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LIQUID HELIUM FLUID DYNAMICS STUDIES

Final Report
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The present report describes the work carried out under the sponsorship of the Division of High Energy Physics. The report is divided into sections according to the original grant proposal. Following the text is a listing of publications which have resulted from work under the grant.

1. Hydrodynamic Studies of Single Phase Helium

A major portion of our work supported under this grant has been in the area of forced flow single-phase helium. This work has utilized the Liquid Helium Flow Facility (LHFF), which has been in operation at the University of Wisconsin since 1985. The LHFF is a versatile horizontal cryostat equipped with heat exchangers for variable temperature operation and liquid helium pump capable of circulating up to 100 g/s of low temperature helium. The use of the LHFF in support of the proposed work is discussed in subsequent sections of this document.

Over the grant period, we utilized the LHFF for a variety of studies of single-phase helium flow. The major effort has involved pressure drop and heat transfer measurements in forced flow normal and superfluid helium, see ref. 1 for details. This work formed the basis for the PhD thesis of John Weisend (now at the SSC Laboratory). A flow loop containing bellows and heat transfer sections was installed in the LHFF. Pressure drop across the bellows was measured and compared to published correlations. Reported correlations were found to be inadequate for these results, a finding which inspired further study. An experiment was performed to investigate the effect of bellows extension on pressure drop. A more complete comparison with published correlations led to a recommendation for design of cryogenic systems. (see refs. 2 and 3)

Heat transfer between the copper test sections and flowing helium was also studied and compared to models based on Kapitza conductance. The work showed that Kapitza conductance was not significantly affected by flow of the helium nearby, a result published in reference 4.

2. Two Phase Flow Studies.

Under the support of this grant, we began a study of two-phase flow of low temperature helium. Progress with this project had previously been hampered by difficulties with the two-phase flowmeter electronics. These problems have since been resolved and we are now able to measure heat transfer and pressure drop in various flow regimes. The two-phase flow program forms a substantial fraction of our new proposal, which is submitted from Florida State University. In the present section we report the performance to date of the two-phase flowmeter for variable temperature operation.

The two-phase flowmeter we are using in this study is based on a design by Hagedorn et. al. (Adv. Cryo. Engn. 31 1299 (1986)). The meter measures void fraction by determining the shift in frequency of an oscillator circuit mounted on top of a concentric capacitor, which contains the two-phase flow. The 4% difference in the dielectric constant between the liquid and vapor is what provides the variable signal. Our first investigation was a study of the temperature dependence of the output.

Plotted in Fig. 1 are frequency data for the flowmeter containing pure liquid. The frequency follows a curve which is similar to the temperature dependence of the dielectric constant. The meter works well even in the superfluid helium regime. We have also tested the signal variation with void fraction for the different temperatures of interest. These results are displayed in Fig. 2. Again, the meter was well behaved showing nearly linear sensitivity over the full range of void fraction. We are very encouraged by these results for they indicate that the flowmeter will be usable at different temperatures and that the sensitivity factor is only weakly temperature dependent. A flow loop has been designed and built to measure the pressure drop versus void fraction at various temperatures in two phase helium.

Fig. 1: Frequency variation with bath temperature for flowmeter.

Fig.. 2: Frequency variation with void fraction.

3. Component Development Studies.

A significant effort over the past three years has been directed toward component development studies for cryogenic system applications. Our largest project in this area has involved studies of various flowmeters for liquid helium service. The first of these was a flowmeter developed by Scott Holmes (PhD in 1989, now at Lake Shore Cryotronics). This flowmeter was based on a propagating second sound signal present in superfluid helium. This work resulted in a paper entitled: "A Thin Film Flowmeter for use in Liquid Helium" (ref. 5) which ultimately received the best paper award for applications at the 1989 Cryogenic Engineering Conference. A second publication based on the fundamental aspects of the second sound flowmeter has also been published (ref.6)

In addition to the thin film flowmeter study, we have also investigated the performance of a fluidic flowmeter for possible helium service. Such a flowmeter uses the Coanda effect, which is the periodic deflection and attachment of a jet to an adjacent surface. Fluidic flowmeters are commonly used in process engineering but we are the first group to suggest their application for helium service. Plotted in Fig. 3 are oscillation frequencies as determined by an attached pressure transducer versus volumetric flow rate. The results indicate that the meter works well for helium as it does for air. The primary difficulty with this kind of flowmeter is the relatively large unrecovered pressure drop. The flowmeter studies are now more or less complete and have been summarized in a review article in Cryogenics (ref. 7).

Fig. 3: Oscillation frequency versus flow rate for a fluidic flowmeter.

Another area of work in component development has involved studies of the performance of various heat exchangers for superfluid helium service. This work began with an investigation by John Weisend of the performance of the heat exchanger in the LHFF. It was noted at that time that conventional heat exchanger analysis techniques were inadequate for superfluid helium because of the strong temperature dependence to the properties and high heat conductivity of the fluid. We subsequently developed an experiment to vary parameters on a tube-in-shell heat exchanger. The experiment was analyzed in terms of the non-linear heat transport relations for superfluid helium (ref 8). This work is of sufficient fundamental interest that we have been able to obtain funding through the NSF to continue the basic study of superfluid helium cooled heat exchangers.

A third component development study has involved the modification of the LHFF to accept a Gifford-McMahon refrigerator as a shield cooler. Originally, the LHFF inner shield was cooled with the output from a CTI 1400. However, it became necessary to decouple the LHFF from that operation because of a pending move to Florida

State University. This plan required purchase of a GM refrigerator for the purpose of cooling the shield. Installation of this system was completed by spring 1992 in time for the last set of experiments with the LHFF.

4. New Research Activities

Under support of the previous grant, we began several exploratory studies to look for new research activities in support of DOE/HEP accelerator development. One such study was an analytical investigation of the effect of transient heat transfer on the stability of high current density superconducting magnets. The work, which was published at the 1991 Cryogenic Engineering Conference (ref. 9) demonstrated the importance of the transient heat transfer coefficient to the optimization of copper to superconductor ratio in high current density magnets, such as accelerator dipoles. The results of such an optimization are shown in Fig. 4, which is a plot of quench energy versus copper to superconductor ratio for different assumed heat transfer coefficients. For high heat transfer coefficients, the result is a broad maximum around 1.5 to 1. This analytical result, which is in contrast to previous analyses neglecting heat transfer, points out the need for more measurements of transient heat transfer in geometries relevant to magnet conductors. The problem with such measurements is to simulate the environment and heat transfer condition actually present in a magnet geometry.

We have also performed a preliminary study of transient heat transfer using a heater-temperature sensor made with a Rh-0.5% Fe thin film device. Previous measurements of this type used carbon film sensors which have negative temperature coefficients and therefore are subject to instabilities. Rh-Fe has a positive temperature coefficient and sufficient sensitivity at helium temperature to be usable as a sensor.

Fig. 4: The influence of transient heat transfer coefficient on the optimum Cu/NbTi ratio.

Using this sensor, we measured the take-off time to film boiling in He I at 2.2 K and compared the result to a model based on diffusion in the helium layer near the heater surface. The experimental results are characterized by three distinct transitions, with the second transition being closely correlated with the diffusion model, Fig. 5. These preliminary results are encouraging and suggest the need for further work in this area.

Fig. 5: Comparison of transient heat transfer data.

List of publications based on work supported in the previous grant period

1. S. W. Van Sciver, "Experimental Investigations of He II Flows at High Reynolds Number" in High Reynolds Number Flows Using Liquid and Gaseous Helium, ed. R. J. Donnelly, Springer-Verlag, 1991, pp.223-232.
2. J. G. Weisend II and S. W. Van Sciver, "Flow of Cryogenics Through Corrugated Bellows", Proceedings of LTEC 90, Southampton, UK, July 17-19. 1990.
3. J. G. Weisend II and S. W. Van Sciver, "Pressure Drop from Flow of Cryogenics in Corrugated Bellows" Cryogenics **30** 935 (1990).
4. J. G. Weisend II and S. W. Van Sciver, "Surface Heat Transfer Measurements in Forced Flow HeII" Proc 5th AIAA/ASME Thermophysics and Heat Transfer Conference, Seattle, WA, June 18-20, 1990.
5. D. S. Holmes and S. W. Van Sciver "A Thin Film Flowmeter for use in Liquid Helium" Adv. Cryo. Engn. **35** 247 (1990)
6. D. S. Holmes and S. W. Van Sciver "Attenuation of Second Sound in Bulk Flowing He II" Journal of Low Temp. Phys. **87** 73 (1992)
7. S. W. Van Sciver, D. S. Holmes, X. Huang and J. G. Weisend II" He II Flowmetering" Cryogenics **31** 75 (1991)
8. A. Shajii, Y. Huang , M. Daugherty, R. J. Witt and S. W. Van Sciver "Design and Performance of Forced Flow Heat Exchangers" Adv. Cryo. Engn. **35** 165 (1990)
9. X. Huang and S. W. Van Sciver "The Influence of Cu/NbTi Ratio of High Current Density Superconductor" Adv. Cryo. Engn. **37** 299 (1992) .

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