Mech. Engg. Res. Bull.
Vol. 12 (1989), pp. 9-19

Surface 'Aging' and Reproducibility of Results in Forced Flow Boiling

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ABSTRACT

The 'aging' effects of a boiling surface was observed experimentally using water as a working fluid and employing a number of flat and ribbed surfaces under forced convective conditions. After a certain period of continuous running, surfaces showed a time-independent steady heat transfer performance. The reproducibility of the experimental results was compared with a number of 'aged' heating surfaces.

NOMENCLATURE

A flat projected area of the heating surface, m^2
e rib height, mm
L rib length, mm
q heat transfer rate, kW
Ra centre line surface roughness average, μm
s spacing between ribs, mm
T temperature, K
V flow velocity, m/s
ΔT_{sub} inlet subcooled temperature, $T_{sat} - T_b$, K

Subscripts:

b inlet bulk
sat saturation
sub subcooled
w wall

INTRODUCTION

The reliability of any experimental study depends on the reproducibility of the data. A characteristic of nucleate boiling heat transfer, more so than in other regimes of heat transmission, is the difficulty encountered in controlling the condition of the heat transfer surface. As a result of this difficulty, boiling heat transfer data frequently show inconsistencies and much scatter. In addition, surfaces which have been in use for long periods of time frequently require higher temperature differences to produce the same heat flux. This effect is attributed to the added resistance on an oxide or deposited layer on the heat transfer surface, or to the decrease in cavity size resulting from mild oxidation (Ref 1). This problem is particularly important where boiling experiments with water are concerned and practically, it is very difficult to overcome. However, the rate of change associated with 'aging' generally diminishes as a function of time and

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this fact provides a basis for elimanting the effects of this parameter. This implies that after a sufficiently long time has elapsed, a surface will reach a quasi-static condition.

Fand and Keswani(2) reported on the 'aging' problems associated with subcooled pool boiling of water from a stainless steel tube. They stated that a set of five experimental measurements corresponding to five increasing values of heat flux were reported again and again until the test cylinder was 'aged', is until two consecutive sets of five measurements were negligibly different. It was reported that this situation occurred after six hours of operation and the data presented at one heat flux value for two consecutive temperature measurements indicated a temperature difference of approximately 0.7°F between the two measurements. A similar technique was adopted by Ferrel and Alevitch (3) for nucleate pool and enhanced pool boiling experiments. In both studies the 'aging' of the heated surface was considered and nucleate pool boiling tests were carried out after the surface had been 'aged'. Very little further change in the heating surface was observed after confirmed. Yamaklguchi (4) 'aged' the heating surfaces by boiling for about six hours with an intermediate heat flux (approximately 150 kw/m^2). Apart from the work of Akhanda and James (5) in which 'aging' was briefly considered in a forced flow situation, all investigations into the question of 'aging' have been confined to pool boiling.

EXPERIMENTAL APPARATUS

The experimental apparatus and instrumentation are shown schematically in Fig.1. LThe rig comprised a closed loop system incorporating a test section, storage and degassing tank, circulating pump, condenser, vacuum pump, vacuum reservoir chamber, flow meters and other auxilliaries. All the components in contact with the working fluid were namufactured from materials which could adequately withstand the liquid boiling temperature and also resist corrosion.

The test section consisted of a detachable base plate assembly and a mild steel frame as shown in Fig.2. the detachable base plate assembly formed the bottom of

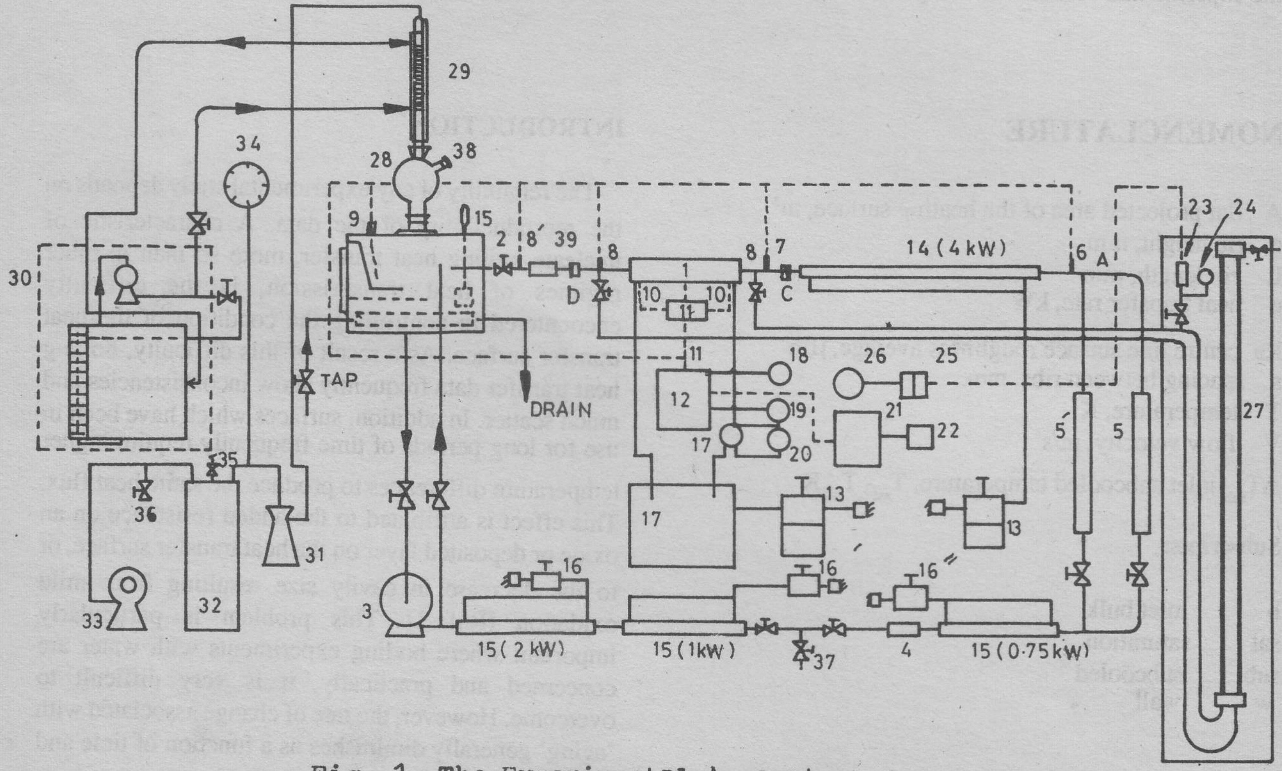


Fig. 1. The Experimental Apparatus

the test channel of inside dimensions of 305 mmx 33mm x 22mm . Two pressure tapping were provided, each of which was installed 40mm away from the test section and these were connected to a pressure gauge and a pressure transducer. The base plate assembly comprised an upper 'tufnol' base and a lower 'tufnol' base. These two components were manufactured from 'tufnol (Phenolic resin, ASP brand) material. These are shown in detail in Figs 3(a) and (b). The heating plate was located in the recess of the former base and held in position by means of heat resistant 'Araldite 2004'. The thermal shock resistant Epoxy Resin (Araldite My750, Hardener HT972 and crack resitant filler-mica flour) was then cast at the back of the heating surface through the specified slot for reinforcement. Before carrying at the above two operations, the thermocouples employed for surface temperature measurement were spot welded to the back of the heating surface. These two 'tufnol' bases were used as backing and insulating materials.

The heating surfaces were manufactured from 16 SWG stainless steel type EN58E (AISI 304) to the dimensions of 304mm x 18mm x 1.60mm. On completion of the rib machining operation on the heat transfer surface, brass electrodes of 65mm x 25mm x 10mm were silver soldered 5mm away from the ends of the test specimens as shown in Fig.3(c). A vaqua blasting technique was employed to obtain a final surface micro-roughness for all test specimens apart from the specimen 'FRO-1". This surface was polished with fine grades of emery paper and liquid metal polish. Information concerning surface geometry variations is given in Fig.3(d) and the detailed dimensions are presented in the table: I

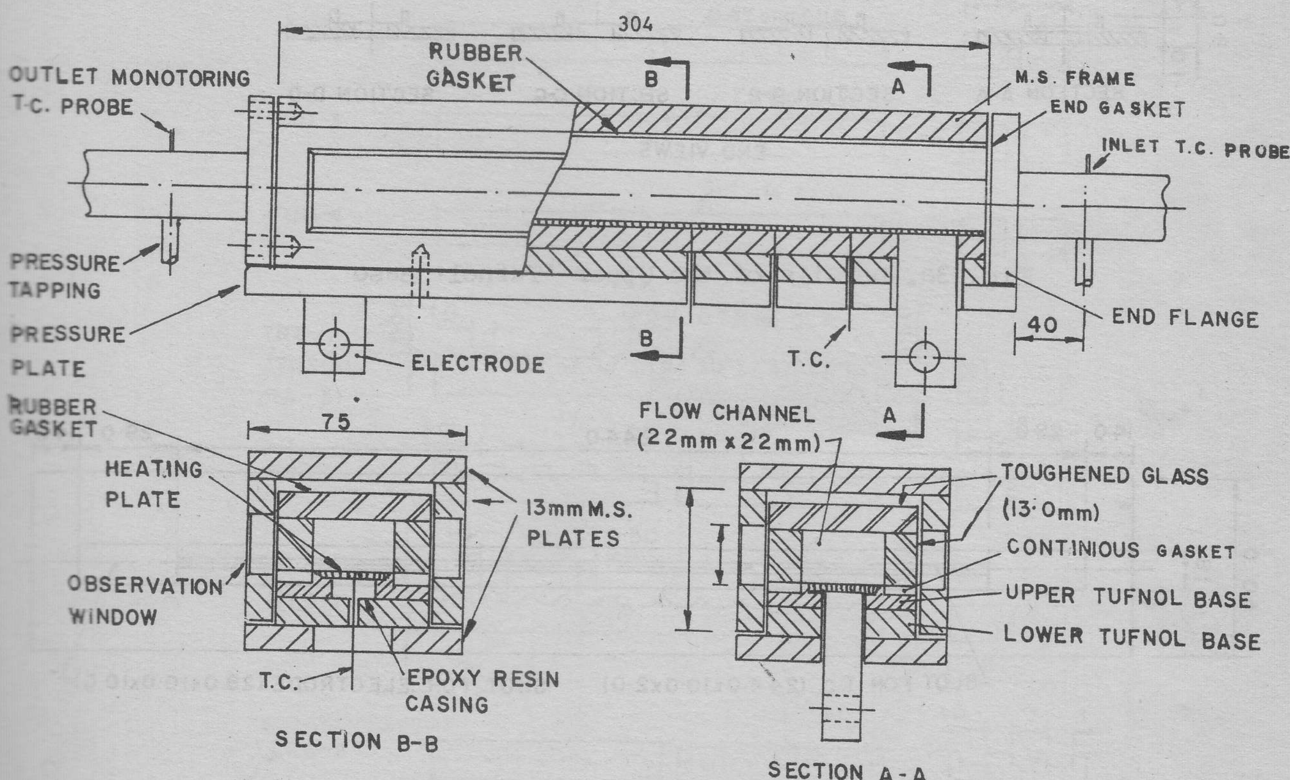


Fig. 2. Details of the Test Section

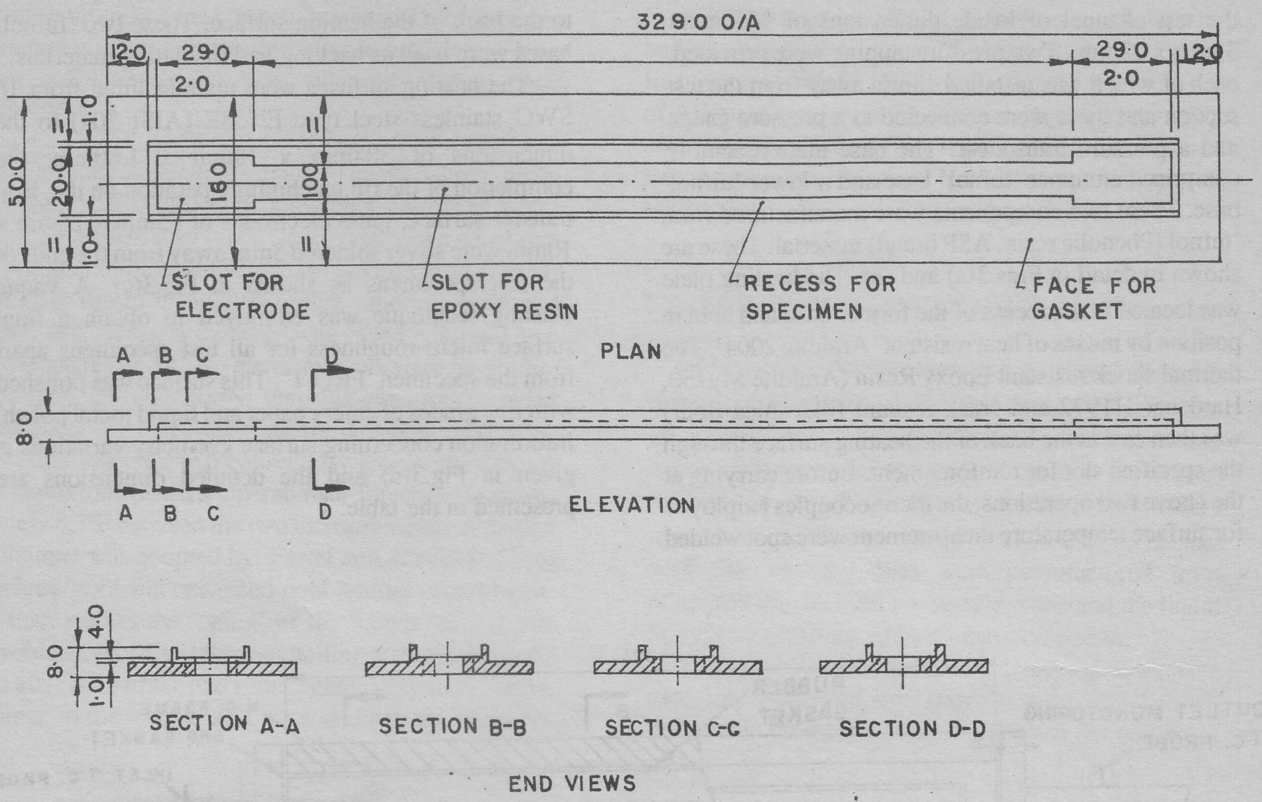


Fig. 3a. Details of the Upper 'Tufnol' Base

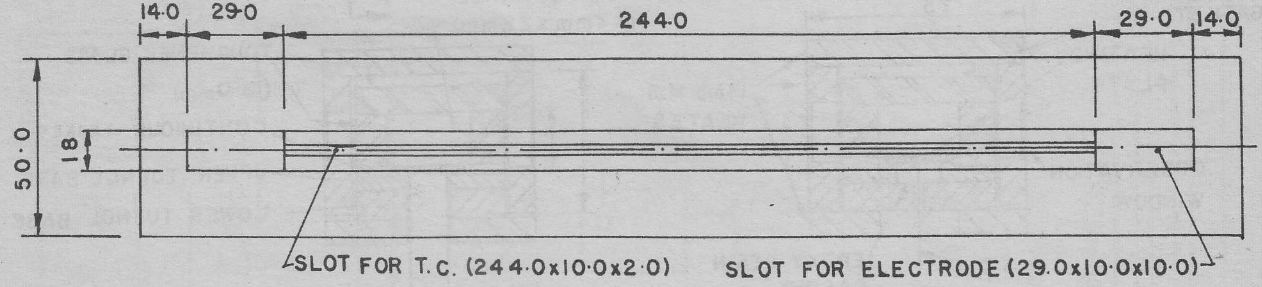


Fig. 3b. Details of the Lower 'Tufnol' Base

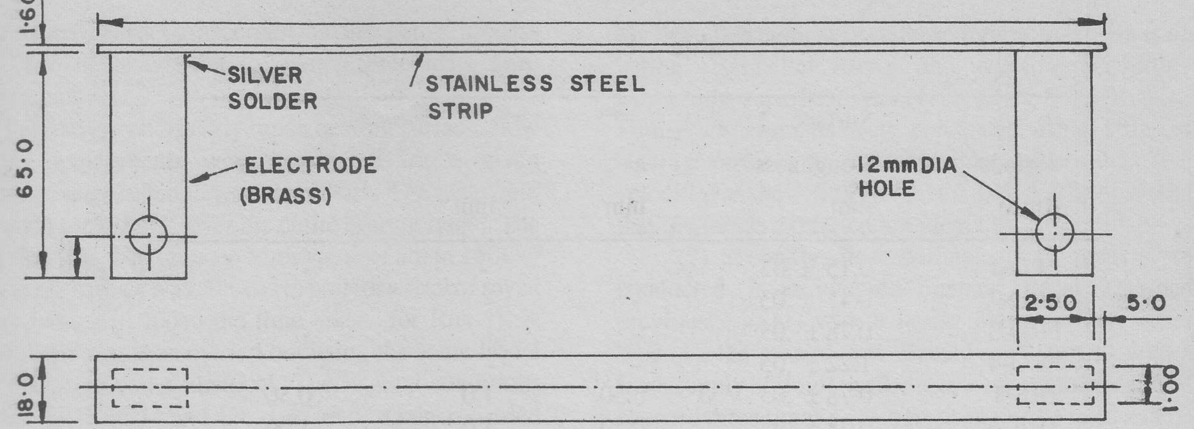


Fig. 3c. Details of a Flat Heating Plate

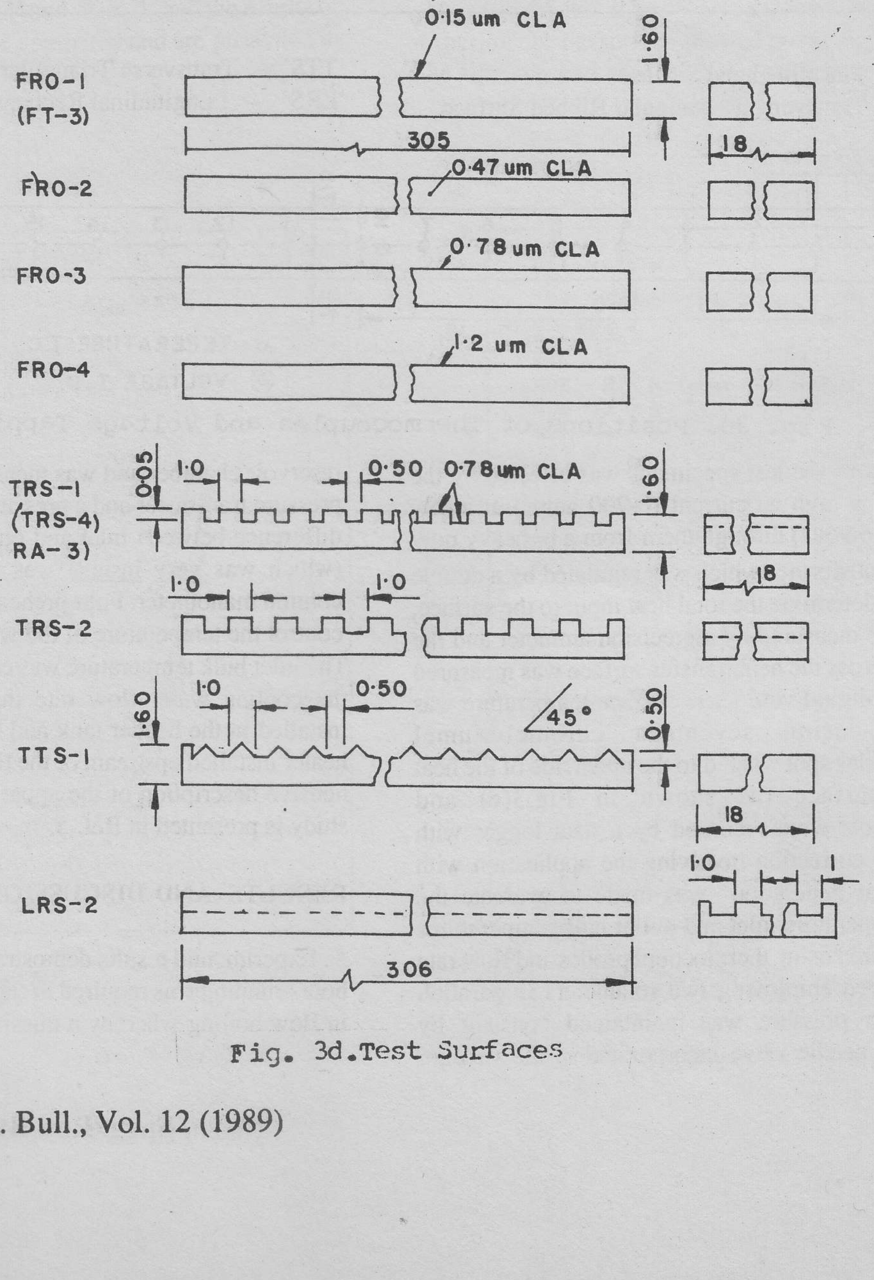


Fig. 3d. Test Surfaces

Table 1.

Surface μm	Surface Roughness mm	e mm	L mm	s
FRO-1	0.15 ±.02	-	-	-
FRO-2	0.47 ±.03	-	-	-
FRO-3	0.78 ± .05	-	-	-
FRO-4	1.22 ± .05	-	-	-
TRS-1	0.78 ± .05	0.50	1.0	0.50
TRS-2	0.78 ± .05	0.50	1.0	1.00
TTS-1	0.78 ± .05	0.50	1.0	0.50
LRS-2	0.78 ± .05	0.50	1.0	1.00

'FRO' - Flat Roughend Surface
'TRS' - Transverse Rectangular Ribbed Surface
'TTS' - Transverse Triangular Ribbed Surface
'LRS' - Longitudinal Rectangular Ribbed Surface

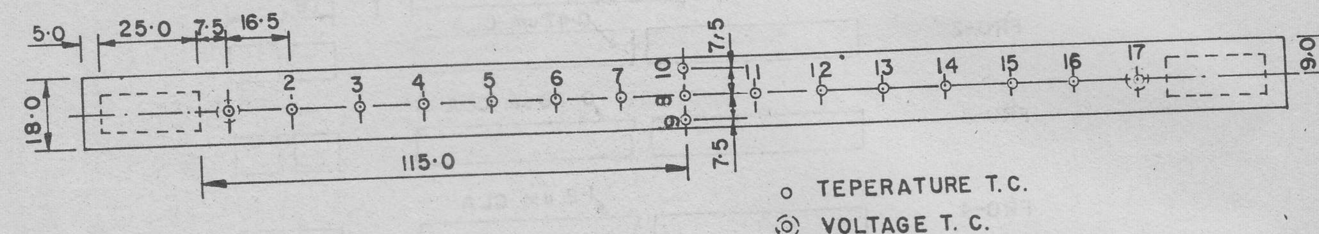


Fig. 3e. Positions of Thermocouples and Voltage Tappings

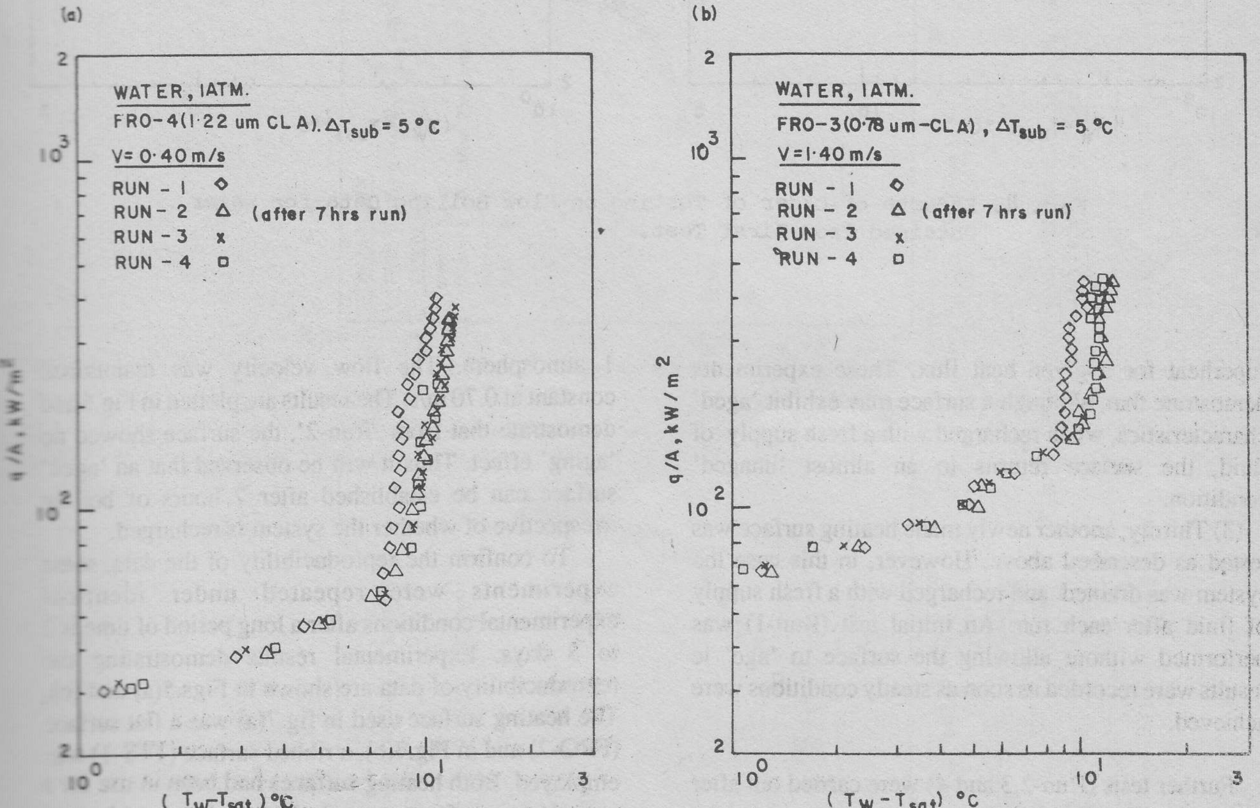
Heating of the test specimens was effected by the passage of a high ac current (0-700 amps) at a low voltage (0-6 volts) through them from a b=heavy duty 10 KVA transformer which was regulated by a double variac. To determine the total heat input to the surface, current was measured by a precision ammeter and the volatage across the heat transfer surface was measured with an ac digital voltmeter. Surface temperature was measured using seventeen chromel-alumel thermocouples spot welded to the underside of the heat transfer surface (as shown in Fig.3(e) and measurements were recorded by a data logger with teletype. A correction involving the application with internal heat generation was made to evaluate the surface temperature inlet and outlet bulk temperatures were measured using thermocoupl probes and flow rate was measured employing two rotameters in parallel. The system pressure was maintained constant by adjusting a needle valve incorporated in the vacuum reservoir chamber and was measured with a calibrated pressure transducer and a pressure gauge. The pressure difference between inlet and outlet of the test section (which was very install) was measured by a water column manometer. Four preheaters were employed to control the temperature of the working fluid in the rig. The inlet bulk temperature was controlled by adjusting the cooling water flow rate through a glass cooler installed in the header tank and by regulating the pre-heater installed upstream of the test section. A comprehensive description of the apparatus employed in this study is presented in Ref. 5.

RESULTS AND DISCUSSION

Experimental results demostrated that at least seven hours running was required to 'age' the heating surface in flow boiling whereby a quasi-steady condition was established. In order to ascertain that the 'aging' process had been achieved, the following three tests were carried out.

(1) Firstly with a newly made heating surface, flow boiling experiments were conducted for a given pressure, inlet subcooling and velocity. The data were recorded for 'Run-1' over the entire boiling range. The heat flux was then reduced to ak value of about 150kw/m^2 and the surface was allowed to boil for a total of seven hours (which included the time taken for Run-1). A second test was then carried out using the same liquid and operating under identical experimental conditions as that of 'Run-1' and the data were again recorded (Run-2). The procedure was repeated for 'Run-1' and the data were again recorded (Run-2). The procedure was repeated for 'Run-3' and 'Run-4' and the results of these experiments were compared and are presented in Fig.4(a). It is evident from these figures that there is no 'aging' effect after 'Run-1' and, therefore, not further increase in superheat was observed as from 'Run-2'. Similar experiments were conducted using different heating surfaces at different inlet subcoolings and velocities as shown in Fig.4(b) to (d). It will be observed that the trends exhibited are identical.

(2) Secondly, flow boiling experiments were conducted in an identical manner to that described previously in (1) with a newly made surface. After 'Run-4', the system was drained and charged with a fresh supply of fluid. In all, the system was drained and charged three times with a fresh supply of fluid and on each occasion a complete set of 12 tests were carried out. Results of these tests are plotted in Figs. 5(a) to (c). From these figures, it will be observed that among each set of experiments, the surface showed no 'aging' effect after the first run and consequently, no further increase in



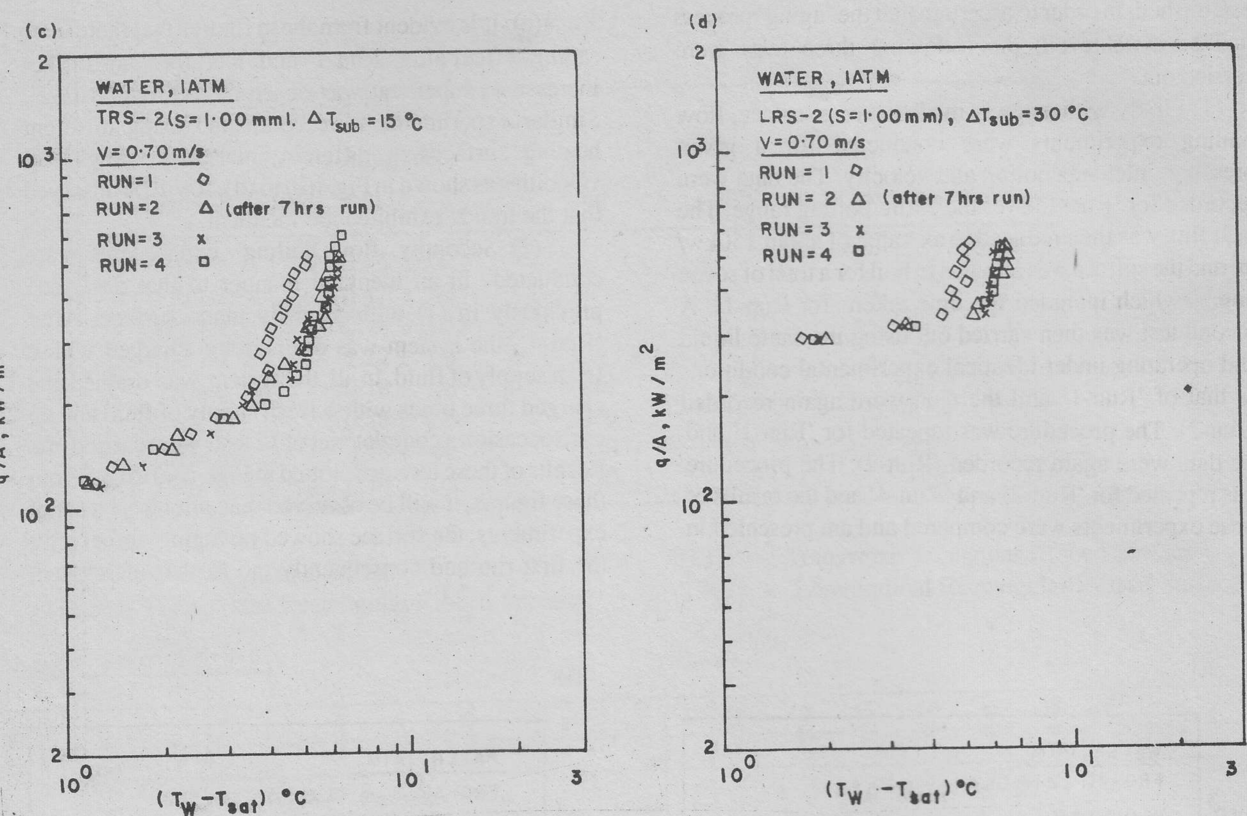


Fig. 4. Effects of Order of Testing on Flow Boiling Data for water Obtained from First Test.

superheat for a given heat flux. These experiments demostrate that, although a surface may exhibit 'aged' characteristics, when recharged with a fresh supply of fluid, the surface returns to an almost 'unaged' condition.

(3) Thirdly, another newly made heating surface was tested as described above. However, in this case the system was drained and recharged with a fresh supply of fluid after each run. An initial test (Run-1) was performed without allowing the surface to 'age' ie results were recorded as soon as steady conditions were achieved.

Further tests (Run-2,3 and 4) were carried out after draining and recharging the system. In these tests the surface was boiled for about 7 hours (aged) at an intermediate heat flux of 150 kw/m^2 and a pressure of 1 atmosphere. The flow velocity was maintained constant at 0.70 m/s. The results are plotted in Fig.6 and demostrate that from 'Run-2', the surface showed no 'aging' effect. Thus it will be observed that an 'aged' surface can be established after 7 hours of boiling irrespective of whether the system is recharged.

To confirm the reproducibility of the data, some experiments were repeated under identical experimental conditions after a long period of time is 2 to 3 days. Experimental results demostrating the reproducibility of data are shown in Figs.5(a) and (b). The heating surface used in fig.7(a) was a flat surface (FRO-2) and in Fig.7(b), a ribbed surface (TTS-1) was employed. Both heating surfaces had been in use for a period of time far in excess of seven hours and were, therefore, 'aged'. From these figures, it is clear that the reproducibility of data was well established.

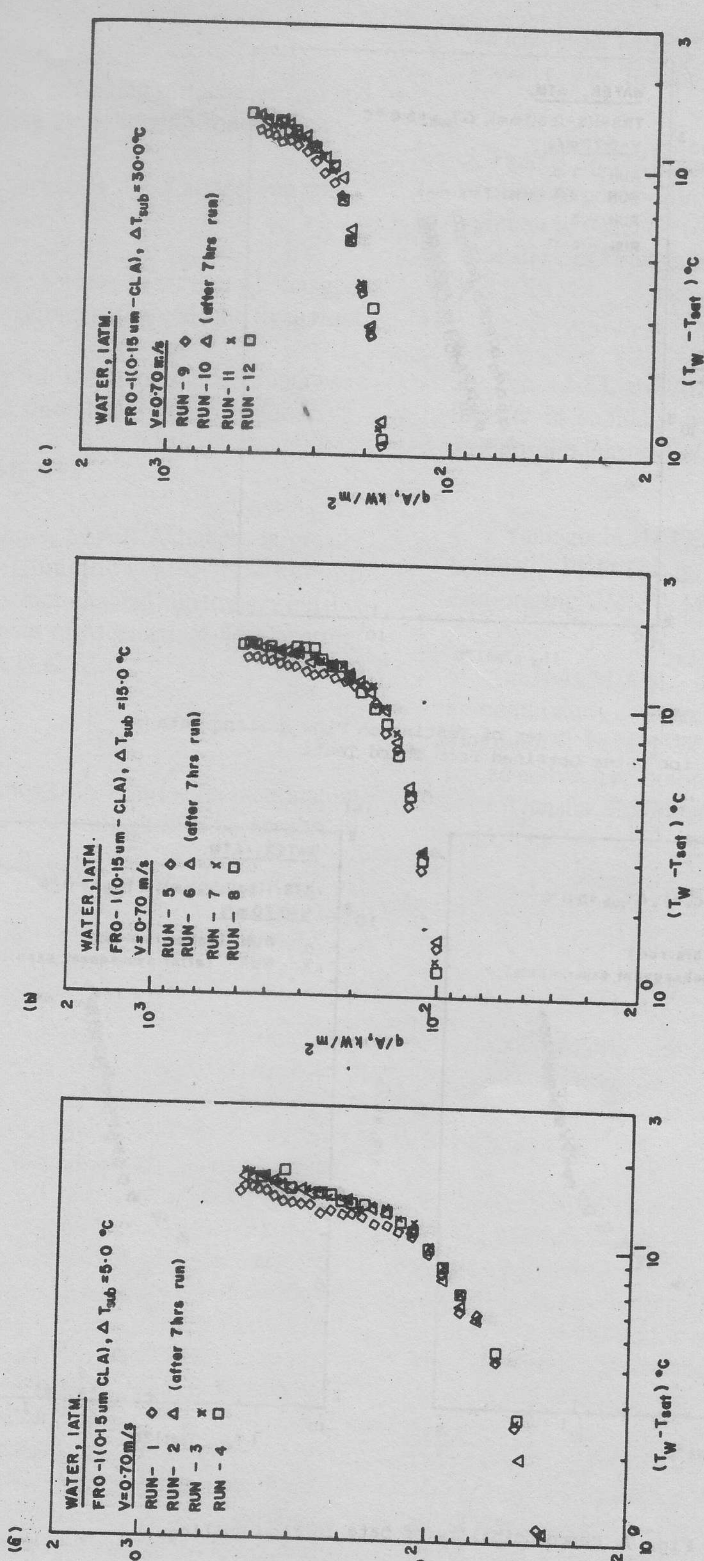


Fig. 5. Effects of Order of Testing on Flow Boiling Data for Water Obtained from Second Test.

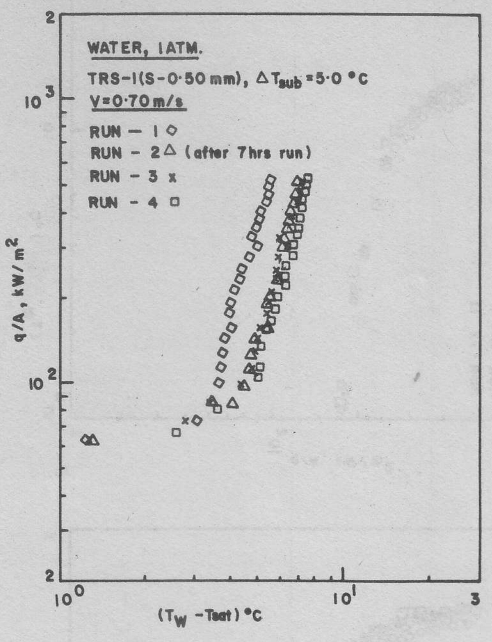


Fig. 6. Effects of Order of Testing on Flow Boiling Data for Water Obtained from Third Test.

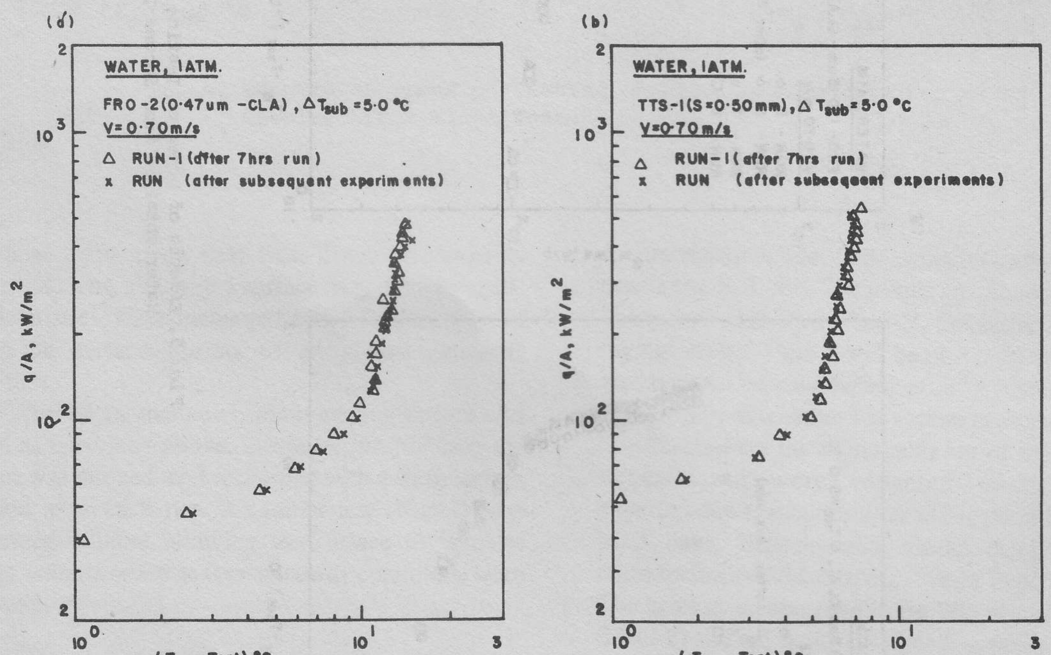


Fig. 7. Reproducibility of Data in Flow Boiling.

CONCLUSIONS

The effects of 'aging' of boiling surfaces was studied experimentally yielding the following conclusions.

(1) In flow boiling a surface is 'aged' after seven hours' continuous boiling.

(2) An 'aged' surface returns to an almost 'unaged' condition when the system is recharged with fresh fluid.

(3) Reproducibility of the experimental data was confirmed using both smooth and ribbed surfaces.

ACKNOWLEDGEMENTS

One of the authors, M.A.R.Akhanda, is greatly indebted to the Commonwealth Scholarship Commission in U.K. which enabled him to carry out this work in the Department of Mechanical Engineering, UMIST, Manchester, U.K.

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