Team 2: Joule-Thompson Valve Two-Phase Flow (Video)

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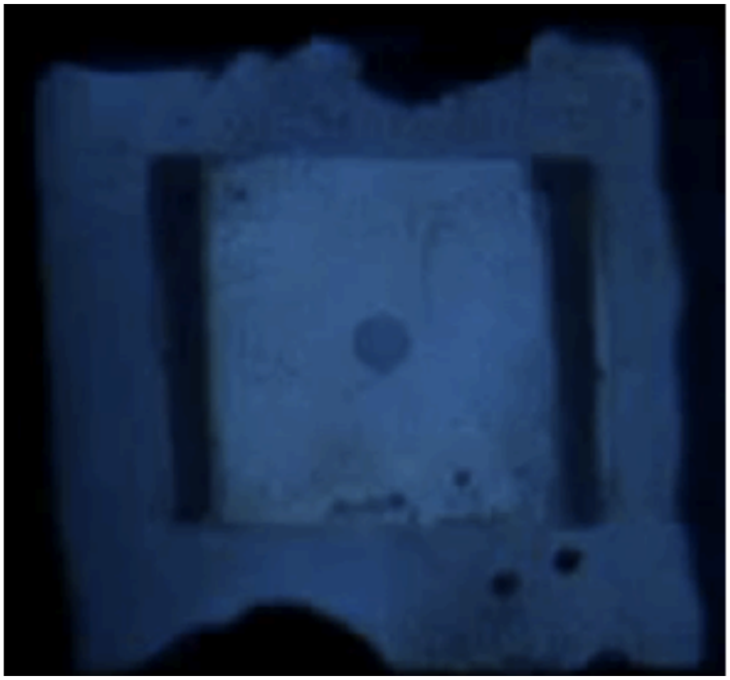

This video of two-phase flow thorough a Joule-Thompson (J-T) valve was created as a part of the team assignment for the Spring 2012 University of Colorado MCEN 4151: Flow Visualization course. It was created in conjunction with research done in the Department of Mechanical Engineering on cryogenic cooling and refrigeration systems. A team of 3 people came together to create this video in addition to video used for computational analysis. This assignment was designed to challenge students to go beyond what they are capable of capturing on their own, and to utilize resources, specifically other people, as an aid in creating an image of higher-level fluid phenomenon. This was the first assignment of the Spring 2012 semester.

Throughout the course of this video, the liquid enters on the edges from the left side of the frame. As the video progresses, the liquid front grows and retracts.

The Micro Cryogenic Cooler (MCC) is a refrigeration system that is able to cool to cryogenic temperatures below 200K (Radenbaugh 2009). This system includes a J-T valve at the cold head of the temperature differential. Figure 1 shows the setup and arrangement of the J-T valve in the system (Lewis 2010). The J-T valve is the small box-shaped instrument at the top of the fiber-based heat exchanger. The fluid used in this system was a mixed refrigerant developed at the National Institute of Standards of Technology and optimized for cooling to 160 K. It was composed of 5 gases with different boiling points shown in Table 1(Lewis 2010).

Table 1: Refrigerant composition

Refrigerant Composition		
Gas	*Percent*	*Boiling Point*
Methane	8%	111.7 K
Ethane	46%	184.6 K
Propane	14%	231.0 K
n-butane	4%	272.7 K
n-pentane	28%	309.2 K

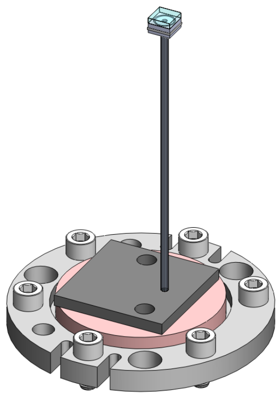

Figure 1: Micro cryogenic cooler setup

In this system, the J-T valve functions as a flow restriction then provides an area for fluid expansion (Lewis 2010). A close-up view of the J-T valve can be seen Figure 2 as well as a cross-sectional view in Figure 3. This is a very small valve with an area of approximately 4 mm^2.

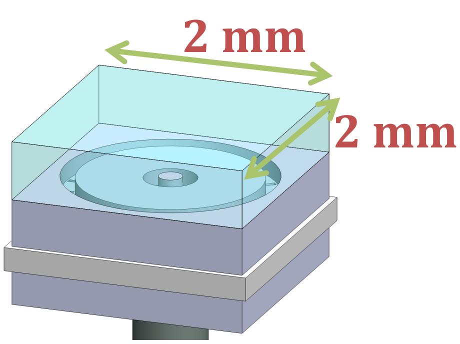

Figure 2: Close-up of J-T valve

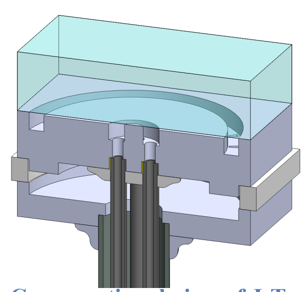

Figure 3: Cross-sectional view of J-T valve

In order to capture the movement of fluid through the J-T valve, it was necessary to design an experimental setup that would allow for the capture of video at a high frame rate and a very small field of view. Figure 4 shows the method used for image capture. An Olympus iSpeed high-speed camera was fixed with a c-mount adapter into a microscope. The microscope then was focused on the J-T valve. Due to the high frame rates required for this flow visualization, it was necessary to light the J-T valve with a fiber-based light source which was affixed to the base of the microscope and reflected off the Pyrex surface at the top of the valve.

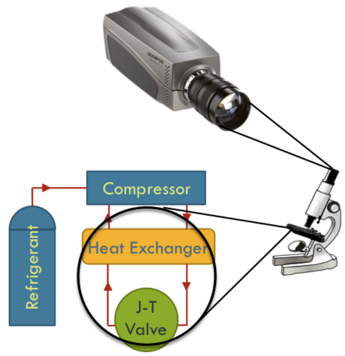

Figure 4: Method diagram

This flow cannot yet be described by equations due to its unusual two-phase gas-liquid nature. During the course of the video, it is possible to see vapor, liquid fronts, evaporation fronts, as well as thin films of liquid. The purpose of capturing this video was to further understand the locations at which liquid develops in the system and to characterize the volume flow rates over time. The Reynolds number cannot be estimated because there are five different gas/liquid combinations occurring at different temperatures throughout the time of the video. However, based on the flows, it is possible to speculate that the flow is laminar.

The frame rate used in this video was 800 fps. The displayed video is played back at the standard frame rate of 30 fps. This was optimized to provide the maximum time resolution without compromising the saturation of light in the sensor. The J-T valve was approximately 4 cm from the lens of the microscope, which was magnified to 20X. The only manipulation of this image was to remove the background and crop to the J-T valve itself rather than the background (original is not shown because it does not aid in understanding).

The captured video revealed flow patterns previously unseen by humans – because the flow moves so quickly, it was impossible to see without a high-speed imaging device. In addition to its scientific attributes, I think this is a very beautiful video. The flow slides across the frame and gives the viewer a feeling of calm and curiosity similar to that found when observing a flame.

Sources

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