Lithium pellet production (LiPP): A device for the production of small spheres of lithium

P. Fiflis, D. Andruscyzk, A. L. Roquemore, M. McGuire, D. Curreli, and D. N. Ruzic

Citation: Review of Scientific Instruments 84, 063506 (2013); doi: 10.1063/1.4811665
View online: http://dx.doi.org/10.1063/1.4811665
View Table of Contents: http://scitation.aip.org/content/aip/journal/rsi/84/6?ver=pdfcov
Published by the AIP Publishing

Articles you may be interested in
Interpretation of the nonlinear mode excitation in the ITER gyrotron
Phys. Plasmas 14, 113103 (2007); 10.1063/1.2802076

Magnetohydrodynamic-activity-induced toroidal momentum dissipation in collisionless regimes in tokamaks
Phys. Plasmas 10, 1443 (2003); 10.1063/1.1567285

Phenomenology of internal reconnections in the National Spherical Torus Experiment
Phys. Plasmas 10, 664 (2003); 10.1063/1.1539031

Understanding and control of transport in Advanced Tokamak regimes in DIII-D

Progress in resolving power and particle control issues for the International Thermonuclear Experimental Reactor
Phys. Plasmas 4, 2631 (1997); 10.1063/1.872405
Lithium pellet production (LiPP): A device for the production of small spheres of lithium

P. Fiflis,1,a) D. Andruyczk,1,b) A. L. Roquemore,2 M. McGuire,1,c) D. Curreli,1 and D. N. Ruzic1
1Center for Plasma Material Interactions, Department of Nuclear, Plasma, and Radiological Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, USA
2Princeton Plasma Physics Laboratory, Princeton, New Jersey 08540, USA

(Received 28 February 2013; accepted 6 June 2013; published online 26 June 2013)

With lithium as a fusion material gaining popularity, a method for producing lithium pellets relatively quickly has been developed for NSTX. The Lithium Pellet Production device is based on an injector with a sub-millimeter diameter orifice and relies on a jet of liquid lithium breaking apart into small spheres via the Plateau-Rayleigh instability. A prototype device is presented in this paper and for a pressure difference of $\Delta P = 5$ Torr, spheres with diameters between $0.91 < D < 1.37$ mm have been produced with an average diameter of $D = 1.14$ mm, which agrees with the developed theory. Successive tests performed at Princeton Plasma Physics Laboratory with Wood’s metal have confirmed the dependence of sphere diameter on pressure difference as predicted. © 2013 AIP Publishing LLC. [http://dx.doi.org/10.1063/1.4811665]

INTRODUCTION

One of the most significant problems in magnetic confinement fusion devices is controlling the recycling of hydrogen from the walls of the vacuum vessel which limits the performance of the plasma. It is known that lithium is a powerful getter of hydrogen and by depositing lithium in specific regions of a fusion device, most notably the divertor,1,2 higher energy confinement times, reduction in the amplitude of Edge Localized Modes (ELMs), higher edge temperatures and densities have been achieved.3 At Princeton Plasma Physics Laboratory (PPPL) the National Spherical Torus eXperiment (NSTX) is a leader in lithium research for fusion and its primary method for depositing lithium is via a lithium evaporation (LITER) system4 or a lithium aerosol.5

Recently, a granular injector has been developed at PPPL and tested on EAST in China and RFX in Italy.6 The granular injector uses spheres of lithium that are released from a dropper3 and then impacted with a rotating impeller that injects these spherical pellets into the plasma and is able to trigger an ELM in a controlled fashion. The supply of pellets at the correct size is important and pellets up to 1 mm diameter are predicted for proper ELM control. Having a method for producing regularly sized pellets would be of great benefit for a device like the granular injector. This paper presents a Lithium Pellet Production (LiPP) device that has been developed at the Center for Plasma Material Interactions (CPMI) at the University of Illinois Urbana-Champaign (UIUC). LiPP is intended to produce small lithium pellets in the range of 1 mm diameter for use with the granular injector and lithium particle dropper at PPPL. The method is based on the disruption of a jet of liquid metal into small droplets and can be extended to any metal with sufficiently low melting point.

The result is a very simple and relatively inexpensive tool that can create hundreds of small spheres of lithium with a very tight size distribution in a matter of tens of seconds.

SPHERE PRODUCTION

Figure 1 shows a schematic and photo of the injector that was developed to produce spheres of a uniform size. The injector consists of three sections; the first is a pressure chamber, the second is a 1/2" heated stainless steel tube, and the third is the nozzle which is also made from stainless steel. The most important section is the nozzle which has the orifice that the lithium is forced through. Several nozzles have been manufactured, each one having a different size orifice: $R_0 = 0.15$ mm, 0.5 mm, and 1.0 mm. The nozzle can be screwed on or off the end of the 1/2" stainless steel tube to change the orifice size as needed. The tube and the nozzle are heated with a coil of nichrome wire with an insulating layer of Kapton tape in between the wire and the tube surface. The nozzle has its own separate heating coil since the nozzle is immersed in mineral oil. The nozzle is immersed in mineral oil to cool the spheres upon ejection and to coat the surface of the sphere to slow oxidation.

To produce the spheres, argon gas is flowed through the injector while a rod of lithium fitting the inner diameter of the stainless steel tube is inserted. The lithium is heated to its melting temperature, 181 °C, while argon gas is flowed. Once the lithium melts it makes a seal and the argon stops flowing, which can be monitored by observing bubbles of argon exiting the nozzle. A ball valve between the tube and a small ballast chamber is then opened and the pressure in the ballast chamber forces the liquid lithium to exit as a jet, shown in Figure 2. This jet
then breaks into droplets or “pinches-off” due to the Plateau-Rayleigh instability.\(^7\) Plateau-Rayleigh theory begins with a sinusoidal perturbation to the radius of the jet, and follows the evolution of this disturbance over a falling column of liquid. To first order, the dispersion relation for the instability is given by

\[
\omega^2 = \frac{\gamma}{\rho R_0^3} k R_0 I_1(k R_0) I_0(k R_0) (1 - (k R_0)^2). \tag{1}
\]

The fastest growth rate in these instabilities occurs at \(k R_0 = 0.697\), or \(\lambda_{\text{max}} = 9.02 R_0\), where \(R_0\) is the nozzle radius. This is the mode which determines the size of the droplets. Let the height of a column of liquid, \(h_{\text{liq}}\), expelled in one cycle of the growth rate be

\[
h_{\text{liq}} = \frac{\psi_{\text{liq}}}{\omega}. \tag{2}
\]

where \(\psi_{\text{liq}}\) is the velocity of the column of liquid exiting the orifice. Using the Young-Laplace equation for pressure, \(\Delta P\), across a capillary surface, and the dispersion relation for the Plateau-Rayleigh instability, substitution yields a droplet volume of the form

\[
V_{\text{droplet}} = 9.2338 \frac{\psi_{\text{liq}} R_0^3}{\sqrt{\Delta P / \rho}}. \tag{3}
\]

The diameter of a sphere is then calculated to be

\[
D_{\text{sphere}} = 2.603 \left( \frac{\psi_{\text{liq}} R_0^3}{\sqrt{\Delta P / \rho}} \right)^{1/3}. \tag{4}
\]

**INJECTOR FABRICATION**

The injector is a stainless steel tube with a nozzle attached to one end and an argon line attached to the other. The nozzle is manufactured by machining a short cylinder of stainless steel that is the same diameter as the tube. The upper part of the nozzle and the inside of the tube are threaded, so that the nozzle may be screwed into the tube. A tapered hole was pre-drilled through the center of the nozzle. At the top of the nozzle, the hole is as wide as may be machined without compromising the threading, in this case, 5 mm in diameter. The hole then tapers down to the desired orifice diameter on the bottom. The injector tube must also be heated beyond the melting point of the sphere material. This was accomplished via a nichrome heating wire electrically insulated from the tube with a layer of Kapton tape. The nozzle and part of the tube was then submerged in mineral oil. The oil serves two purposes, one is to cool the droplets, the second is to coat the lithium produced in a protective layer of oil to slow the process of impurity growth.

Since the mineral oil degrades the adhesive coating of the Kapton tape, each end of the heater coil was crimped to the previous loop to ensure that the coil stayed in place. The mineral oil is also thermally conductive so it was necessary to use two heating coils, one for the submerged portion of the injector and the other for the remainder of the injector tube that is not submerged. In this manner, the power to the submerged portion of the injector could be controlled independently. Three type-K thermocouples were used to monitor the temperature on the outside of the injector tube.

**EXPERIMENTAL RESULTS (SIZE DISTRIBUTION)**

Experiments were performed with the injector where sphere diameter and quality were monitored. The nozzle used for these experiments had an orifice of \(R = 0.15\) mm in radius and the pressure difference \(\Delta P = 5\) Torr. Using Eq. (4), the predicted droplet diameter is 1.04 mm. Experimentally, the distribution has been measured and agrees with the theoretical plot and over 80% of the pellets fall within a sphere diameter \(0.91 < D < 1.37\) mm.

When the 0.15 mm nozzle was replaced with a nozzle of 0.5 mm in radius, the mean diameter of the spheres...
was approximately 3.1 mm in size, also in agreement with 
theory. Experiments were attempted to confirm the relation-
ship between sphere size and backing pressure, however,
equipment constraints limited both accurate pressure con-
trol and pressure measurement. However, experiments per-
formed at PPPL verified the dependence predicted by Eq. (4).
The setup for these tests consisted of a heated pool of Wood’s 
metal ejected through a 0.15 mm radius nozzle by a backing 
pressure of argon. Wood’s metal was used because its sur-
face tension is comparable to that of lithium, and it therefore
should also produce spheres of similar diameter predicted by 
Eq. (4). Figure 3 illustrates the relationship of the drop diam-
eter on pressure, plotting sphere diameter against the parameter 
\((\nu_{\text{eq}} R_0^2(P/\rho)^{1/2})^{1/3}\). As can be seen from the graph, the experi-
mental points fit along a line with the slope 2.6, as can be 
calculated from Eq. (4).

EXPERIMENTAL RESULTS (QUALITY)

To ensure the quality of the spheres, they were checked 
for voids and deformation. Several larger spheres were sec-
tioned and found to contain no voids. Deformation was ob-
served for droplets that were still molten when impacting 
the surface. To combat such deformations, droplets were pro-
duced at a greater depth within the oil to ensure that they had 
more time to solidify before reaching the surface. Figure 4 
shows the spherical pellets produced by LiPP.

CONCLUSION

A method for producing small diameter spheres of low 
melting point, malleable metals were created at the University 
of Illinois. This device has been used to produce spheres of 
lithium in mineral oil, whose size distribution centered on ap-
proximately \(D = 1.1\) mm and agrees with theory. This process 
is adaptable, and by adjusting the nozzle’s orifice diameter 
and pressure, the different size spheres have been produced in 
agreement with theory. The size of the spheres is determined 
by the Plateau-Rayleigh instability as described in the Sphere 
Production section of this paper. It is also important to en-
sure that the lithium droplets are solidified before they impact 
the surface of the mineral oil where they are produced inside 
to minimize deformation. Additional experiments performed 
at PPPL with Wood’s metal confirmed theoretical predictions 
for droplet diameter versus pressure. In short, the device can 
be used to produce spheres of variable diameter either by al-
tering the nozzle radius or the backing pressure behind the 
fluid.

---

6D. Mansfield, in Proceedings of 24th IAEA FEC, San Diego, CA, 8–13 
October 2012. Abstract may be found at following link: http://www-naweb. 
7N. Ashgriz and A. L. Yarin, “Capillary instability of liquid free jets,” Hand-