Title

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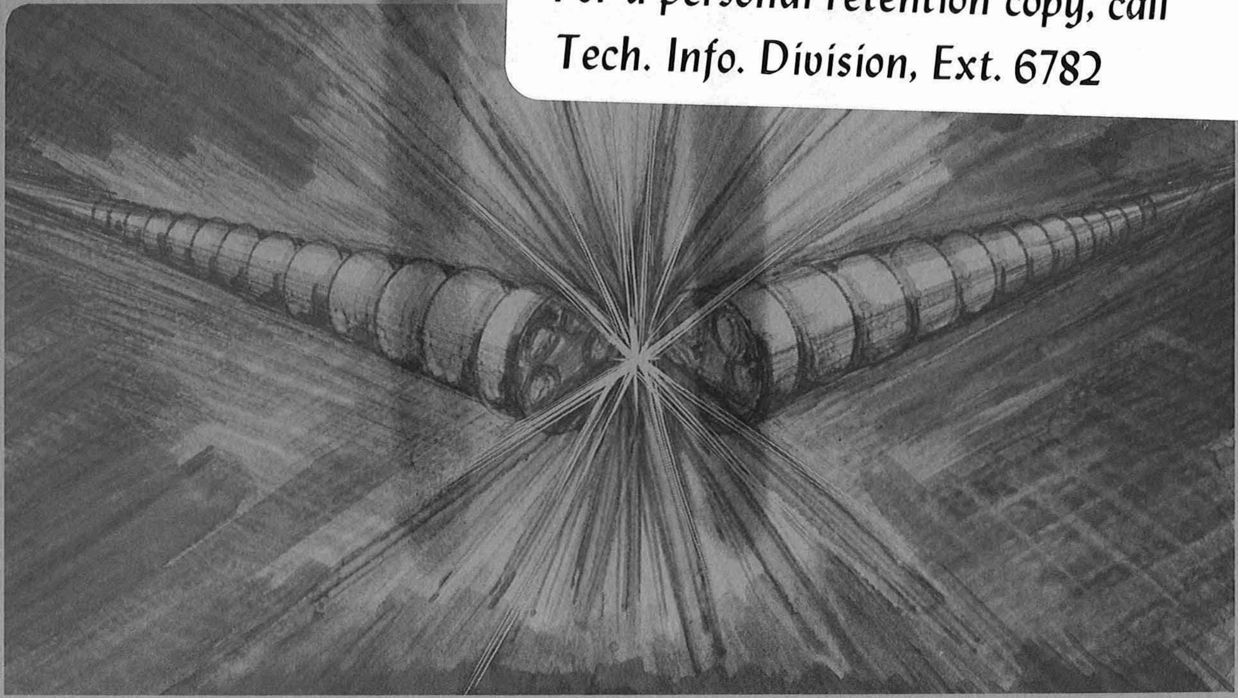

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Abstract

Acoustic Emission techniques are being investigated for use as protection systems in neutral beam accelerators and water cooled beam dumps. For this purpose, the characteristics of the boiling curve for forced-convection surface boiling have been compared to the Acoustic Emission (AE) produced. Results indicate that AE, in the form of count-rate, is a sensitive indicator of nucleate boiling incipience and is relatively insensitive to flow velocity in the 0 - 12 m/s range.

Introduction

Actively cooled high heat flux surfaces are becomming increasingly important in the design of neutral beam accelerators, ion sources and beam dumps.[1] A method of detecting boiling could be useful in protecting these and other beamline components from damage due to boiling burnout. One possible boiling detection technique is Acoustic Emission monitoring. Acoustic Emission (AE) is defined as the class of phenomena whereby transient elastic waves are generated by the rapid release of energy from a localized source or sources within a material, or alternately, as the transient elastic wave so generated.[2] Acoustic Emission is extremely sensitive to minute changes within materials. Among many other uses, AE has been useful in detecting such small scale phenomena as dislocation movement, inclusion fracturing and the initiation and growth of fatigue cracks in various crystalline materials. Additionally, acoustic monitoring techniques have been used to detect boiling in liquid metal fast breeder reactor simulations.[3] Since AE generated by boiling is most likely due to sources on the monitored material's surface it does not technically fit the definition of Acoustic Emission. However, for the purpose of this paper, the term Acoustic Emission will be assumed to include transient waves originating by natural means at the material's surface.

If Acoustic Emission is to be useful as a technique for protecting water cooled devices it must be related to a known heat transfer condition. For this purpose a correlation between a change in an AE parameter, AE count rate, and the transition of a system from forced convection to surface flow boiling was sought. The parameters affecting surface boiling and the point of boiling incipience are discussed elsewhere.[4] To produce known and repeatable heat transfer conditions, the experiment of Bergles and Rohsenow's[4] study on forced convection surface-boiling heat transfer was recreated with the addition of an Acoustic Emission monitoring device.

Apparatus

The forced-convection boiling apparatus fabricated for this study is shown in Fig. 1. This device consists of a 0.318 cm (.125 in nominal) OD, 0.236 cm (0.093 in) ID, commercially drawn stainless steel tube, ohmicly heated over the center 12.7 cm. Copper blocks brazed to either end of the heated section serve as electrical connections. Small holes drilled through these blocks into the tube act as pressure taps. A calming length of 27 L/D's of tube precedes the heated section to reduce entrance length effects. To measure the tube wall temperature a thermocouple was attached to the exterior tube wall, at 48 L/D's from the start of the heated section, with "Thermobond," a heat conducting, electrically insulated epoxy. Each end of the tube is brazed into brass blocks which contain the water connection and a thermocouple. These thermocouples, which extend into the flow stream are electrically isolated from the remainder of the test assembly. The heated tube section and downstream copper block is insulated with asbestos. The remaining downstream portion of the assembly was covered with foam-type insulation. The difference between the electrical power input to the assembly and the measured power absorbed by the water was less than 3%.

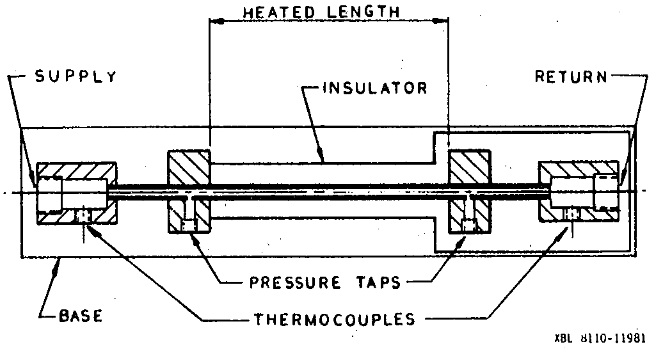

Figure 1: Forced-Convection Flow-Boiling Test Assembly.

Power for heating of the stainless steel tube was provided by a 7.5 kW d. c. power supply, which is capable of supplying 500 amperes. To prevent heat from entering the test assembly by resistance heating of the power cables, these electrical connections are water cooled. Voltage drop and current readings were taken from meters on the power supply. As a check on the voltage measurement, a second voltmeter was attached across the heated test section. Readings of the two voltmeters agreed within 5%.

Low conductivity water was circulated through the stainless steel tube by a close loop water system shown schematically in Fig. 2. Water resistivity was maintained at better than 1 megohm-cm by continuous deionization. Dissolved oxygen was removed prior to

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taking data be passing the water through an external oxygen removing resin tank. After degassing, reintroduction of air was minimized by maintaining a cover gas of nitrogen at 3 psi in the water reservoir. A modified Winkler test indicated that the D.O. content was less than 1 mg./l. for all test runs. The temperature of the water supplied to the stainless tube was maintained at 22 to 26°C by a heat exchanger. Throttle valves upstream and downstream of the test section were used to maintain the correct pressure and flow rate. A bypass line was used to shunt the excess flow from the water system. Flow rate measurements were taken at a precision flowmeter downstream of the test section.

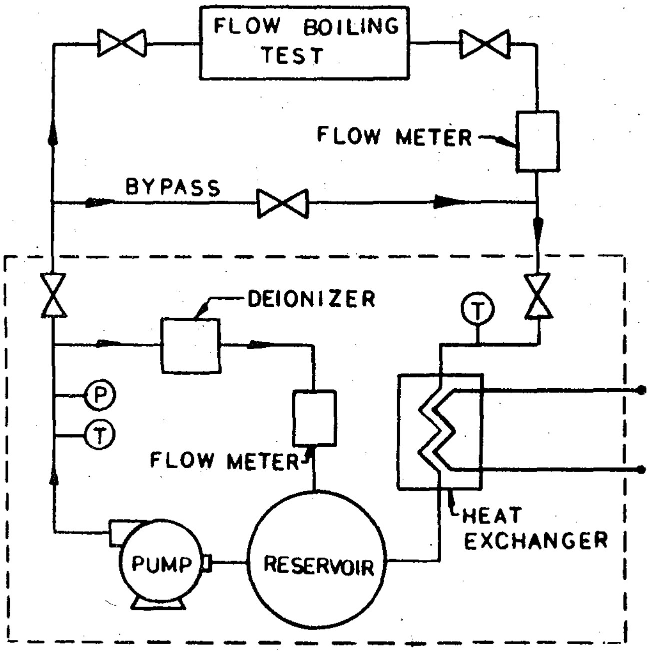

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Figure 2: Schematic of Closed Loop Water Supply and Attached Plumbing.

Acoustic Emission measurements were performed with a AETC Model 204A unit with a type AC175L Piezoelectric Transducer. A schematic of this equipment is shown in Fig. 3. The AE transducer was mounted on the upstream electrode on the test section with, AETC, "SC-3", a viscous coupling material. Output from the transducer enters the pre-amplifier/ band pass filter unit, which has a gain of 60dB and a frequency range of 100 kHz to 300 kHz. This signal is further amplified by the main frame unit to a total gain of 80 dB. Incorporated in this unit is an AE count detector and time base. An AE count occurs when the amplified signal exceeds a given threshold value. A fixed threshold value of 1.00 volt was used in these tests.

All temperatures were measured with pre-calibrated thermocouples using an ice bath reference junction and a Hewlett Packard 3455A Digital Voltmeter.

Results

Preliminary data for the forced-convection boiling test is shown in Fig. 4. All data runs were made at a fluid velocity of 6.1 m/s and a local pressure, at 48 L/D's, of approximately 0.193 MPa. The local subcooling (Ts-Tb), where Ts is the saturation temperature and Tb is the bulk temperature, decreased with increasing heat flux from 76 to 54°C. The heat flux value, q/A, was computed by dividing the electrical input power by the surface area of the heated tube section. The wall temperature, Tw, is the temperature at the exterior surface of the tube. No correction was made for the radial temperature drop through the tube wall. The AE count rate data is the number of counts per second generated by the entire test assembly plotted against the Tw-Ts value of the 48 L/D position. The solid line in Fig. 4 represents a forced convection correlation for heating in tube flow,

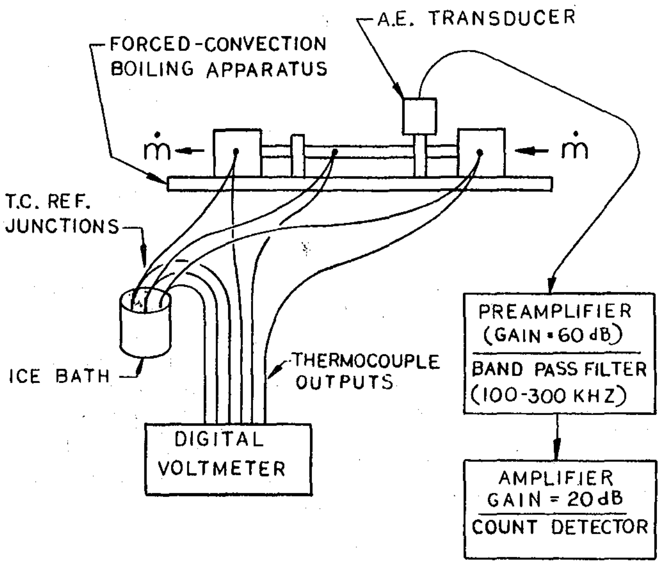

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Figure 3: Acoustic Emission and Temperature Sensing System.

$$Nu_f = CRe_f \quad Pr_f$$

where C, for this graph, equals 0.016. All properties of the fluid were evaluated at the mean film temperature.

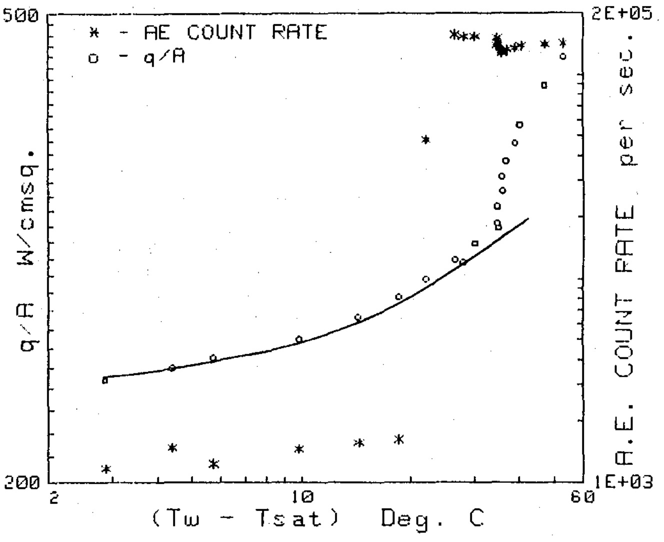

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Figure 4: Acoustic Emission and Corresponding Boiling Curve Showing a Rise in Emission Prior to Departure from forced Convection.
P = 0.193 MPa, V = 6.1 m/s, Ts-Tb = 76-54°C

Discussion

At low values of Tw-Ts there is apparent agreement between the measured heat flux and the forced convection correlation line. However, at higher wall temperatures the data tends to diverge sharply from this correlation. These results are in general agreement with the results of Bergles and Rohsenow[4] among others. Bergles and Rohsenow postulate that the character of the heat transfer changes with increasing wall temperatures from essentially forced-convection at low values of Tw-Ts to a combination of nucleate boiling and forced-convection at intermediate values to fully developed surface boiling at high values of superheating, where q/A v. Tw-Ts takes a steep slope.

It is noted that the Acoustic Emission count rate increases from less than 2000 counts per second to more than 100,000 counts per second in the intermediate range of wall temperatures. This nearly step-like rise clearly precedes the sharp change in slope of the heat flux curve normally associated with fully developed boiling. Since the location of the Acoustic Emission cannot be discerned it is possible that the increase in count rate is the result of the increase in boiling length as the heat flux is increased. However, this does not seem plausible since the axial wall temperature gradient for intermediate values of heat flux is a function of the bulk water temperature which is rising 20 to 40^{o}C across the length of the heated section. Therefore, it seems reasonable to assume that the increase in AE is due to a transition, locally, from non-boiling to subcooled nucleate boiling.

The results presented in this paper represent a preliminary study and as such incorporate some over-simplistic assumptions. The most important of these is the assumption of a negligible radial temperature gradient in the tube wall. Lower values of Tw, will affect the value of the super heating but should not radically change the shape of the heat flux curve. Additionally, a lower wall temperature value will affect the fluid properties which enter into the forced convection correlation. This may explain why it was necessary to use a proportionality constant of C = 0.016 as opposed to the generally accepted value of C = 0.023 for the forced convection correlation $Nu = C\,Re^{.8}Pr^{.4}$.

Acknowledgements

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