a fast selector. All the interfaces have been designed and a prototype injector is being built, to demonstrate that the required performance is achievable.



II.10 Schematic drawing of the PELIN pellets injector

A new hydrogen/deuterium pellet injector capable of injecting small pellets for ELMs mitigation experiments and large pellets for plasma fuelling is in preparation for JET as part of the JET-EP2 programme. This injector is fully ITER relevant apart from tritium aspects.

Conclusion

Different types of pellet injection systems are available and they all have their own pros and cons. Now the main requirement of the pellet injection is higher density, continuous injection and high reliability.

From all the PIS available extruder type pellet injection systems are the latest and can inject the pellet continuously with high frequency. From below table we can compare the different pellet injection systems.

Table 2 Comparison of different PIS

	Pipe gun type	**Piston Extruder**	**Single Screw Extruder**	**Twin Screw Extruder**
Advantages:	simple design	5 Hz pellet production Simple design	pellet production with high frequency >95% reliability Continuous production	- Positive pumping. -Low supply pressure. -Increased mass flow. -Low risk of stalling. -Still simple design. -Larger fluid volume with lower shearing at wall.
Disadvantages:	very low frequency not continuous less reliability	not continuous	Stalling issues supply pressure high	-High shearing between two screws and screw thread and barrel wall.

From the above table we can say that the Twin screw extruder system is most suitable PIS for the fusion reactor.

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