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EVALUATION OF COMMERICAL ENHANCED TUBES IN POOL BOILING

Topical Report

by
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16. Abstract (Limit: 200 words)

In support of a study of shellside boiling with enhanced tubes, a pool boiling apparatus was developed and used to test single tubes with various structured boiling surfaces in R-113. The basic design of the tube-bundle test section was carried out and certain critical design features were tested experimentally. Copper tubes, 3/4 in. o.d. and 4 in. long, were selected with 1/4 in. diameter cartridge heaters. Four thermocouples were inserted in 3/32 in. diameter, 2 in. long holes.

The pool boiling characteristics of a plain tube agree well with previous tests. Wolverine Turbo-B tubes with small, medium, and large features performed identically for a heat flux greater than 20 kW/m^2. For lower heat flux, however, the Turbo-B S was slightly superior. In general, the Wolverine Turbo-B tubes had more favorable boiling characteristics than the single Wieland Gewa-T tube that was tested. The test procedure is deemed entirely adequate for screening enhanced tubes to see which ones should be used in the tube-bundle test section.

Three different ways of mounting the tubes were tested in R-113 at 65°C and 5 bar gage pressure. As all three constructions sealed well, the simplest design is recommended in which a snap ring fixes the tube to the wall and an O-ring seals against the pressure. The general design features of the tube bundle test chamber are also presented.

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Enhanced tubes
Pool boiling

b. Identifiers/Open-Ended Terms

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Nomenclature

A	tube surface area
AZ	arrangement Z of the pool boiling test section
d	tube diameter, including a surface enhancement
dT_{av}	uncertainty of the average tube surface temperature
$dT_{i,r}$	uncertainty of the temperature measurement with thermocouple i
dT_{pp}	uncertainty of the conduction temperature drop
g	= 9.81 m/s^2, acceleration of gravity
H	height of liquid above the tube axis
I	current through the cartridge heater
L	tube length
q''	heat flux at tube surface, referred to diameter d
$q''_{max,bundle}$	maximum heat flux in the bundle
$q''_{max,pool-b}$	maximum heat flux in pool boiling
q''_{CHF}	critical heat flux
P	power dissipated in the cartridge heater
P_{max}	maximum required power of the cartridge heater
p_{atm}	atmospheric pressure
p_{hydr}	hydrostatic pressure
r	distance from thermocouple bead to tube axis
R	radius of the tube without surface enhancement
r_1	radius of the hole for the thermocouple
r_2	radius of the rod

r_{tcpl}	= 0.38 mm, radius of the thermocouple bead
R_{ch}	resistance of the cartridge heater
T_i	tube surface temperature, i=1,..4
$T_{i,r}$	measured thermocouple temperature (radius r), i= 1-4
T_{av}	average temperature of the tube surface
T_{bath}	temperature of the water bath
T_{pool}	temperature of the pool
T_{sat}	saturation temperature of R-113
T_{WSH}	wall superheat
U	voltage measured at the cartridge heater
U_s	voltage measured at the shunt to determine I
U_{true}	true voltage at the cartridge heater
$U_{s,true}$	true voltage at the shunt to determine I

Introduction

The Overall Project

Shell-and-tube heat exchangers with shellside boiling are widely used in the process and air conditioning industries. Because the thermal resistance of hydrocarbons and refrigerants is quite low, even when boiling, it is desirable to use tubes with external structured boiling surfaces. Toward this end, the DOE Office of Industrial Programs has sponsored a program directed at the assessment of typical enhanced boiling surfaces.

Several commercial tubes are to be evaluated to enhance the common heat transfer modes that occur together or individually in shell-and-tube heat exchangers.

One issue is to systematically investigate the relationship between the performance of a single enhanced tube in pool boiling and in a tube bundle. In tube bundles, the convective crossflow through the bundle can increase the boiling heat transfer coefficients in the upper part of the bundle by as much as a factor of ten compared to a single tube in pool boiling. This "bundle effect" and other items, such as the initiation of boiling or the manner boiling spreads in a bundle, are to be explored to adapt basic data from a single tube and enable a scale-up (see Fig. 1). Bundles with both enhanced and plain surface tubes will be tested to optimize the ratio of the overall heat transfer coefficient to the pressure drop. It is planned to test three different tube types, the plain tube, the Linde High Flux and the Wolverine Turbo-B. The bundle consists of 68 tubes, arranged in a pitch (= distance between two tube axes/tube diameter)

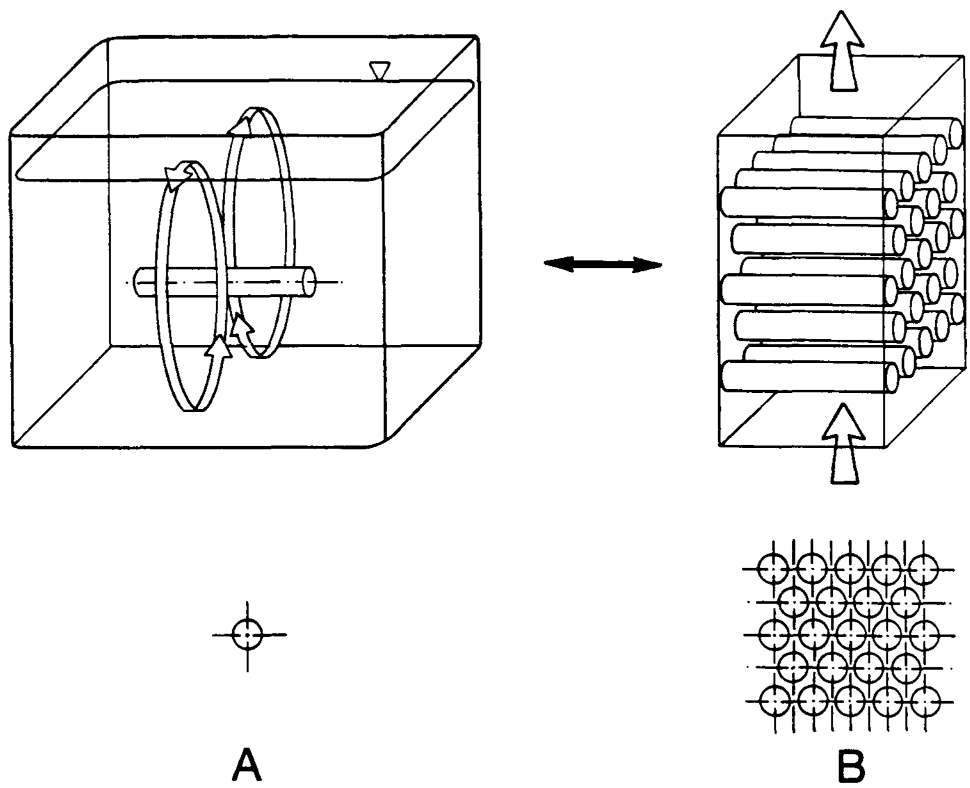


Fig. 1. Comparison of the flow pattern in pool boiling (A) and in a tube bundle (B)

of 1.17 or 1.5. The experience obtained in this study should result in a design algorithm (computer code) that can predict the performance of a full scale bundle.

Shellside boiling with multicomponent mixtures, typical for most industrial heat exchange processes, is to be investigated subsequently. Enhanced tubes maintain their advantage over plain tubes when boiling mixtures; however, the characteristics change. No studies have been performed so far to quantitatively determine the behavior of enhanced surfaces, especially in a mixture of volatile fluids.

Pool boiling fouling tests are conducted simultaneously to examine the problem of fouling, which is encountered in almost any industrial application. Contradictory former results and the inability to "design" a surface that would prevent or minimize fouling substantially impedes the commercialization of structured boiling surfaces.

Present Study

In this preliminary study some of the construction problems of the aforementioned project are delineated, and solutions are proposed and experimentally investigated.

This work has three goals:

1. to determine the best instrumentation method for a tube
2. to design and optimal mounting arrangement of a tube
3. to obtain reference data for single tubes in pool boiling.

Relative to goal 1, several methods of instrumenting a tube with thermocouples and an industrial cartridge heater have been used in former, similar experiments [2,6,7]. However, none of them can be considered absolutely satisfying. Looking forward to three (or more) different sets of 68 tubes for each bundle, the question is, how expensive does the instrumentation method need to be to provide good results? Or, basically, do the thermocouples in the tube wall affect the steady state temperature measurements significantly? Also, is it worthwhile to provide an "optimal" contact between the cartridge heater and the tube to obtain a uniform radial heat flux, or is the heat flux from the cartridge heater too non-uniform already?

Relative to goal 2, in the tube bundle test section the tubes are mounted onto one wall, which makes it possible to handle them as a unit (see Fig. 2). Only two walls, for the two different pitches, will be manufactured. Therefore, the tubes should be easy to change. The mounting has to seal against pressure and the machining should be inexpensive and must not affect the structured tube surface. So the question is, how to mount the tube to a wall?

Finally, relative to goal 3, the pool boiling experiment provides the basic data for the aforementioned project. One setup is needed to obtain reference data for the bundle tests and a second one is required to run the fouling tests. Again, experience is available [2,6], but not completely satisfying. The test section must allow a controlled experiment to be conducted with perfect visual observation. The tubes must be exchanged easily. In general, the design should be flexible to allow modifications.

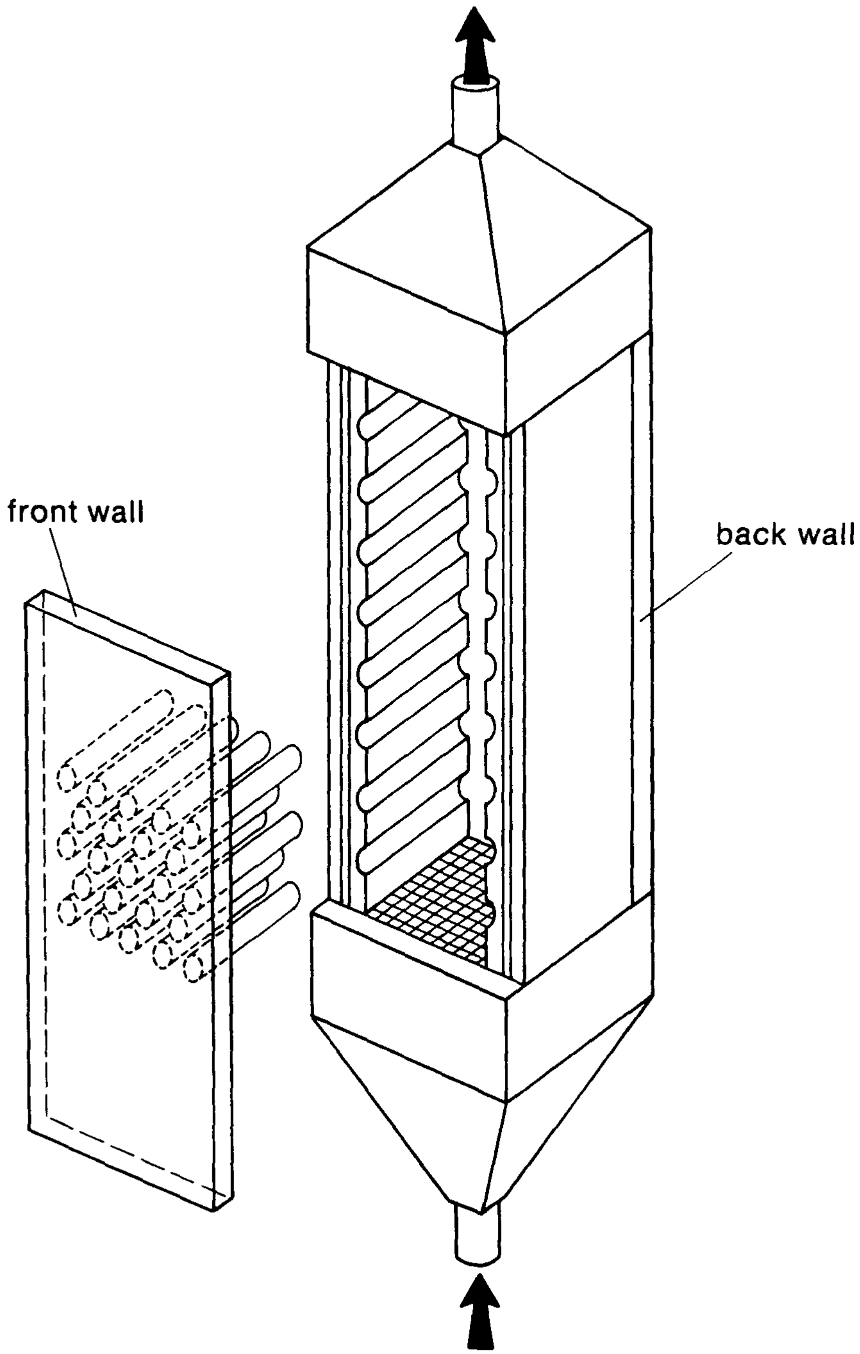


Fig. 2. Concept of the tube bundle test section

I Construction Elements for a Pool Boiling and a Tube Bundle Test Section

1. The Instrumentation of a Copper Tube

1.1. Given Variables

The copper tube is 4" long and measures 3/4" o.d. To achieve a uniform temperature distribution, the tube should have a thick wall. An inner-diameter-to-outer-diameter ratio of 2 is desired [1]. Therefore, a 1/4" or 3/8" diameter cartridge heater will be used.

The cartridge heater is press-fitted to provide a good heat transfer to the tube. Conductive grease may be added to fill a remaining gap. For a removal of the heater the tube must be open at both ends.

Four thermocouples in 12/3/6/9 o'clock positions measure the temperature in the middle of the tube wall. The thermocouple beads are located 2" deep so that the temperature readings are free from end effects.

The thermocouple wire necessitates a minimum 0.035" diameter hole.

1.2. The Instrumentation with Thermocouples

1.2.1. Requirements

The thermocouples should be as close as possible to the surface.

The holes for the thermocouple wires should be small to (1) prevent distortion of the heat flow in the copper and (2) to position the thermocouple beads accurately for a correction of the radial temperature drop to the tube surface.

The construction should provide easy, repeatable and cheap machining. The tube surface must not be affected.

1.2.2. Constructions

The general problem is the difficulty to drill a 2" deep, straight hole with a diameter smaller than 3/32" into copper.

Next listed are five different ways of instrumenting a copper tube:

a. Two tubes are hard-soldered into each other. A groove, machined on the outside of the inner tube, accommodates the thermocouple (Fig. 3a) [3].

b. Two tube halves are cut with wire-EDM (electric discharge machining). The grooves for the thermocouples are machined and

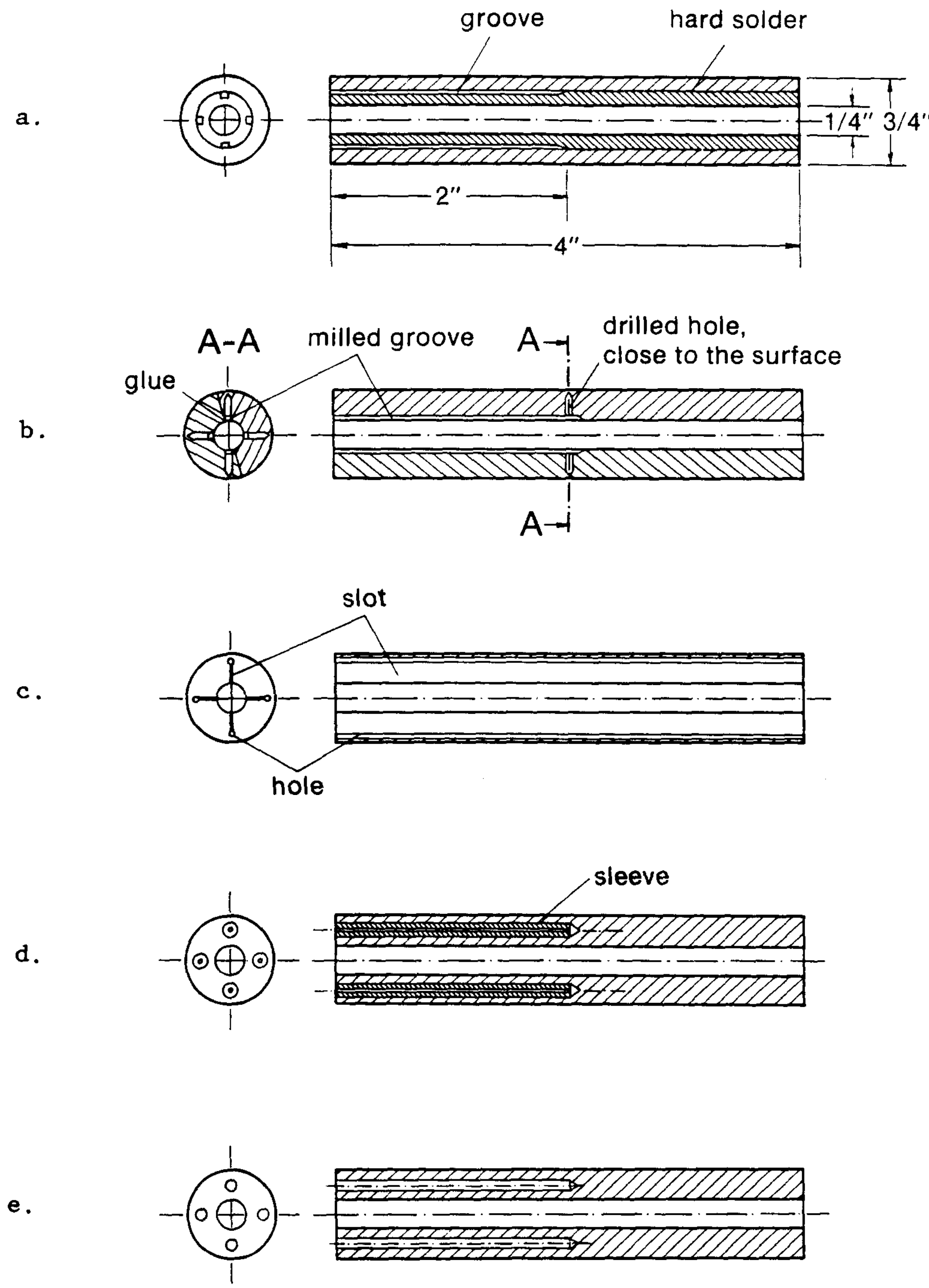


Fig. 3. Constructions for instrumenting a copper tube with four thermocouples

the halves are soldered or glued together (Fig. 3b).

c. A thin gap and a hole for the thermocouples is cut from the inside of the tube with wire-EDM. Optionally, the gap can be closed afterwards by pressing in a piece of copper or by soft-soldering (Fig. 3c).

d. The thermocouple lies in a plain well drilled into the tube wall (Fig. 3d) [4].

e. A hole is drilled into the tube wall. It accommodates a small copper tube with the thermocouple inside (Fig. 3d).

   To achieve good thermal conductance, the tubing can be
   - soldered,
   - inserted with a snug fit, and, optionally,
     - press-fitted for the first 1/4"
     - wetted with conducting grease.

The following table shows a comparison of the aforementioned constructions.

feature \ construction	a	b	c	d	e
experience available	P	N	N	P	P
tube surface not affected	P1	N2	P	P	P
good circumferential thermal conductance	P	P	P3	P4	P
good radial thermal conductance	N5	P	P	P	P
good radial positioning	P	P	P	N	P
thermocouple close to surface	N	P	P	N	N
doesn't require wire-EDM	P	N6	N	P	P
doesn't require soldering	N	P7	P7	P	P7

index:

P	positive feature
N	negative feature
1	must be soldered in vacuum oven
2	nucleation sites in the contact area of the two halves
3	gap must be closed
4	only if hole is very thin
5	non-uniform soldering probable
6	could be manufactured out of two tubes, if not cut with a wire-EDM
7	can also be soldered

Constructions c., d. and e. are chosen to be investigated in the pool-boiling tests.

1.3. The Heating with a Cartridge Heater

1.3.1. Requirements

The cartridge heater used for the tests with R-113 is 4" long and 1/4" in diameter. For later tests with water, we might have to switch to 3/8" diameter to get higher power.

In the tube bundle the maximum heat flux $q''_{max,bundle}$ through the tube surface will be in the intermediate range of nucleate boiling, whereas in the pool-boiling experiment this heat flux $q''_{max,pool-b.}$ should be almost critical (q''_{CHF}) to obtain the full characteristic of the surface.

$$q''_{max,bundle} = 4*10^4 \text{ W/m}^2$$

$$q''_{max,pool-b.} = q''_{CHF} = 2*10^5 \text{ W/m}^2$$

Both values are taken from former pool boiling experiments with R-113 [2,7].
With a surface area A

$$A = d\pi L = 0.75\pi 4*0.0254^2 = 0.00608 \text{ m}^2$$

the required maximal power P_{max} of the cartridge heater can be calculated as

$$P_{max} = q''_{CHF}\, A = 1216 \text{ W}$$

The heater can be ordered with 120V or 240V nominal voltage. A heater designed for a low voltage has three advantages:

- The coil is wound out of a thicker wire, which gives more security against a burn out.
- It is easier to overload the heater when the nominal power is

not sufficient.

- The insulation of the heater wire is less critical.

In particular, for the tube bundle tests the heater must be durable.

A cold area in the middle of the cartridge heater, as observed in former investigations [1], cannot be tolerated, because of the location of the thermocouples.

The contact to the tube should be

- thermally good, to keep the heater on a low temperature level and increase its lifetime
- uniform, to prevent hot spots.

The mounting arrangement must allow an easy exchange of the heater.

1.2.2. Constructions

There are three different possibilities to accommodate the heater inside the tube:

a. The heater is press-fitted into the tube.
b. Conductive grease is used between the heater and the tube wall.
c. The heater is soldered into the tube.

The following table compares the constructions.

feature \ construction	a	b	c
thermally good, uniform contact	N1	P	P
easy to install/exchange heater	P	P	N2

index:
- P positive feature
- N negative feature
- 1 the heater usually varies in diameter and is slightly crooked, which causes a non-uniform contact to the tube
- 2 requires a vacuum furnace to insure the tube surface does not oxidize during the soldering process.

Construction a. and b. will be checked in the pool-boiling tests. The preference is for a.

1.2.3. Commercial Cartridge Heater

We checked two brands of 1/4" cartridge heaters, 4" long, with the highest power rate available:

- Indeeco, 400W and
- Durex, 500W.

Both heaters are designed for 120 volts. Pool-boiling tests with the plain heaters show a uniform temperature distribution in the middle, and cold ends about 1/4" long.

Three out of four Indeeco heaters burned at a power level even below the nominal maximal value. The problem seemed to be the connection between the resistor wire inside the cartridge and the lead wire going out of the cartridge. Durex solved this problem by extending the resistor wire out of the cartridge and connecting it there to the lead wire. However, the stiff resistor wire tends to break when it is bent.

The Durex heaters could easily handle 750W power. Even a higher power might be possible if the temperature of the heater stays below approximately 150 ^{o}C.

2. The Mounting of a Tube to a Wall

2.1. Given Variables

One basic idea of the design of the tube bundle test section is to mount all tubes to one wall and handle this arrangement as a unit (as shown in Fig. 2).

The tubes must be positioned accurately and mounted perpendicular to the wall to insure a constant gap size between the tubes. The bundle with the smallest pitch of 1.17 limits the maximum available space for the mounting arrangement.

During the experiment the mounting must seal in R-113 up to 5 bar gage pressure.

The mounting arrangement used in the pool-boiling test section needs not fulfill the aforementioned criteria. However, a similar design is desirable. This would allow direct testing of a tube of the bundle in the pool-boiling test section. The behavior of the liquid at the mounting could be studied in the pool, too.

2.2. Requirements

The tube must be easy to exchange.

Virtually any connection between a tube and a wall requires reduction of the tube diameter at that point. This diameter loss should be as small as possible to give room for the thermocouples, and enable use of a 3/8" cartridge heater (for later tests with water, which require a heater with higher power).

The sealing, featuring an O-ring or a gasket, should always be on the liquid side of the wall. Otherwise liquid trapped in the mounting starts boiling there.

The tube should be thermally insulated from the wall to minimize heat loss.

Facing approximately 4 sets of 68 tubes and 2 different walls (for 2 different pitches), the machining should be inexpensive.

2.3. Constructions

Four classes of constructions are listed next:

a. The tube is threaded and is sealed with an O-ring (Fig. 4).

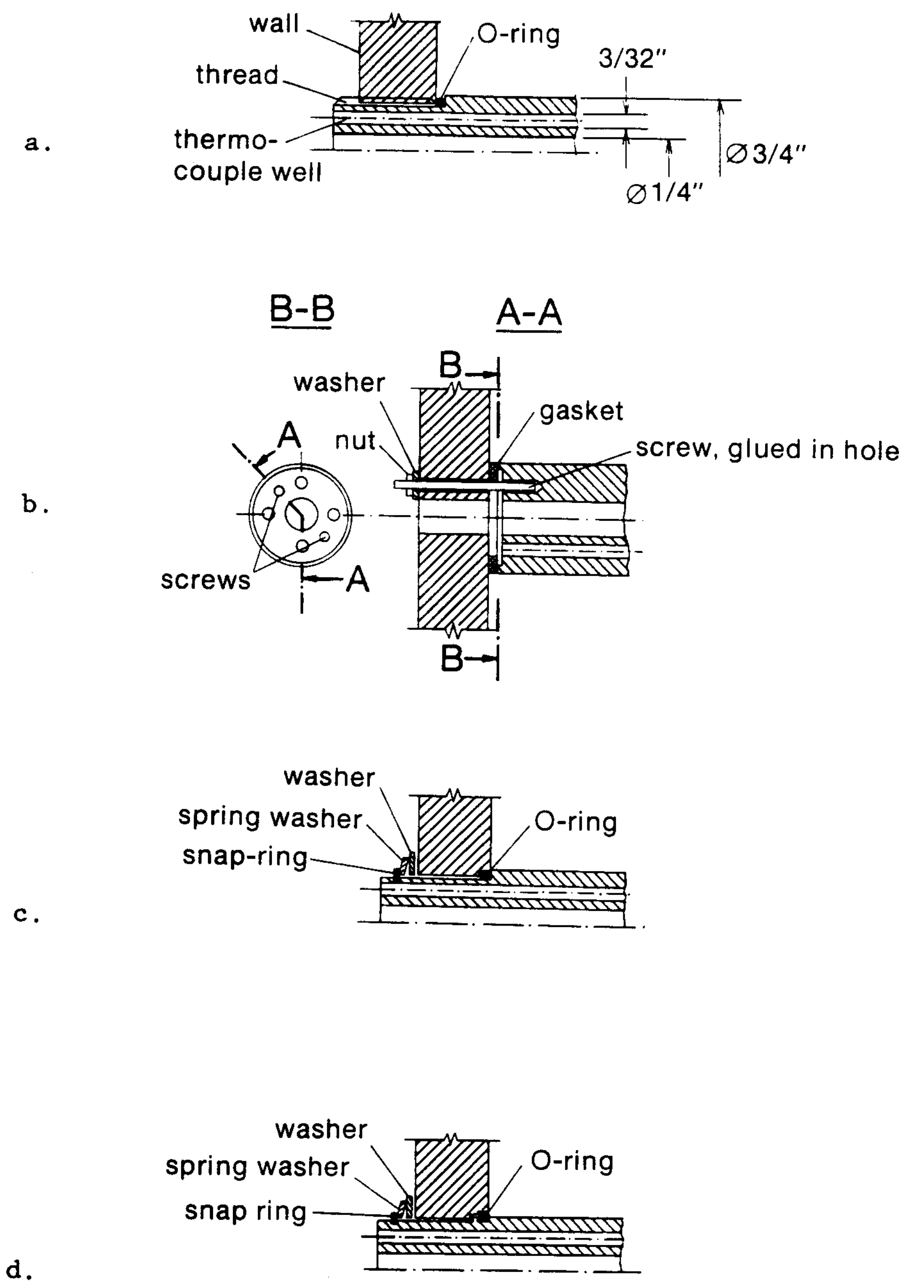


Fig. 4. Constructions for mounting a tube to a wall

b. Screws are glued into two (or four) small holes at the front side of the tube. Nuts tighten the tube to the wall. A gasket provides the sealing (Fig. 4b).

c. A snap ring pulls the tube against the wall. Thin washers are used to adjust the spacing. A machined groove in the wall accommodates an O-ring (Fig. 4c).

d. Similar to c., a snap ring is used, however the arrangement of the features is different (Fig. 4d).

The following table shows a comparison of the aforementioned constructions.

feature \ construction	a	b	c	d
accurate positioning	P	P	P	P
perpendicular to wall	P	N1	P	P
easy to exchange the tube	P	P	P	P
small diameter loss	N2	P	P	P3
no liquid trapped	P	P	N	P
tube thermally insulated	N	P	N	N
easy to machine the tube	N	P	P	P
easy to machine the wall	N	N	P	N

index: P positive feature

N negative feature

1 the tube sits undefined on the soft gasket material

2 can be improved using a very fine thread

3 smallest diameter loss possible

Construction b. is chosen for the pool-boiling tests. It provides a well defined area of the heat transfer from the tube to the liquid. The heat loss to the wall can be neglected. The positioning of the tube is not critical in this experiment.

For the tube bundle test section construction c. is considered best. According to an O-ring manufacturer the critical dimensions of the construction are shown in Fig. 5.

3. The Chamber for the Tube-Bundle in the Test Section

This chapter presents a basic concept of the tube bundle test section design. The construction element "side wall" is discussed briefly.

3.1. Given Variables

A staggered bundle of 68 (=8*5+7*4) tubes is mounted to one wall and inserted as a unit into the open box of the test section (Fig. 2).

The far tube ends contact the box to guarantee a proper flow

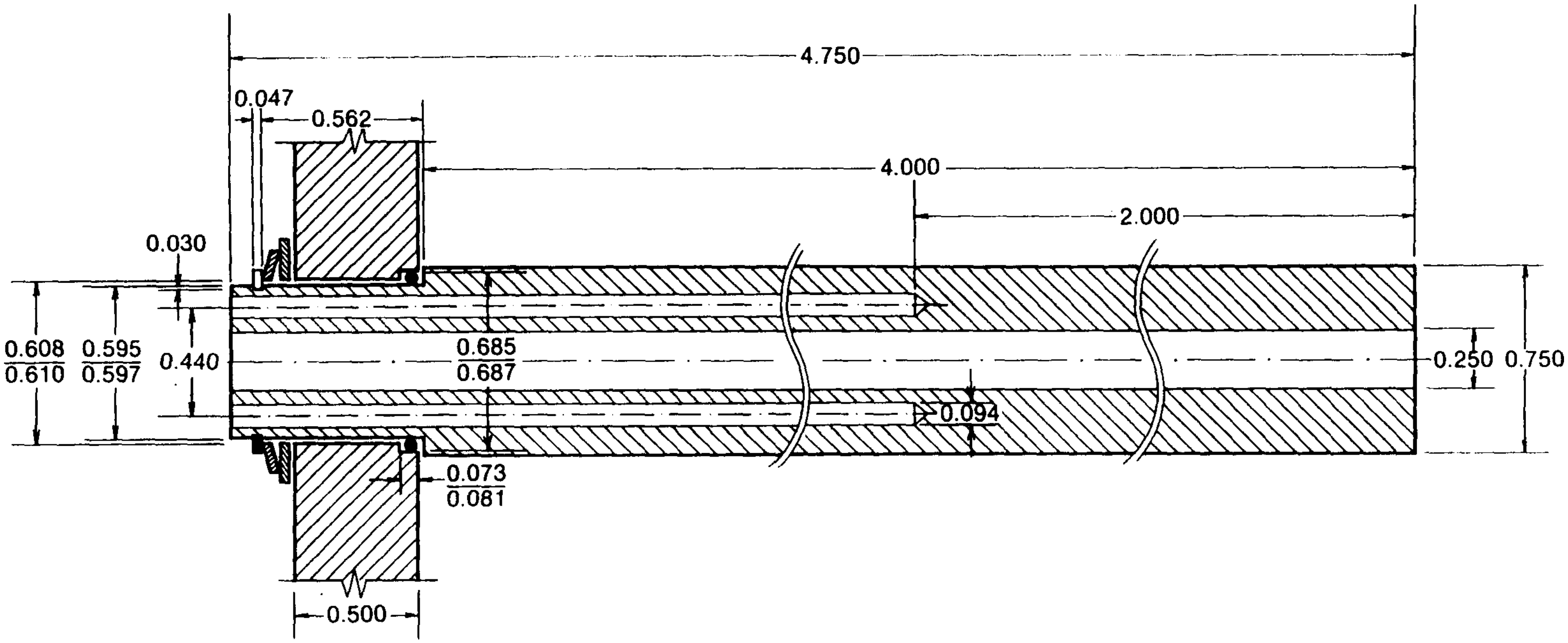


Fig. 5. Dimensions (in inches) of a mounting arrangement, featuring an O-ring and a snap ring

pattern.

The working fluid is R-113. The chamber must withstand 5 bar gage pressure.

3.2. Requirements

The side walls of the box cover half of the outside tubes and reduce or prevent a flow between the tube and the wall. This should minimize wall effects.

The side walls should be adjustable to different tube diameters and should work with rough, enhanced tube surfaces. Slightly crooked mounted tubes should be tolerated. Thermal insulation is desirable.

Windows, which allow an observation of the flow pattern, should be built in, at least at the back side of the chamber.

3.3. Constructions

The chamber consists of a containment and two exchangeable side walls (as shown in Fig. 6). These side walls separate the problems (1) to seal the chamber and (2) to adjust for different tube types and pitches:

1. The containment, together with the wall for the tube bundle, forms the pressure vessel.

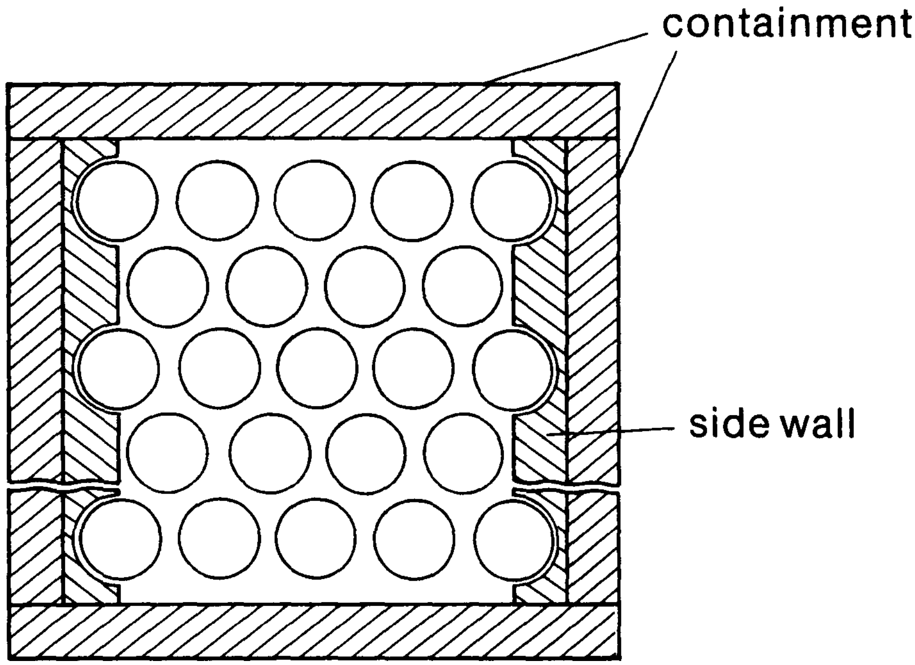


Fig. 6. The chamber of a tube bundle test section

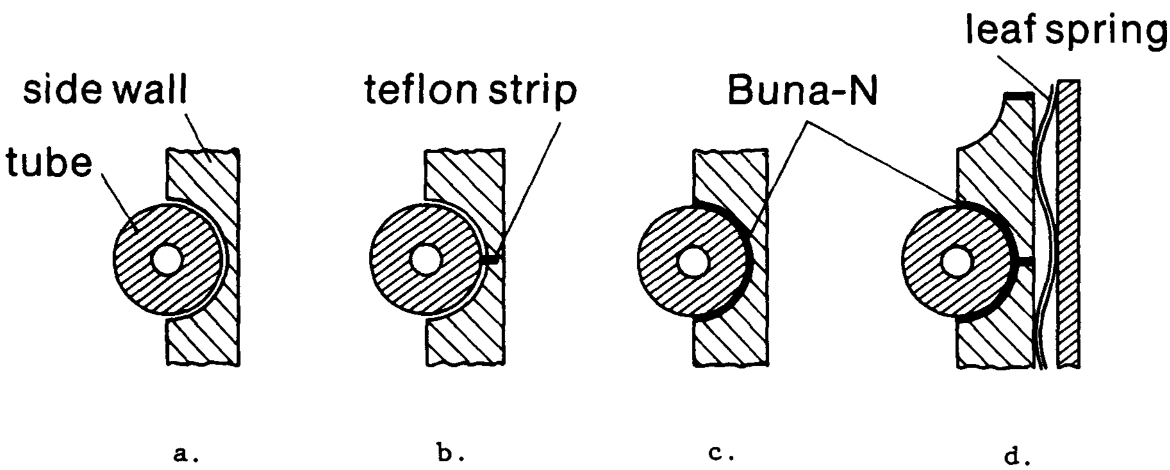


Fig. 7. Construction a.-d. of the side wall of the chamber

2. The side walls cover half of the tubes and produce the proper flow inside the chamber. They can be exchanged for different tube types and different pitches. A construction feature that moves the wall provides an easy insertion of the bundle and subsequent snug fit to the outer tubes.

Four possible constructions for the side walls are mentioned here:

a. The tubes reach into side walls with plain half-round shaped grooves (Fig. 7a).
b. Similar to a., but with adjustable teflon strips (Fig. 7b).
c. Similar to a., but with a layer of a soft gasket material (e.g. Buna-N) (Fig. 7c). In this construction the side walls must be movable.
d. Similar to c., but designed as a chain with soft joints (out of Buna-N), leaf springs and a second plate (Fig. 7d).

The following table shows a comparison of the side wall constructions.

feature \ construction	a	b	c	d
no flow between tube and wall	N	P	P	P
no liquid between tube and wall	N	N	P	P
side wall needs not to be movable	P	P	N	N
tolerates crooked mounted tubes	N	N	N	P

index: P positive feature

N negative feature

Construction d. is the most sophisticated one, which, however, might cause problems to manufacture. We recommend to start with construction a. and, if necessary, modify this approach.

The parts are manufactured out of 3/8" thick stainless steel or brass plates to prevent bending under pressure and to withstand corrosion in the hot freon.

The front wall, carrying the tubes, is screwed to the rest of the containment, which is soldered together. An O-ring, pressed into a groove, provides sealing.

One option could be to manufacture the back wall out of a transparent plate. If tempered glass is too expensive, a softer material like Lexan could be used, having a metal support grid in addition.

On the far end of every tube a soft disc with the same diameter as the tube is glued on. This disc seals the gap between the tube and the back wall of the chamber. The material could be Buna-N.

II. Experiments

1. Pool-Boiling Experiment

1.1. Apparatus

The plain copper tube is horizontally attached to a plate, which is positioned inside a pool filled with R-113 (as shown in Fig. 8). The pool sits in a bath where water circulates in a loop with an external, temperature controlled source. Both chambers, the pool and the bath, are made out of glass (Pyrex, 238x181x324 mm, cat# 6944-11L and 308x308x305 mm, cat# 6944-23L), to allow perfect visual observation. A coil (20 windings of a 1/4" copper tubing, 40 mm in diameter), cooled with tap water on the tube side, is installed underneath the cover of the pool to condense the freon vapor. An open Graham condenser (Pyrex, Krackeler Scientific, Inc., cat.# 2540-300) at the top insures atmospheric pressure in the chamber vapor space.

The freon level must be at least 4 cm underneath the copper coil to guarantee that no liquid directly cools down when the pool is highly agitated.

The tube, 3/4" o.d., 4" long, is heated with a 1/4" cartridge heater (Durex, 500W, 120V) supplied with AC power. A press fit, with 0.002"-0.004" tolerance, provides a good, homogenous heat transfer without soldering. However, it requires the tube to be open at two

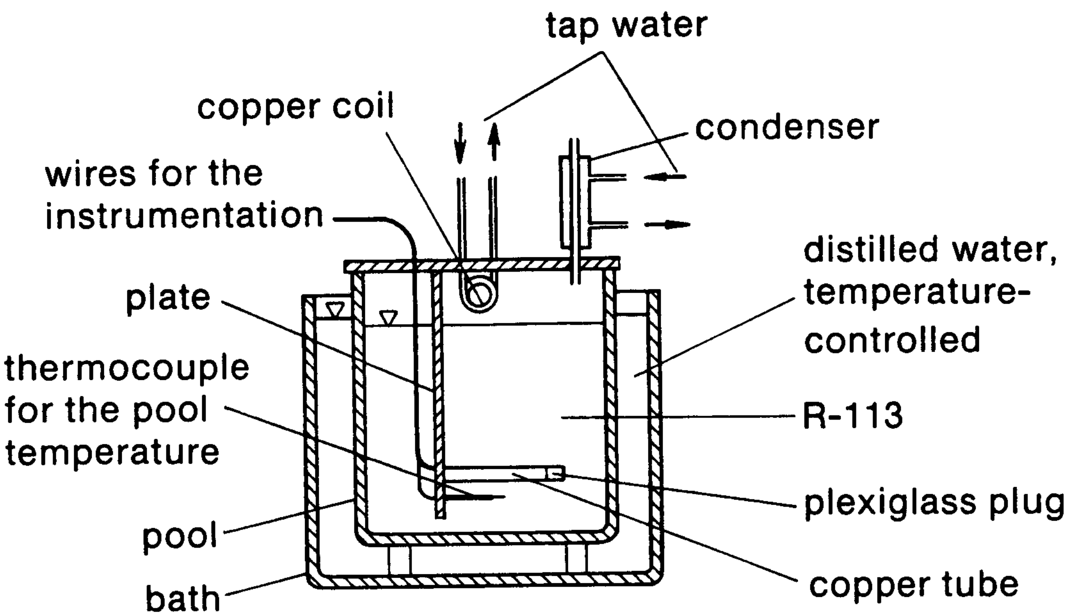


Fig. 8. Pool boiling test section schematic

ends for removal of the heater. The tube is mounted to the plexiglass plate with two screws (as shown in Fig. 3b). A plexiglas plug, 1" long, 3/4" o.d., insulates the far end and extends the tube to prevent turbulences. This design insures a well-defined area for the heat transfer to the liquid. The heat loss through the tube endings is negligible. The entrances of all holes are closed with epoxy (Devcon Corp., 5 Minute Epoxy) to keep the freon out.

Prior to running, the test section is cleaned with alcohol to ensure cleanliness.

A HP-3241 data acquisition system together with a HP-310 personal computer read the data:

- 4 temperatures in the tube wall: $T_{1,r}$, $T_{2,r}$, $T_{3,r}$ and $T_{4,r}$, located in the 12/3/6/9 o'clock positions
- the pool temperature T_{pool}, measured under the tube
- the bath temperature T_{bath}
- the voltage U at the cartridge heater
- the voltage U_s at the shunt, which is in series with the cartridge heater to measure the current I.

The data acquisition system is calibrated for temperatures, the voltage U and the voltage U_s (as described in IV.2). Temperatures are measured with copper-constantan thermocouples (ANSI type T, Teflon insulated, AWG 36, Omega Engineering, cat# TT-T-36).

The atmospheric pressure in the room is determined with a precision mercury manometer. A second precision manometer verifies that the gage pressure between the room and the freon vapor inside the tank is negligible.

1.2. Procedure

First the system must be degassed. To achieve this, the pool is heated up to saturation temperature through the temperature controlled water jacket and the tube pre-boils with a heat flux of about $3*10^4$ W/m^2 for at least half an hour.

Next, we turn the power of the heater off and wait until the thermocouples in the tube wall indicate that the saturation temperature of the freon and the system is stable.

Then the experiment starts. The heat flux is increased stepwise from 0 to $1.4*10^5$ W/m^2, and then is decreased again to get data points for the pool-boiling curve: heat flux q" versus average wall superheat T_{WSH}

$$q" = (UI)/A$$

$$T_{WSH} = T_{av} - T_{sat}$$

$$T_{av} = (T_1+T_2+T_3+T_4)/4$$

$$T_i = T_{i,r} - [q"R/k]\ln(R/r) \quad , \ i = 1,..4$$

$$T_{sat} = f(p = p_{atm} + p_{hydr})$$

$$p_{hydr} = \rho g H$$

The power UI, dissipated in the cartridge heater, divided by the surface area A of the tube gives the heat flux q". T_{av} is the average value of the tube surface temperatures T_1 to T_4, which are obtained by correcting each thermocouple temperature $T_{1,r}$ to $T_{4,r}$ for the radial temperature gradient between the thermocouples and the tube surface. As a simplification one-dimensional conduction is assumed. The distance between the thermocouple bead and the tube axis is estimated as r and the radius of the tube surface without enhancement as R. The saturation temperature T_{sat}, a function of pressure (atmospheric plus hydrostatic), refers to freon at the level of the tube axis, a height H beneath the liquid surface.

Data are taken when the system is stable, which is defined that none of the measured variables (see I.1.1.) changes more than 0.1% within 30 seconds. This check also makes sure the fluctuations of the data acquisition system readings are small.

Note, there is a steady, "blind" heat flow from the water bath to the freon to the environment. This occurs because the condenser always trends to cool too much, to make sure no freon vapor is leaking. The "blind" heat flow should be as small as possible. It can be regulated by (1) the temperature of the water bath and (2) the flow rate of the tap water running through the condensers (copper coil and Graham condenser). These two parameters determine the pool temperature, which adjusts at a level to equal the heat flow from the bath and the heat flow to the environment (tap water and air). The pool temperature can be below or even above the saturation temperature of the freon. If the bath temperature is too high, or the flowrate is too low, the pool can superheat several degrees. This is possible, because the smoothness of the glassy pool wall impedes the liquid to find nucleation sites and remove the heat by evaporating. It is found that a bath temperature of about 1.5 ^{o}C above the saturation temperature of the freon and a tap water flow rate of 0.1 l/min establish saturation inside the pool.

1.3. Tested Enhanced Tubes

In the present study four different enhanced surfaces are tested, the Wolverine Turbo-B S, M, L and the Wieland Gewa-T Bl. The tubes are made out of copper.

The surfaces of the Turbo-B tubes are provided by successive cross-grooving and rolling operations performed after finning. The general appearance is a grid of rectangular flattened blocks that are wider than the fins and separated by narrow openings between the fins and narrow grooves normal thereto [13]. The finning and the cross-grooving operations are supposed to be the same for the three tube types manufactured especially for this study. The final rolling operation, however, is different for the Turbo-B S, M and L and provides small, medium or large mushroom-shaped fins, respectively. The resulting openings are supposed to be both larger and smaller than the optimum minimum pore size for nucleate boiling of freon. Fig. 9a and Fig. 9b show photo-micrographs of typical cross sections of the tube surfaces cut in the axial direction and normal thereto, respectively. A statistical analysis of the important dimensions could not be done in this study because the produced surfaces are rather irregular.

The Wieland Gewa-T is manufactured by a somehow similar process; however, compared to the Turbo-B, it does not have cross grooves, the number of fins per unit length is less and the fin geometry appears to be very regular. This standard surface from Wieland has been rather thoroughly investigated in former studies

[11,14]. The surface structure is shown in Fig. 9c [11].

Below are listed the measured major dimensions for the aforementioned enhanced tubes. The data for the Turbo-B tubes pertain to the cross sections shown in Fig. 9a and Fig. 9b.

type	o.d.(mm)	r.d.(mm)	gap (mm)	fins/m	g.d.(mm)	cross g.
Turbo-B S	19.14	18.06	0-0.11	1890	0.16	80
Turbo-B M	19.14	18.04	0-0.11	1890	0.13	78
Turbo-B L	19.16	17.96	0-0.11	1660	0.13	83
Gewa-T B1	18.88	17.24	0.25	770	-	-

Here, the following comments apply:

- o.d. — outer diameter of the tube including the enhancement
- r.d. — maximum (root) diameter of the tube without the enhancement
- gap — distance between the fins at the fin mouth
- fins/m — number of fins (windings) per m, axially measured
- g.d. — depth of the cross grooves
- cross g. — number of cross grooves per winding, circumferentially measured

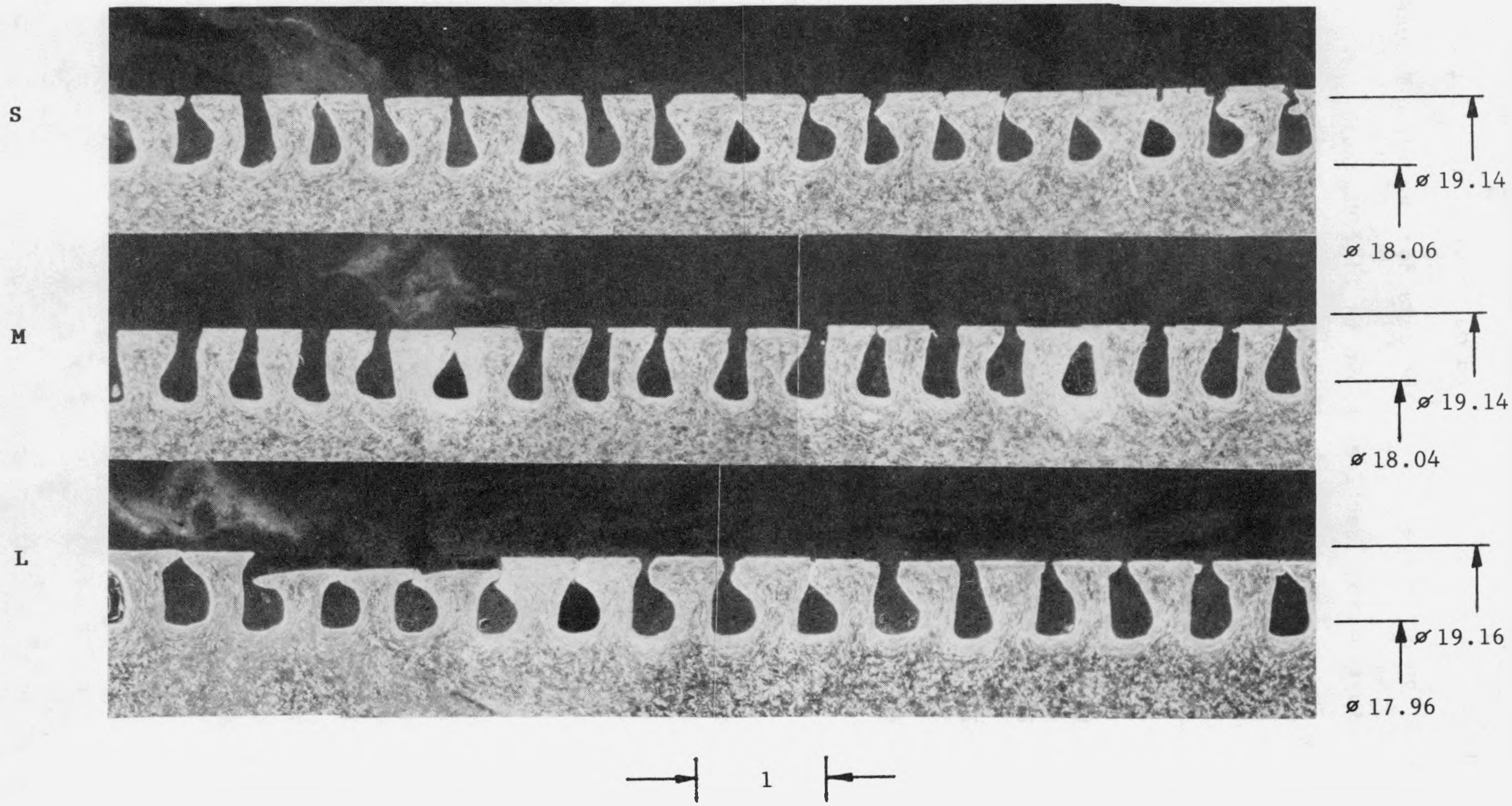


Fig. II.1.3.a.: Cross section of the Turbo-B S, M and L cut axially (enlarged 20x)

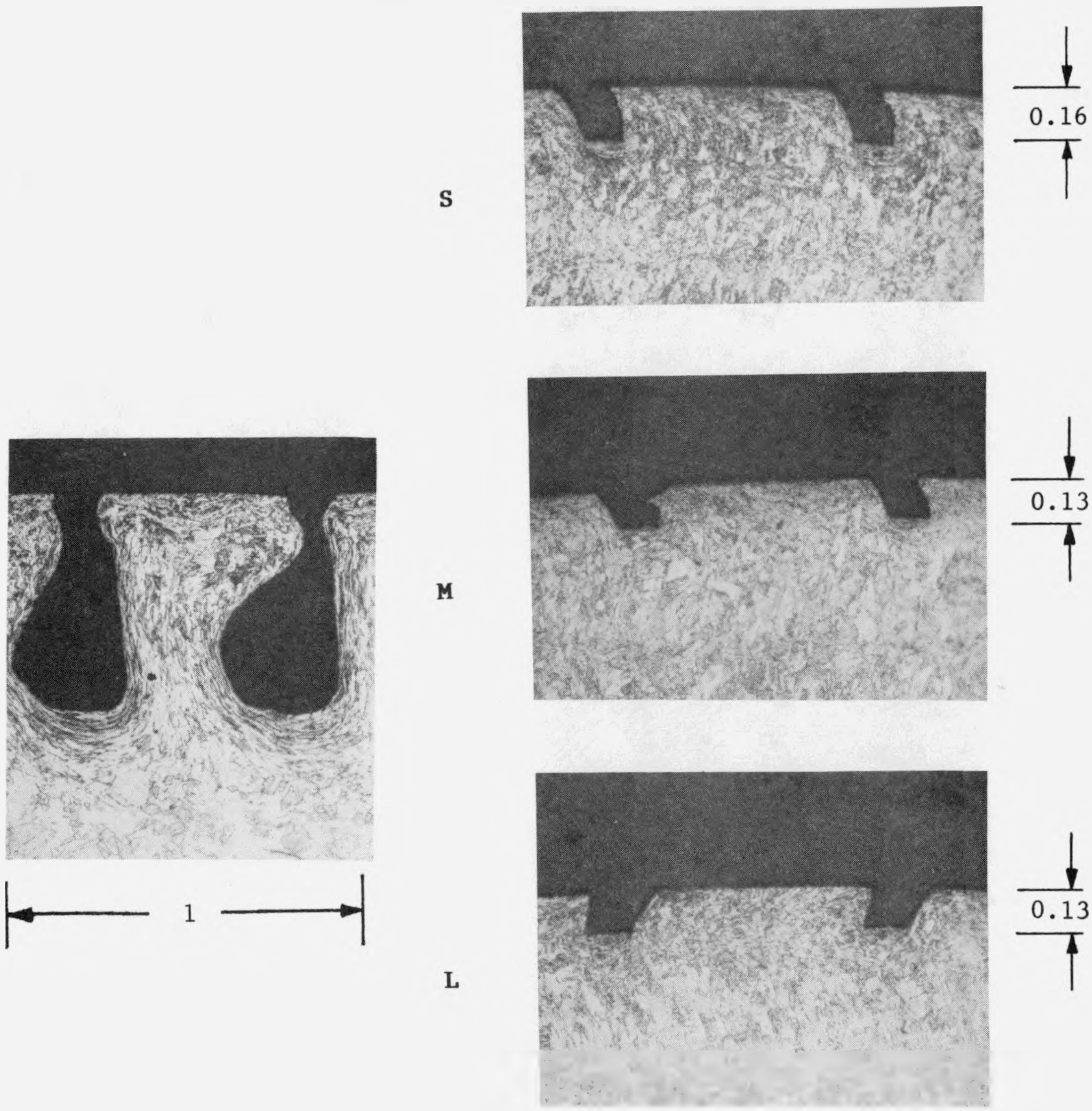


Fig. II.1.3.b.: Cross section of the Turbo-B S, M and L cut normal to the axes, compared to an axial cut of the Turbo-B M (all enlarged 50x)

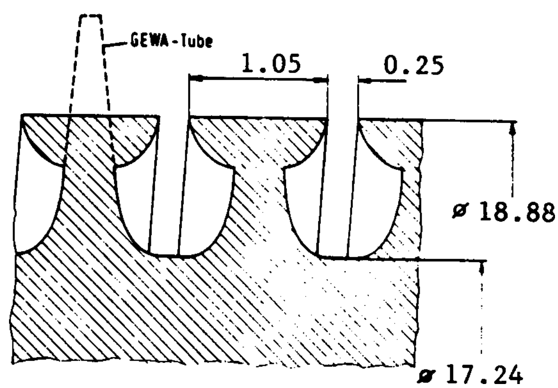


Fig. 9c. Cross section of the Gewa-T B1 cut axially

1.4. Tested Arrangements

A plain tube is tested with 10 different arrangements:

A1 One tube end is fixed to a plate; the far end has an extension plug and is free. The thermocouples lie in copper sleeves (1/8" o.d., 1/16" i.d.), which snugly fit into the tube wall (as shown in Fig. 3c). The tube surface is polished with 600 grit paper.

A2 Similar to A1, but a second plate is placed symmetrical to the first one, at the far end of the tube (as shown in Fig. 10) to force a two-dimensional flow pattern.

A3 Similar to A1, but the tube surface is polished with a 100 grit paper.

A4 Similar to A1, but the thermocouples are accommodated in plain wells with 3/32" diameter. No sleeves are used (as shown in Fig. 3d).

A5 Similar to A4, but the tube surface is highly polished with Crocus paper.

A6 Similar to A4, but with conductive grease between the heater and the tube.

A7 Same as A4.

A8 Similar to A1, but the thermocouples lie in slots, which are almost touching the tube surface (as shown in Fig. 3c).

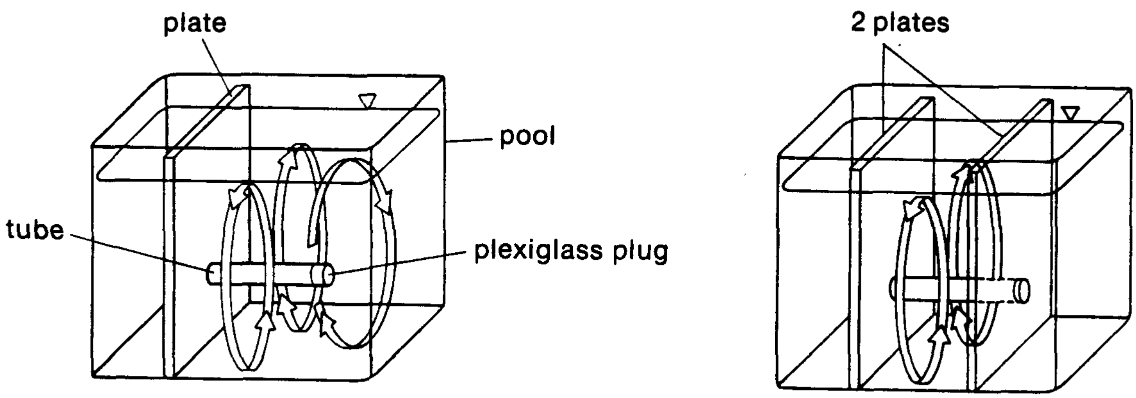


Fig. 10. Flow pattern in pool boiling with one plate and two plates

The slots are left open.

A9 Similar to A8, but the slots are closed with solder.

A10 Similar to A9, but the tube is rotated for 180 degrees around its axis.

Four different enhanced tubes, the Wolverine Turbo-B S, M, L and the Wieland Gewa-T B1 are tested in the present study. The arrangement chosen for the Wolverine Turbo-B tubes is similar to A1; however, the sleeves used to accommodate the thermocouples measure 0.093" o.d. and 0.036" i.d..

A11 Turbo-B S

A12 Turbo-B S

A13 Turbo-B L

The Wieland Gewa-T B1 has slots machined with wire-EDM, which, different from the plain tubes (A8-A10), only reach into the middle of the tube wall.

A14 Gewa-T B1

All tests are conducted with the same equipment. We assume an exchange of the cartridge heater may change the temperature distribution, but not the average temperature of the tube wall.

The wells for the thermocouples in arrangement A4-A7 could be drilled with a thinner drill bit than 3/32". However, we found out that to use a significantly thinner drill bit, like a 3/64", e.g., takes much more time to drill, causes a much higher risk to break the drill bit and often produces a crooked hole.

The wells for the Turbo-B tubes (arrangement A11-A13) are drilled in two stages. For the first 1.5" depth we use a #40 drill bit, which is slightly bigger than 3/32". The remaining 0.5" is drilled with a 3/32" drill bit. This method allows a faster in/out movement of the drill bit when drilling the second part of the well.

The thermocouples are accommodated in custom-made sleeves with 0.093" o.d. and 0.036" i.d., mainly to provide an accurate positioning of the thermocouple bead to reduce the uncertainty of the temperature measurement (as explained in IV.5.). These sleeves have not been available for earlier tests with plain tubes. However, the improvement there is not that crucial because the plain tube operates at a higher temperature (compared to the enhanced tube), thus the relative error of the temperature reading is smaller.

The inner diameter of the Turbo-B S, M and L tubes measure 0.266", 0.261" and 0.261", respectively, instead of 0.249", the diameter we ordered. A 0.005" thick copper sleeve (of shim stock) reduces the inner diameter of these tubes and provides a proper heat transfer from the cartridge heater.

The silicon-based thermal conductive grease (Omega Engineering, Inc., Conductive Grease Omegatherm 201, cat# OT-201), as used for arrangement A6, requires enlargement of the inner tube diameter for about 0.002" to achieve a similar tight fit.

In arrangements A8-A10 the geometry of the hole and the slot (as shown in Fig. 3c), is dimensioned so that the thermocouple bead fills out the hole and cannot slide into the slot.

The thermocouples of arrangement A10 are directly soldered into the holes. A tin-based soft solder with a melting point of 220 °C, provides 25 °C "security" to the melting point of the Teflon insulation of the thermocouples. The soldering operation requires a temperature-controlled furnace.

1.5. Results

Most of the results refer directly to an interpretation of the pool-boiling curve of the tested arrangement. Our main interest is to recognize trends in the range of nucleate boiling and the transition from natural convection. Data of plain and enhanced tubes in natural convection are recorded to establish the characteristics of the specific surfaces, not to investigate their detailed behavior at this flow pattern.

Next listed are the results, summarized in 14 items. The expression "data A1" for example, refers to results obtained with arrangement "A1" (as explained in II.1.4.). The exact data of the experiments are listed in the appendix (IV.7.).

R1 Concerning the accuracy of the experiments, the results agree well with former investigations [2,6,7,9,14]. A comparison of the data for the plain tube with 3/4" o.d. and a surface polished with a 600 grit paper (data A1) is shown in Fig. 11. In Fig. 12 the present data for the Turbo-B S tube (data A11) are plotted together with results obtained for a Turbo-B tube boiling R-114 [8]. A comparison for the Gewa-T is given in Fig. 13 [14].

R2 Data of the same test section setup can be reproduced virtually identically.

R3 A comparison of data A4 and data A6 shows that the temperature deviation in the tube wall cannot be smoothened out by filling the air gap between the cartridge heater and the tube with conductive grease. The non-uniformity must be due to the heater itself.

The temperature profile due to the flow pattern is always clouded by the temperature profile of the heater.

R4 The temperature deviations among the thermocouples in the tube wall continuously rise with increasing heat flux. The maximum spread, depending on the tube arrangement, is 1.2 ^oC to 2.6 ^oC at about 70 ^oC average wall temperature and $1.4*10^5$ W/m^2 heat flux (nucleate boiling).

The temperature variation in the tube wall can be interpreted as the superposition of two effects:

- The rising liquid cools the bottom of the tube better than the top (E1).

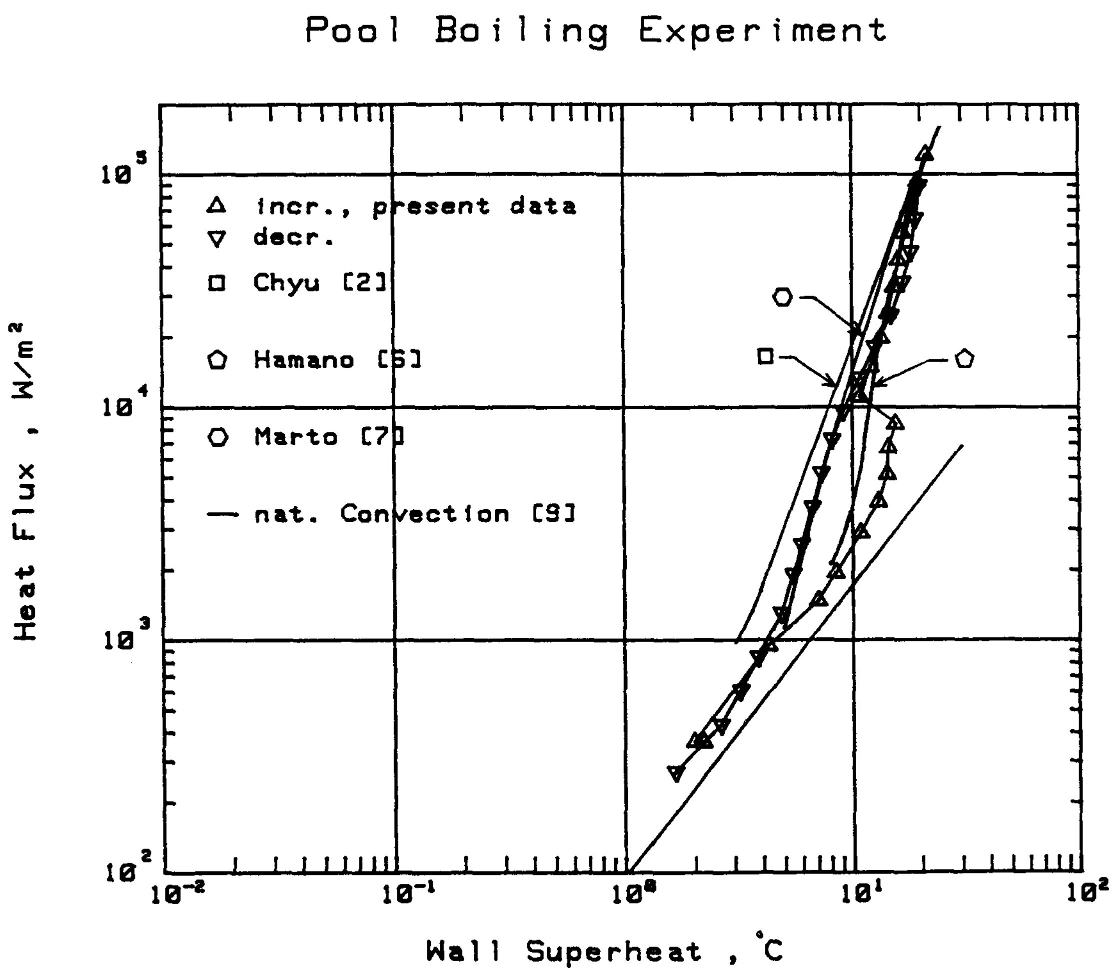


Fig. 11. Pool boiling curves of a plain, polished tube in R-113

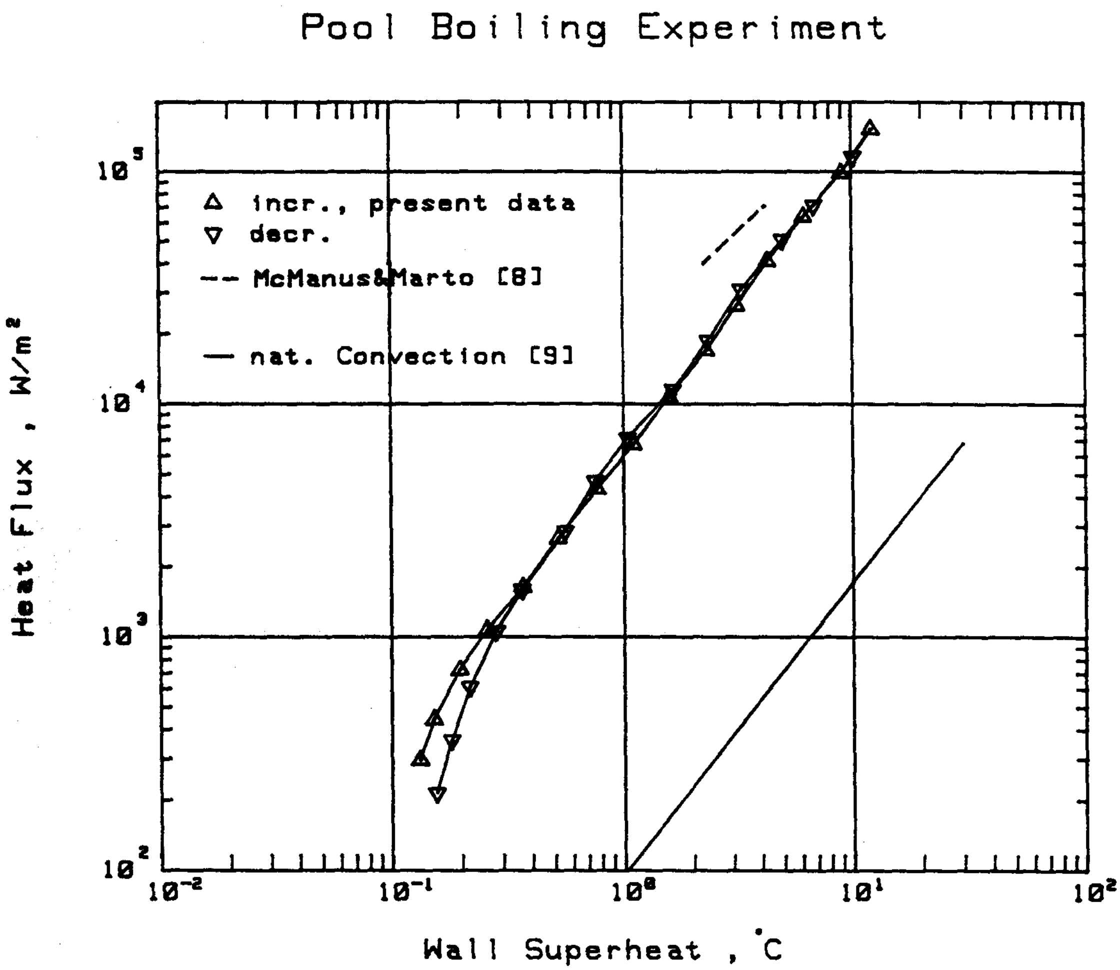


Fig. 12. Pool boiling curves of a Turbo-B S tube in R-113 (All) and of a Turbo-B tube in R-114 [8]

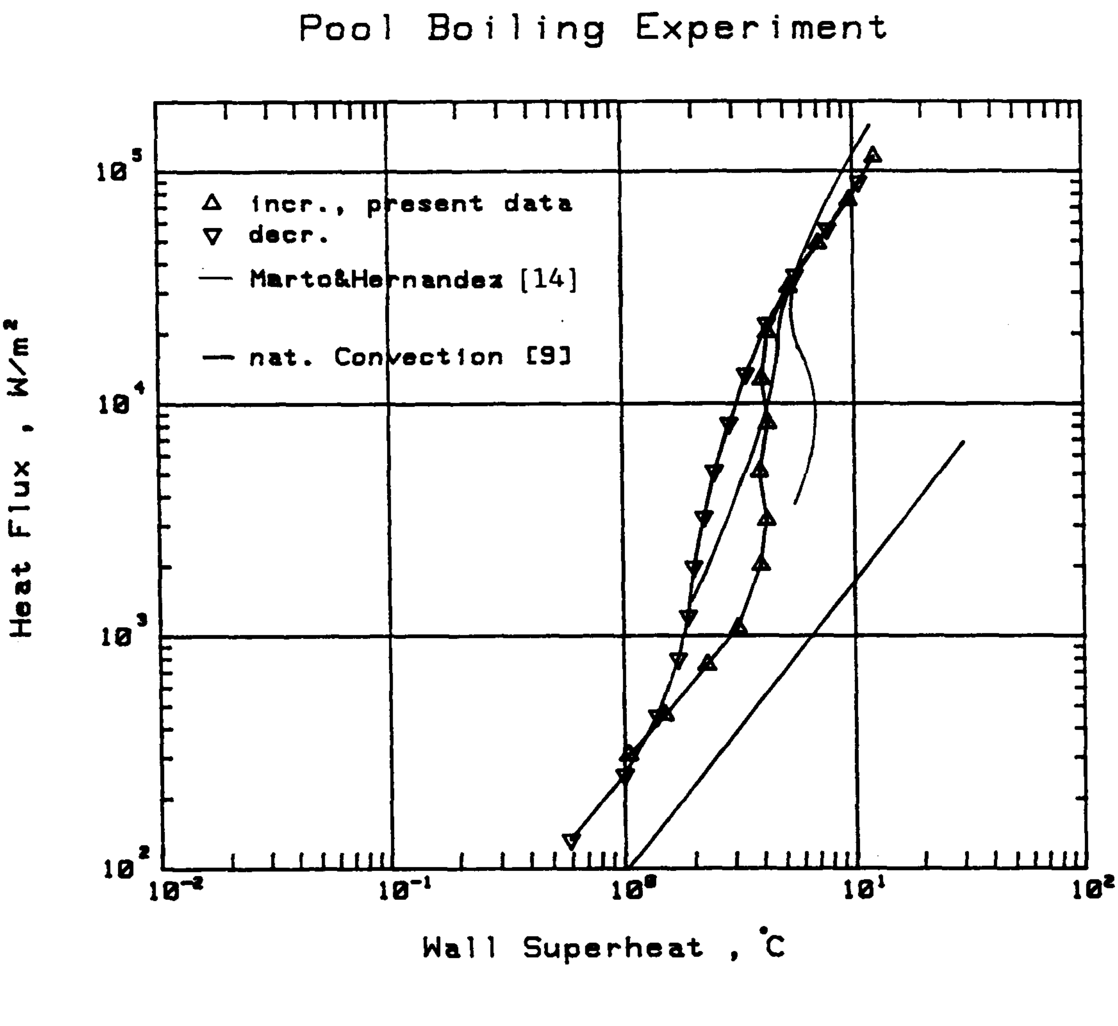


Fig. 13. Pool boiling curves of a Gewa-T B1 tube in R-113

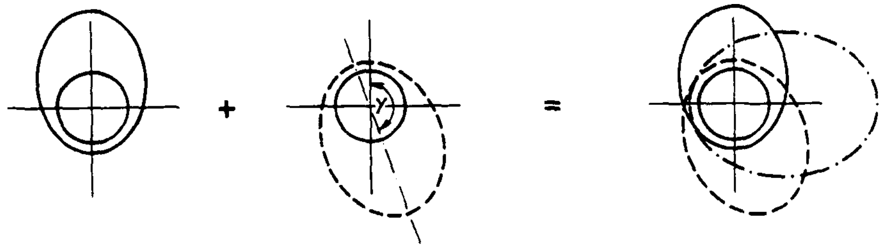
- The cartridge heater distributes the heat non-uniformly (E2).

The temperature profile of E1 has a fixed orientation, whereas the profile of E2 depends on the particular mounting. Both effects increase with rising heat flux. They are assumed to be of the same order of magnitude.

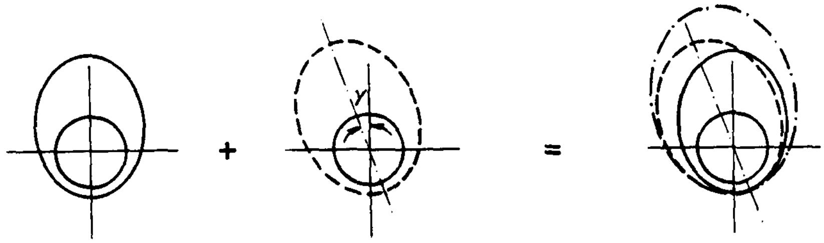
With T1, T2, T3 and T4 as the tube wall temperatures in the 12/3/6/9 o'clock positions, we observe the following combinations of the hottest/coldest temperatures: T1/T2, T1/T3, T1/T4, T2/T3, T2/T4 and T3/T4 (at about $1.3*10^5$ W/m^2 heat flux).

Two examples are mentioned next to explain these temperature distributions with a superposition of effects E1 and E2. γ is defined as the angle between the maximum temperatures as related to temperature profile caused by E1 and E2:

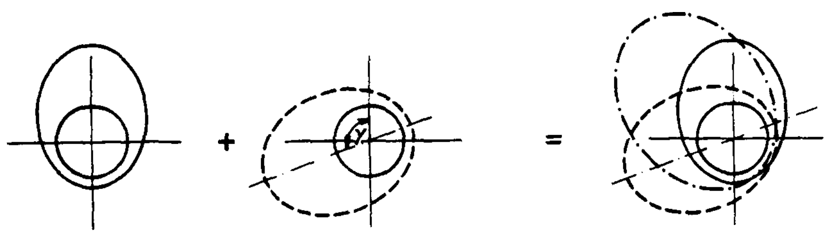
- In Data A9 we find the combination T2/T4, whereas in data A10 (same arrangement as A9, but the tube is turned 180 degrees around its axis) this combination is T1/T3. Fig. 14a and Fig. 14b show the temperature profiles for both data sets as a superposition of the temperature profiles from E1 and E2 with γ=150 degree and γ=150-180=30 degree shifts, respectively.
- Data A7 gives information about the temperature distribution in the tube wall during the transition between nucleate boiling and film boiling (at $1.9*10^5$ W/m^2 heat flux). Here, E2 dominates E1 because of the less effective heat



a. γ = 150 degree shift



b. γ = 180 - 150 = 30 degree shift



c. γ = 60 degree shift

Fig. 14. Superposition of the temperature profiles due to the fluid mechanics and the non-uniformity of the cartridge heater

transfer process at the tube surface. The temperature combination at this regime is T4/T2, compared to T1/T2, at nucleate boiling ($1.3*10^5$ W/m^2 heat flux). The temperature distribution T4/T2 at the high heat flux ($1.9*10^5$ W/m^2 heat flux) "detects" the hot spot of the cartridge heater. The temperature maximum, due to effect E2 is located near to the thermocouple for T4. If we superpose a T4/T2 temperature profile to the temperature profile, caused by effect E1, we can obtain T1/T2, the temperature profile of the tube wall at nucleate boiling (as shown in Fig. 14c).

R5 According to Bier and Goetz [3] the average heat transfer coefficient can be calculated from the average wall superheat. The error caused by this simplification is negligible if there are "enough" temperature measurements available. Only the average wall temperature is important, not the deviation.

Data A8, Data A9 and Data A10, for example, refer to tubes with slots in the tube wall (wire-EDM, Fig. 3c). With this instrumentation method the tube is divided into 4 sections. The slots in the tube of A8 are left open, whereas the slots of A9 and A10 are closed with a soft solder. All tubes have the same surface quality.

As expected, the temperature deviations in A8 is greater than in A9 and in A10 (2.6 ^oC compared to 1.5 ^oC and 1.3 ^oC at $1.3*10^5$ W/m^2 heat flux), because of the retarding of the circumferential thermal conductance by the slots. The temperature profiles of A9 and A10 are altered by about 90 degrees (as explained in R4). However, the three boiling curves, using the average wall temperature, are essentially the same (as shown in Fig. 15).

R6 Having the tube fixed to one plate only, we observe a 3-dimensional flow in the pool. One convection plane is perpendicular to the tube axis, the second plane is parallel to the tube axis. In the tube bundle, as in an "ideal", infinitely long pool-boiling test section, the liquid mainly flows perpendicular to the tube axis (2-dimensional). To check the influence of the flow pattern in the pool-boiling experiment, we placed a second plate symmetrical to the first one (as shown in Fig. 10) to obtain a 2-dimensional convection. Regarding data A1 (one plate) and data A2 (two plates) one can see the second plate has no significant influence (as shown in Fig. 16). The boiling curve seems to be insensitive to this small variation of the pool geometry.

R7 Three different constructions, featuring a copper sleeve (A1), a plain well (A4) and a slot (A9), are tested to find out whether the instrumentation method affects the readings of the tube temperature. The plain well obviously is the simplest way, while the slot, machined with wire-EDM and soldered, is the

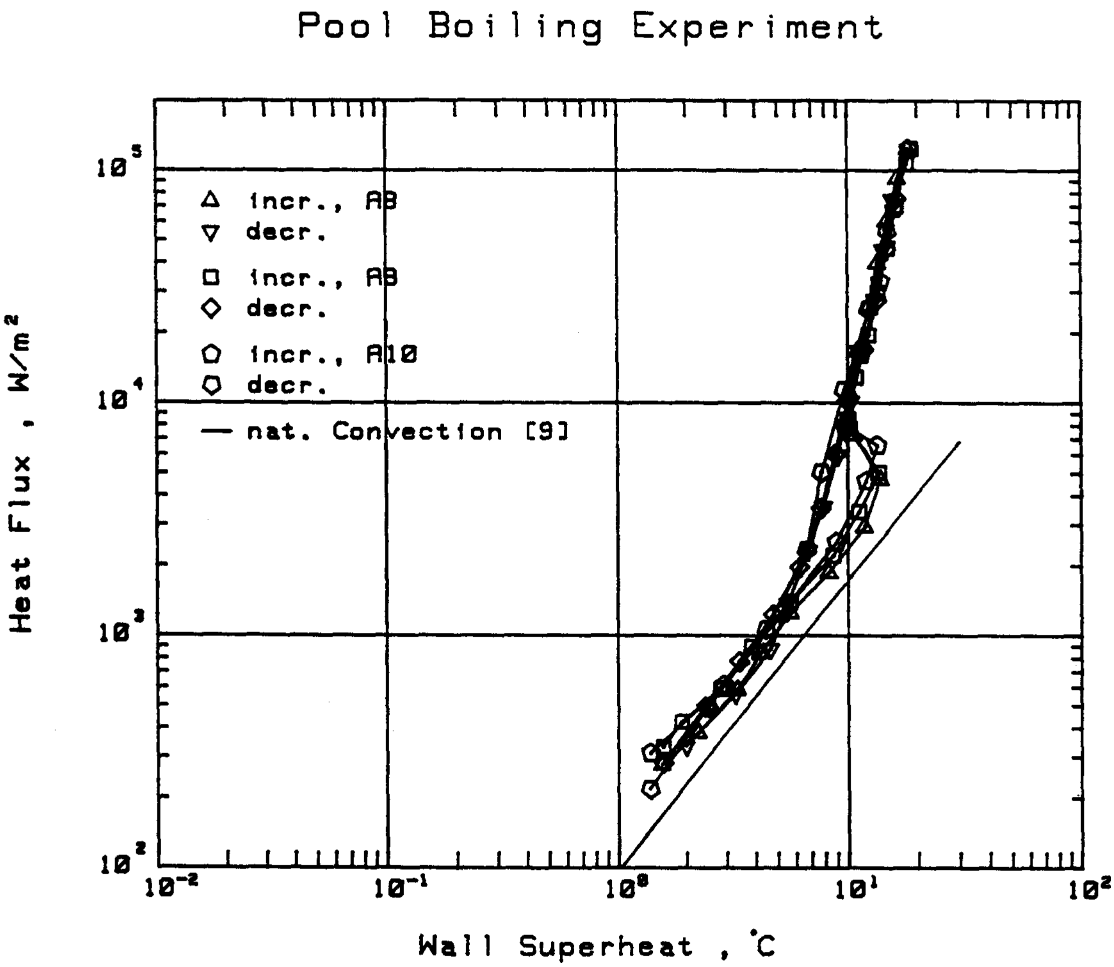


Fig. 15. Pool boiling curves of tubes with the same surface quality and different temperature profiles

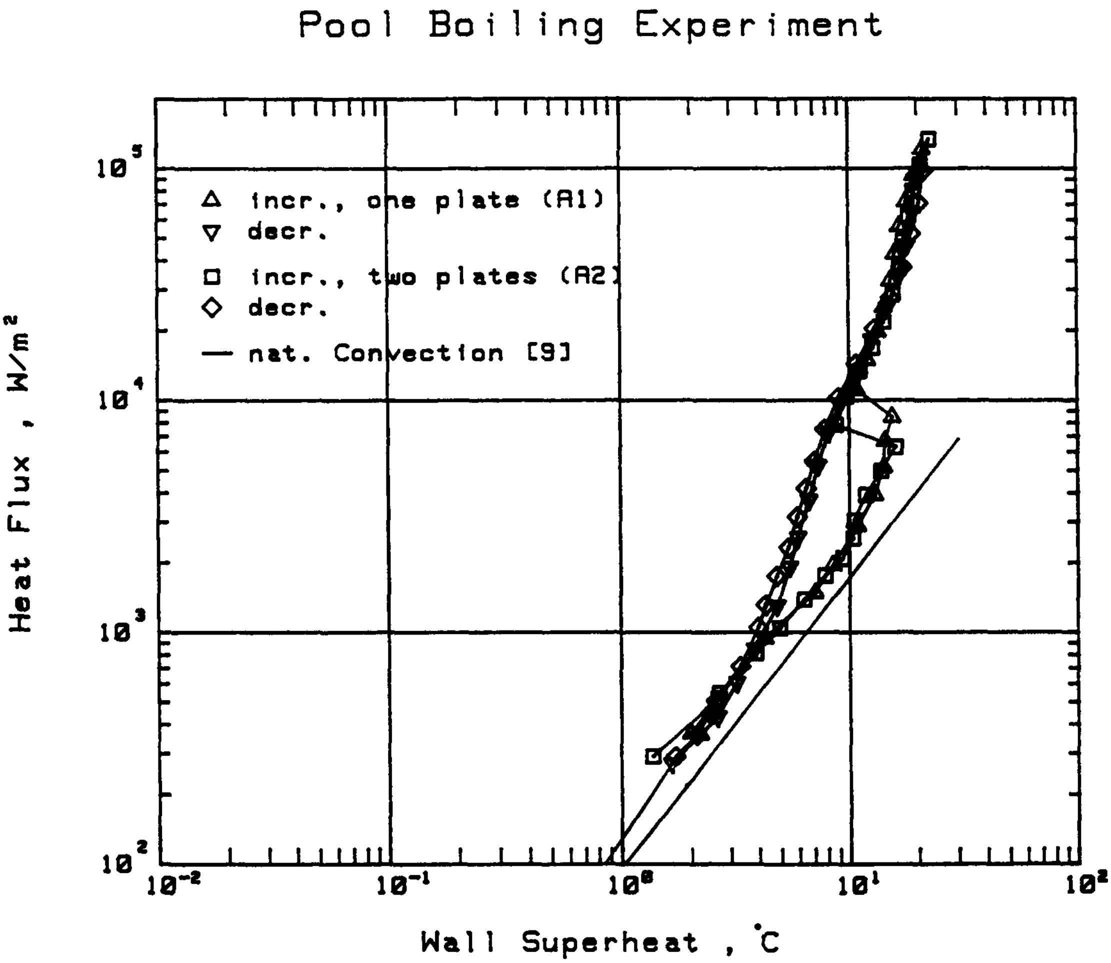


Fig. 16. **Boiling curve of a plain tube in a pool with 3-dimensional (A1) and 2-dimensional (A2) flow pattern**

most difficult way to accommodate the thermocouples in the tube wall.

The boiling curves of the three arrangements are not significantly different (as shown in Fig. 17).

R8 A noticeable shift of the boiling curve in the region of nucleate boiling is obtained by changing the surface roughness. Using 600 or 100 grit paper (as in A1 or A3) instead of Crocus paper (A5) reduces the average wall superheat about 2 ^{o}C or 4 ^{o}C, respectively (Fig. 18).

R9 A high temperature overshoot, followed by a sudden change of regimes from natural convection to nucleate boiling during an increase of power is not observed. The reasons for this are different for (1) the enhanced tubes and (2) the plain tubes.

Relative to 1, the Turbo-B tubes immediately start boiling when the power of the heater is turned on. The onset of nucleate boiling occurs below 300W/m^2 heat flux and cannot be determined in this experiment (see IV.2. calibration).

Relative to 2, on plain tubes, rogue sites trigger boiling at both tube ends and activate nucleation sites which settle on parts of the surface. Two heat transfer mechanisms, natural convection and nucleate boiling, can be seen at the same time in a steady system. The first rogue sites appear at a low heat flux of 500W/m^2, far before the expected onset of nucleate boiling (ONB). Increasing the heat flux, the area covered with

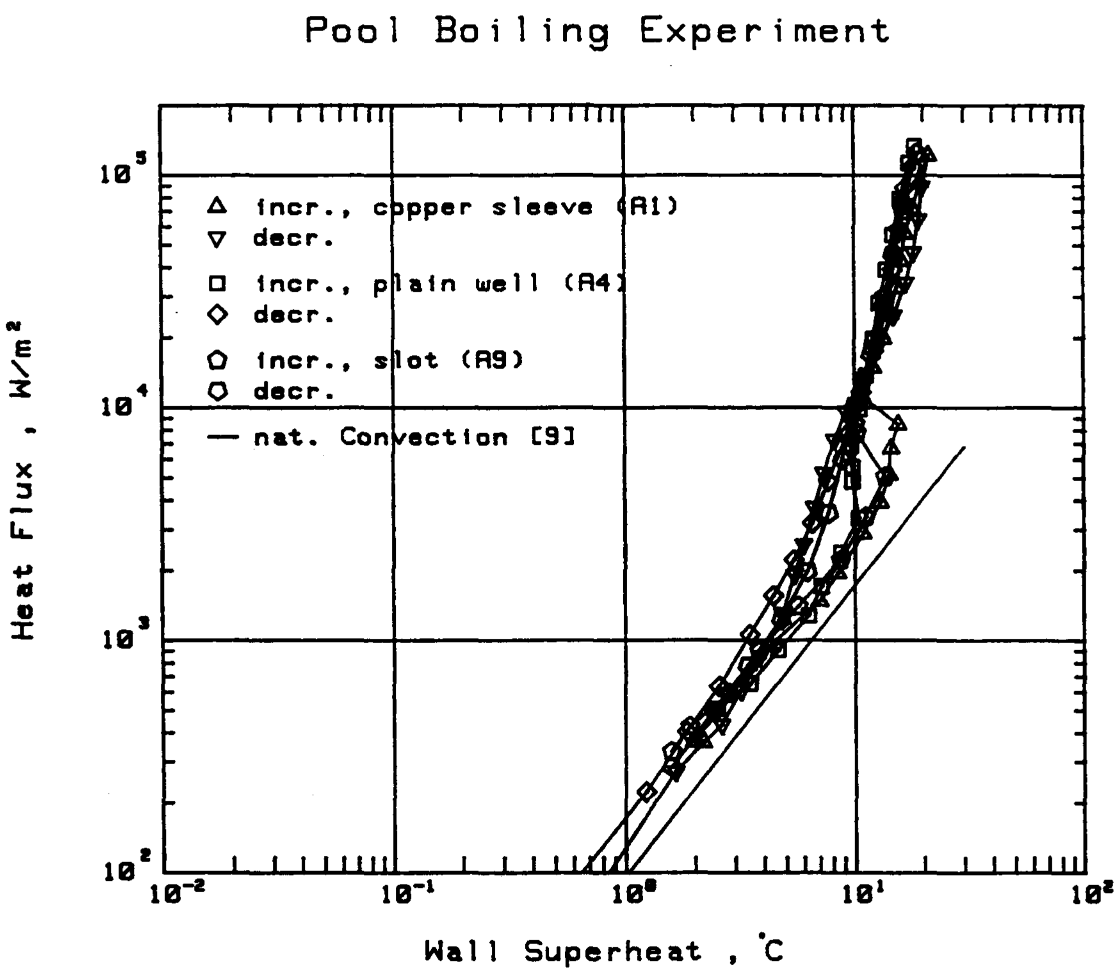


Fig. 17. Pool boiling curves of plain tubes with different instrumentation methods, featuring a copper sleeve (A1) a plain drilled well (A4) and a wire-EDM slot (A9)

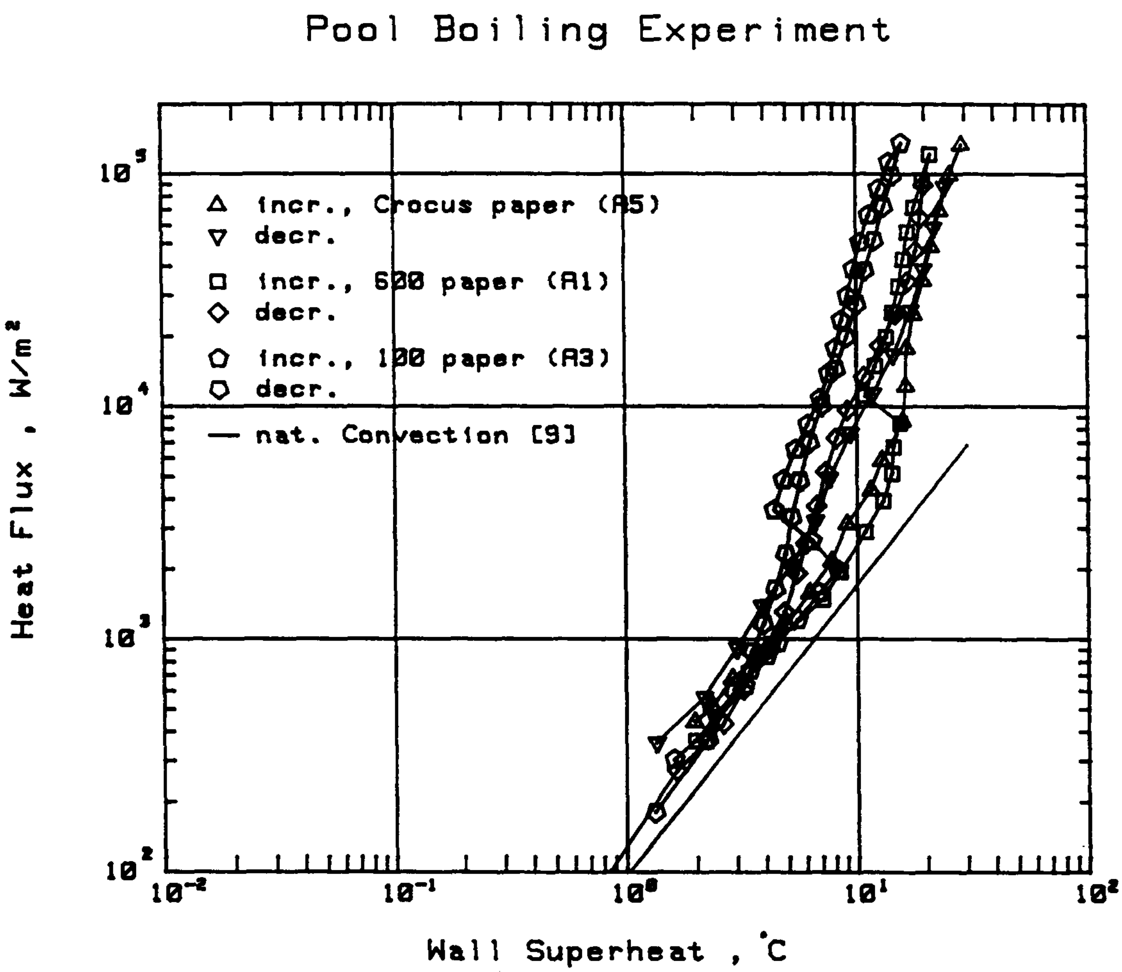


Fig. 18. Pool boiling curves of plain tubes polished with Crocus paper (A5), 600 paper (A1) and 100 paper (A3)

activated nucleation sites enlarges, sometimes up to half of the tube surface. The tube middle, where the thermocouples measure the temperature is cooled according to two effects:

- The bubbles due to rogue sites increase the convection velocity of the circulating liquid (E1).
- The areas with nucleate boiling (rogue sites, mainly at the tube ends) remove heat from the area with natural convection, through the thick copper wall (E2).

These two effects shift the apparent natural convection curve to a lower temperature (E1) and to a lower heat flux (E2) (as shown in Fig. 19). Therefore, the boiling curve for increasing power does not strictly follow the predicted natural convection curve [9] up to ONB. Getting closer to ONB, it slightly bends to a lower temperature.

R10 The spread of the nucleation sites seems to depend on the surface quality. Increasing the heat flux a polished surface (fine Crocus paper, A5) gets an increasing number of small, isolated nucleation sites all over the tube surface, whereas a rough surface (100 paper, A3) develops well defined, compact areas of nucleate boiling, which spread from both ends towards the middle.

R11 To preserve the cartridge heaters, critical heat flux is only examined twice. A value of $1.8*10^5$ W/m^2 is obtained

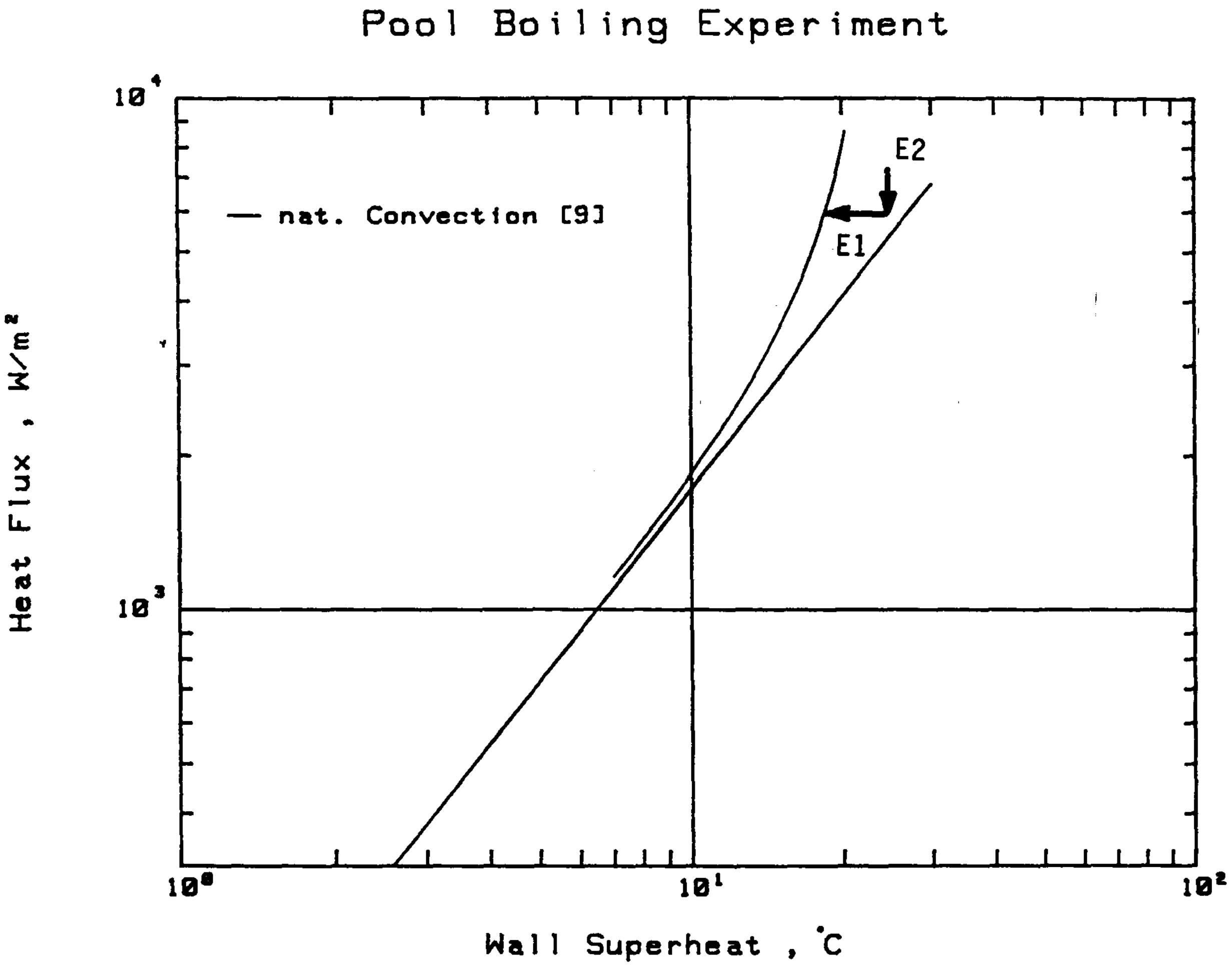


Fig. 19. Reduction of (E1) the wall superheat and (E2) the radial heat flux because of rogue sites

twice for the plain tube polished with a 600 paper (Data A4, Data A8).

R12 The pool temperature, measured beneath the tested tube (as shown in Fig. 8), decreases continuously during an increase of the heat flux and vice versa. The maximum temperature drop is about 0.5 °C (e.g., Data A4).

This effect can be explained as follows:
Freon vapor condenses, subcools and mixes with the liquid. The higher the heat flux, the more freon evaporates and the more subcooled liquid is returned and reduces the pool temperature.

We measured the temperature distribution inside the pool during an experiment with a heat flux of $2*10^4$ W/m^2 (nucleate boiling). The liquid right underneath the condenser (copper coil) is about 0.2 °C cooler than the liquid in the rest of the pool. The condensed freon cools the pool. However this temperature drop only appears at a high heat flux with a high wall superheat, where a slight subcooling of the pool is not that critical.

R13 The Wolverine Turbo-B tubes start boiling at a heat flux below 300 W/m^2. A classical temperature overshoot cannot be detected in this experiment. In the range between 10^3 W/m^2 and 10^4 W/m^2 type S has a slightly higher heat transfer coefficient than type M and type L, while in the range between

10^4 W/m^2 and 10^5 W/m^2 the performance of the three tubes is similar (as shown in Fig. 20).

R14 The Wieland Gewa-T B1 tube has a hysteresis similar to the hysteresis of the plain tube (as shown in Fig. 21).
Boiling starts at the top of several channels at a low heat flux of $2*10^3$ W/m^2 and spreads first circumferentially ($q"=3*10^3$ W/m^2) and then axially ($q"=4*10^3$ W/m^2).
Compared to the Wolverine tubes the wider fin tips seem to impede the activation of nucleation sites in adjacent grooves.
At a heat flux greater than $2*10^4$ W/m^2 the tube surface is completely covered with nucleation sites.

Over the whole tested range the Gewa-T B1 tube has a smaller heat transfer coefficient than the Turbo-B (as shown in fig. II.1.5.14.). It is emphasized that both types of surfaces are specified for R-113 at atmospheric pressure.

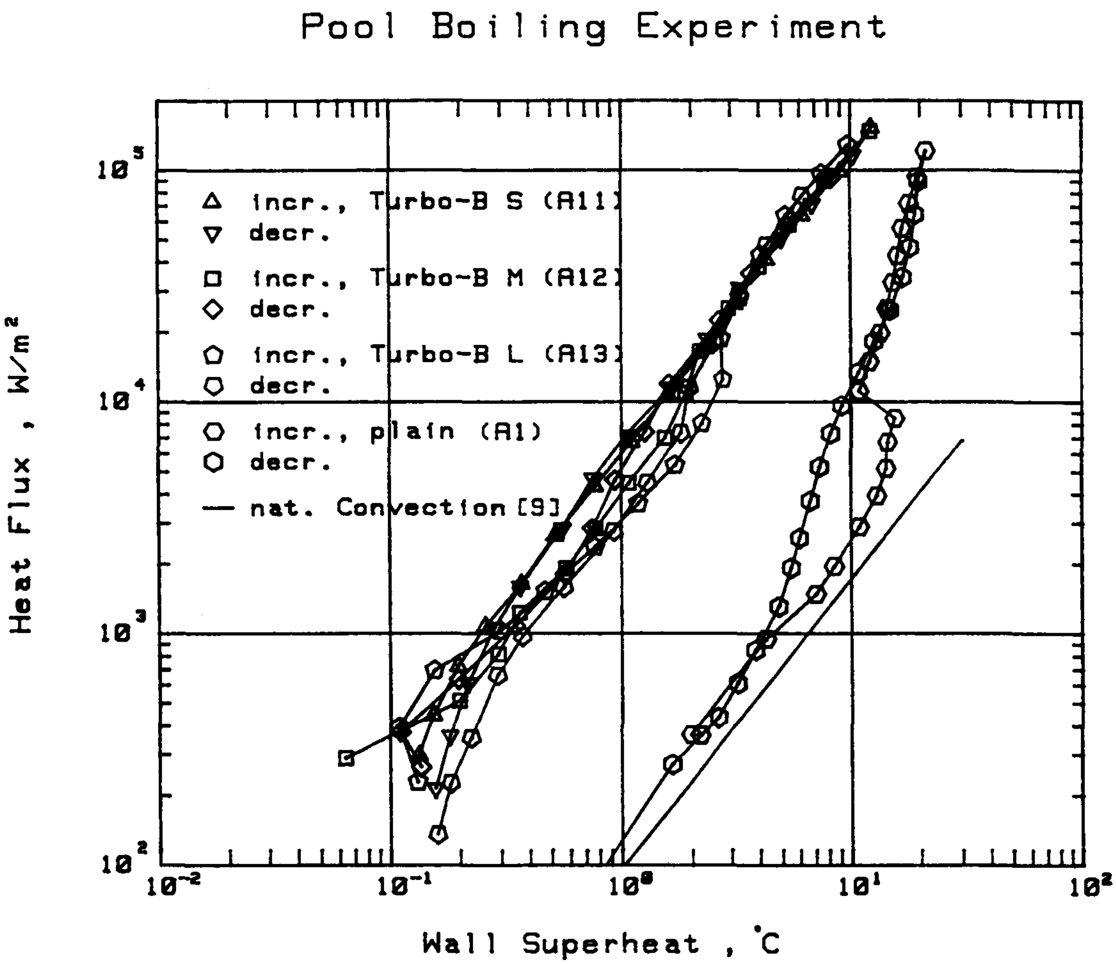


Fig. 20. **Pool boiling curves of the Wolverine tubes Turbo-B S (A11), M (A12) and L (A13)**

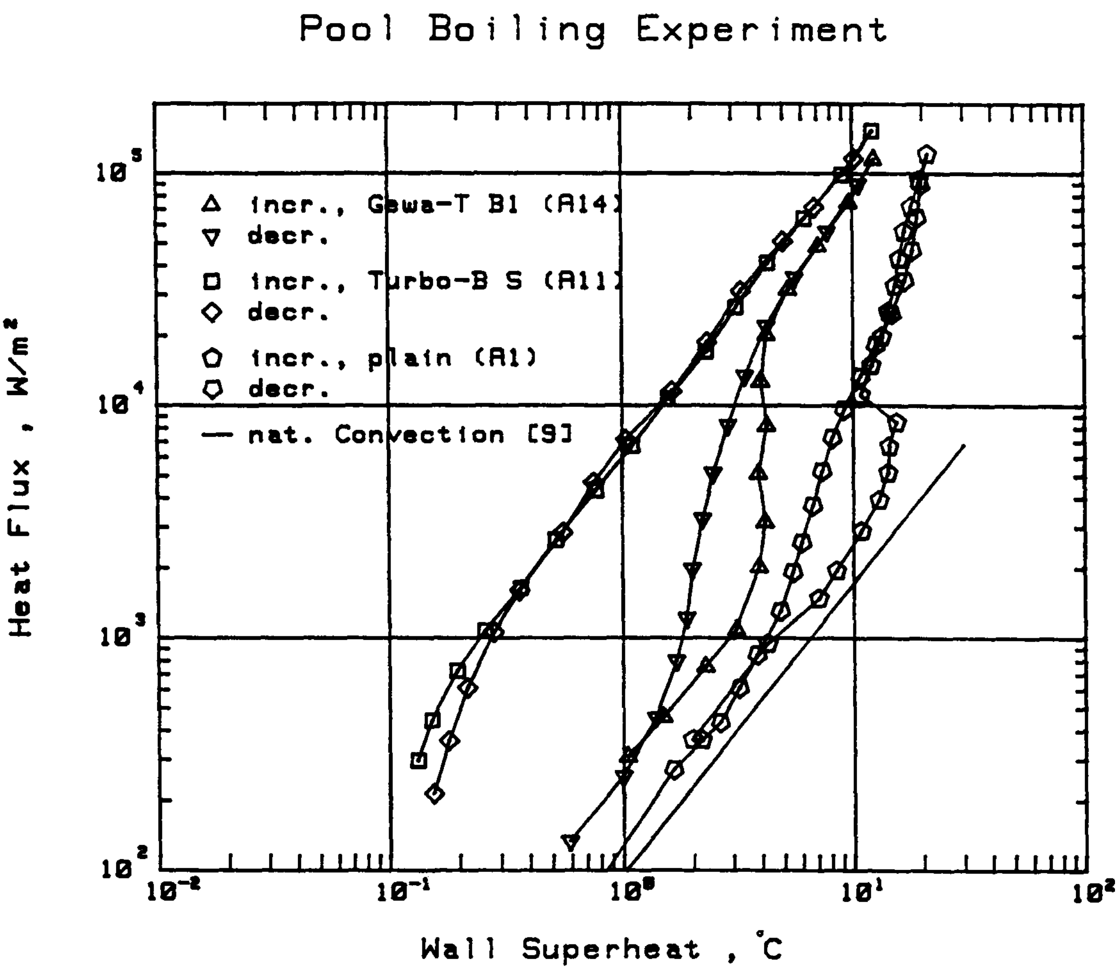


Fig. 21. **Pool boiling curves of the Turbo-B S (A11) and the Gewa-T B1 (A14) in R-113**

1.6. Conclusions

Considering the data gathered during this investigation for pool boiling with R-113, the following conclusions are reached:

C1 The heat transfer coefficient of a single tube in pool boiling is not sensitive to the instrumentation of the tube with thermocouples and the method of installing the cartridge heater. A circumferentially distorted temperature profile in the tube wall can be tolerated if enough thermocouples are employed.

C2 The Wolverine Turbo-B tubes start boiling at a heat flux below 300 W/m^2. In the range between 10^3 W/m^2 and 10^4 W/m^2 type S has a slightly higher heat transfer coefficient than type M and type L, while in the range between 10^4 W/m^2 and 10^5 W/m^2 the performance of the three tubes is similar.

C3 Over the whole tested range the three Turbo-B tubes performed with a higher heat transfer coefficient than the tested Wieland Gewa-T tube.

Note, other, more efficient Gewa tubes are available, but they could not be tested in the present study because of time constraints.

2. Pressure Tests with Different Mountings of a Tube to a Wall

2.1. Apparatus

Three tubes are mounted to a 3/8" thick plate on the inside of a stainless-steel pressure vessel.

The constructions used are (according to I.2.3.):

- a threaded tube, sealed by an O-ring (Fig. 4a)
- a tube, tightened with two screws, sealed by a gasket (Fig. 4b)
- a tube, fixed with a snap ring, sealed by an O-ring (Fig. 4c)

The vessel filled with R-113 is connected to a pressure gauge and can be pressurized with air.

2.2. Procedure

For two full days, the vessel is pressurized with 5 bar to check whether the tube mountings seal. In addition, the vessel is heated up to 65 ^{o}C (and held at 5 bar gage pressure) for a period of two hours.

To prove no freon is leaking through the mountings, we wetted the outside parts with a special soap that produces bubbles at the site of a leak.

2.3. Results and Conclusions

None of the mountings leaked during the tests.

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IV. Appendix

1. The Influence of the Power Supply, AC or DC

The cartridge heater consists of a wound coil and, therefore, has an electrical inductance. As we use an AC power supply for the cartridge heater, this inductance may cause a phase shift between the voltage and the current. The impedance has an imaginative component, which causes an imaginary power dissipation.

To estimate this imaginary power dissipation of the coil (and the shunt) the test section was run with direct current.

The measured impedance ($R_{ch}=U/I$) using a DC power supply increased only 0.4% compared to using an AC power supply (see IV.4.). The error in the power dissipation ($P=U*I=U^2/R_{ch}$) can be neglected.

2. Calibration

All data measured in the pool boiling experiment are directly taken by the HP3421 data acquisition system and sent to the HP310 personal computer. There are three different types of readings listed next together with the maximum ranges of the observations:

- temperature: $40\ ^oC < T < 90\ ^oC$
- low AC voltage (shunt): $14\ mV < U_s < 450\ mV$
- high AC voltage: $5V < U < 200\ V$

Each type of reading requires a calibration to get information about the accuracy of the obtained data and to minimize the systematic error.

2.1. Temperature

Two special features are integrated in the HP3421 data acquisition system:

- the simulation of the ice-point temperature and
- the conversion of the voltage of a type-T thermocouple (copper-constantan) to a temperature value.

With these two features data for temperatures can be directly provided.

A calibration conducted in a former experiment shows the temperature readings are accurate within ±0.3 °C, including the error of the thermocouple wire. This "high" uncertainty limits the accuracy of the whole experiment.

To make sure the characteristic of the data acquisition system did not shift since that calibration, we measured the temperature of ice water. An average temperature reading of 0 °C with a fluctuation less than 0.1 °C proved that the data acquisition system works still accurately.

Note, the simulation of the ice point temperature is reliable even when the room temperature, and, therefore, the temperature of the data acquisition system, is changing. Measuring a constant reference temperature (ice water) with the data acquisition system and a thermocouple, we changed the room temperature by turning the room air-conditioning on and off. The temperature readings were not affected by this.

The thermocouples are not directly connected to the data acquisition system, but are interrupted by a junction board. This board needs to be thermally insulated, otherwise the fluctuation of a temperature reading increases by about 0.1 °C.

A higher accuracy of the temperature readings could be obtained by using an ice point reference junction and calibrating the thermocouples individually. This, however, is considered as not necessary for this experiment.

2.2. Low AC Voltage

The HP-3421 data acquisition system is designed to measure low DC voltage with high resolution. It also can handle AC voltage; however, the accuracy is less.

The weakest point of the data acquisition used in the pool boiling experiment is the AC voltage measurement at the shunt (U_s), which determines the current through the cartridge heater. At a heat flux of 400 W/m^2, for example, 0.28 ampere current induces only 0.0187 volts in the shunt with a precise resistance of 1/15 ohm. This AC voltage is below the recommended range of the data acquisition system.

A former calibration proved the resistance of the shunt to be an absolutely constant 1/15 ohms over the range from 0 to 5 amperes.

Reference data of a HP3468A multimeter for the shunt voltage U_s show the data acquisition system measures too low values. Both the systematic error (bias) and the random error (uncertainty), diminish with increasing the voltage.

A quadratic polynomial is taken to fit the data:

$$y(x) = b_0 + b_1x + b_2x^2$$

where x is the indicated temperature, and y(x) the error between the indicated value and the true value. The least-squares criterion requires

$$b_0n + b_1\sum_{j=1}^{n} x_j + b_2\sum_{j=1}^{n} x_j^2 = \sum_{j=1}^{n} y_j$$

$$b_0\sum_{j=1}^{n} x_j + b_1\sum_{j=1}^{n} x_j^2 + b_2\sum_{j=1}^{n} x_j^3 = \sum_{j=1}^{n} x_jy_j$$

$$b_0\sum_{j=1}^{n} x_j^2 + b_1\sum_{j=1}^{n} x_j^3 + b_2\sum_{j=1}^{n} x_j^4 = \sum_{j=1}^{n} x_j^2y_j$$

where n is the total number of data points. The parameters b_0, b_1 and b_2 are obtained from these equations. The least-squares fit of the 230 calibration data points for the voltage U_s measured at the shunt is

$$U_{s,true} - U_s = - 0.001523 - 0.001789U_s - 0.005196U_s^2$$

where voltages are in volts and $U_{s,true}$ denotes the true voltage at the shunt.

Correcting the shunt voltage with this expression, the uncertainty of the readings is

- $< 1.5\%$ for $14 \text{ mV} < U_s < 70 \text{ mV}$
- $< 0.6\%$ for $70 \text{ mV} < U_s$.

Assuming the shunt resistance is perfectly constant (as calibrated in former tests), these values also represent the uncertainty of the current I through the heater.

For comparison, the shunt voltage of 70 mV is associated with a heat flux q" of about 5000 W/m^2.

2.3. High AC Voltage

The maximum voltage drop at the cartridge heater is about 200 volts. The data acquisition system in its standard version is limited to 30 volts maximum. With a special resistor plugged in the circuit board, measurements up to 300 volts can be taken. However, the data acquisition system then starts to become non-linear in the range below 20 volts.

A calibration with a subsequent least-squares fit, analogous to IV.2.2, provides the equation

$$U_{true} - U = - 0.3667 - 8.9054U - 0.000743U^2$$

where voltages are in volts, U_{true} denotes the true voltage at the heater and U the voltage measured by the data acquisition system.

Including this correction, the uncertainty of the voltage measurement at the cartridge heater is

- $< 1\%$ for $6\ V < U < 10\ V$
- $< 0.3\%$ for $10\ V < U$.

Again for comparison, a voltage of 10 volts at the cartridge heater induces a heat flux q" of about 500 W/m^2.

3. Locating the Thermocouples

As there is a radial temperature gradient in the tube wall, due to the heat flow from the inside to the outside, it is necessary to locate the thermocouples precisely. With R as the radius of the tube surface and r as the radial distance between the thermocouple junction and the tube axis, the ratio R/r must be determined (as required in II.2.). Knowing this ratio, we can calculate the temperature drop, which corrects the measured temperature to obtain the true surface temperature.

To accommodate the thermocouples the tested tubes are either (1) machined with a wire-EDM or (2) drilled.

1. The geometry of the holes, machined with a wire-EDM is constant over the tube length. Measuring one cross section with

a venier caliper provides the location of the thermocouple bead precisely.

2. If drilled wells are used to imbed the thermocouples (or the sleeves with the thermocouples inside) the radial distance r may change over the well depth, because the well can be curved.

With the following method [4], using two rods, the radial distance between the bottom of the well and the tube surface can be determined easily (as shown in Fig A1). This consists of inserting a rod down to the bottom of the hole, estimating the slope of the rod with a gauge in alignment with the tube surface, and calculating the distance between the surface and the bottom of the hole. As shown in Fig. A1a., the rod A is placed in the hole, and B is the gauge in contact with the tube surface. The rod A must have a diameter considerably smaller than the hole and it must be pushed outwards radially, so that one end of the rod is in contact with the lateral surface of the hole. The other point of contact is at the mouth of the hole. There should be only two points of contact, even if the hole is slightly curved.

An arbitrary point P is taken on gauge B, and d, d_2, and l_2 are measured, as shown in Figs. A1b. and A1c.. A venier caliper with a resolution of 0.02 mm is used in the present measurement. By considering the exaggerated geometry as shown, the ratio R/r can be expressed as

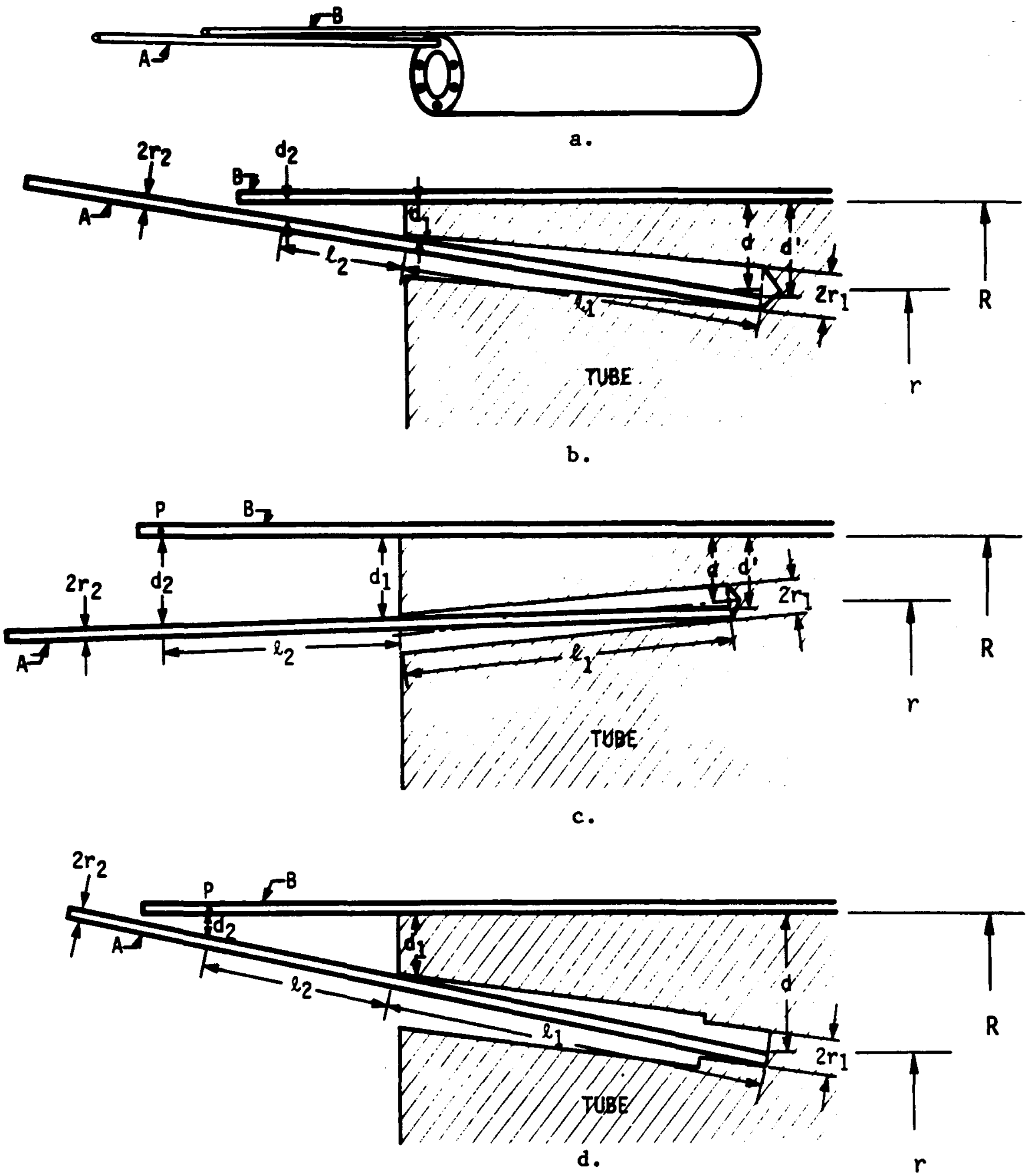


Fig. A1. Technique to measure the radial distance between the bottom of thermocouple well and the tube surface (not to scale)

$$R/r = R/(R - d)$$

$$d = (d_1 - d_2)(l_1/l_2) + d_1 - r_1 + 2r_2$$

with r_1 and r_2 the radius of the hole and the rod, respectively. This equation is valid for the hole drifting radially either inwards or outwards, as shown in Figs. Alb. and Alc., respectively.

For those thermocouple wells prepared by two stages of drilling, as shown in Fig. Ald., the equation is still valid. Note that the radius of the bottom instead of the mouth should be taken as r_1 in this case.

4. Error Analysis

The total error of the measurement process is composed of the systematic error and the random error. Once the system has been calibrated, the systematic error can be removed; the random error, however, always exists. To estimate the total uncertainty of the experimental data a propagation-of-error analysis must be conducted. The analysis for the heat flux q" and the wall superheat T_{WSH} is presented here.

The expression used to calculate the uncertainty W associated with any quantity Z is

$$W_Z = \{ \sum_{i=1}^{n} ([\partial z/\partial x_i] W_{xi})^2 \}^{1/2}$$

where x_i is any of the n parameters of which the quantity Z is a function. The contribution of each error source to the total uncertainty is determined by a weighing factor, $\partial z/\partial x_i$.

4.1. The Uncertainty of the Heat Flux

The heat flux data presented are calculated from the equation

$$q'' = (UI)/A$$

The uncertainty of the tube surface area A, measured with a vernier caliper, is assumed to be smaller than 0.2%. The errors of the voltage U and of the current I reduce for increasing values. Combining typical values, as listed in IV.4.2.-3., we can finally estimate the uncertainty in the heat flux q" as

- $< 1.9\%$ for $200\ W/m^2 < q'' < 500\ W/m^2$
- $< 1.6\%$ for $500\ W/m^2 < q'' < 5000\ W/m^2$
- $< 0.8\%$ for $5000\ W/m^2 < q''$

4.2. The Uncertainty of the Wall Superheat

The data for the wall superheat T_{WSH} is calculated from the equations

$$T_{WSH} = T_{av}-T_{sat}$$

$$T_{av} = (T_1+T_2+T_3+T_4)/4$$

$$T_i = T_{i,r}-[q"R/k]\ln(R/r) \qquad , \; i= 1,..4$$

$$T_{sat} = f(p-p_{atm}+p_{hydr})$$

$$p_{hydr} = \rho gH$$

The uncertainty $dT_{i,r}$ of measuring the temperatures $T_{i,r}$ in the tube wall is estimated as smaller than 0.3 ^{o}C (as described in IV.2.1.). The conductive temperature drop $T_{i,r}-T_i$ depends on the radii R and r, and is linear with the heat flux q". The uncertainty in the radial positioning r of the thermocouples consists of two components: (1) the positioning of the end of the well (see IV.4.), assumed as ±0.05 mm and (2) the play ($=r_1-r_{tcpl}$) of the thermocouple in the well, which depends on the instrumentation method. We define the uncertainty dT_{pp} for the play of the thermocouple in the hole and the inaccurate positioning of the well end. Combining this uncertainty dT_{pp} with the uncertainty of the temperature readings $dT_{i,r}$, we obtain the uncertainty dT_{av} of the average tube surface temperature.

The uncertainty for the average wall temperature T_{av} is listed next for

- two different heat fluxes:
  - $q"_1 = 10^4$ W/m^2
  - $q"_2 = 10^5$ W/m^2
- four typical instrumentation methods (arrangements):
  - A1, 1/8" drilled well with a 1/16" i.d. sleeve
  - A4, 3/32" drilled well without a sleeve
  - A11, 3/32" drilled well with a 0.036" i.d. sleeve
  - A9, 0.036" hole, machined with a wire-EDM

arrangement	$dT_{pp}(q"_1)$	$dT_{pp}(q"_2)$	$dT_{av}(q"_1)$	$dT_{av}(q"_2)$
A1	0.02	0.16	0.3	0.34
A4	0.03	0.31	0.3	0.43
A11	0	0.03	0.3	0.3
A9	0	0.03	0.3	0.3

where dT_{pp} and dT_{av} are in ^oC.

The saturation temperature T_{sat}, calculated by an expression fitting data from the steam tables [12], requires the local pressure at the tube axis, which is composed of the atmospheric plus the hydrostatic pressure.

The atmospheric pressure p_{atm} at the tube surface is measured with two manometers, one for the absolute pressure in the room, a second one for the gage pressure between the room and the pool surface. The variation of the atmospheric pressure during the experiment plus the uncertainty of the measurement are estimated to be less than 120 N/m^2.

The uncertainty for the hydrostatic pressure p_{hydr} is assumed to be 80 N/m^2, which corresponds to a 5 mm change of the liquid height H.

Combining the deviations for the hydrostatic and the atmospheric pressure, the uncertainty of the saturation temperature is 0.04 ^oC and, therefore, can be neglected.

Based on the uncertainties obtained for the two terms T_{av} and T_{sat}, it is noticed that the total uncertainty in the tube surface superheat is predominated by the temperature measurement which is estimated as 0.3 ^oC.

The uncertainty in the conductive temperature drop becomes important, too, when an arrangement with large holes ($r_1 > 0.03"$) for the thermocouples is used at high heat flux ($q"_2 = 10^5$ W/m^2). Then the uncertainty for the tube surface superheat increases to about 0.45 ^oC.

5. Properties of R-113

Next listed are properties of liquid R-113 at saturation temperature corresponding to standard atmospheric pressure (as listed in [12]).

$T_{sat} = 47.6\ ^{o}C$	saturation temperature
$\mu = 516*10^{-6}\ Ns/m^2$	dynamic viscosity
$k = 0.0705\ W/mK$	thermal conductivity
$\rho = 1507.3\ kg/m^3$	density
$c_p = 984\ J/kgK$	specific heat
$\beta = 0.00163\ k^{-1}$	thermal expansion coefficient

These data are required for the pool boiling experiment to determine (1) the natural convection curve [9] and (2) the saturation temperature of the freon at the level of the tube axis.

6. Software

The software listed next is written to run the pool boiling tests, using a HP3421 data acquisition system.

```
10    !=================== CHRISTIAN JUNG ==========OCTOBER 31,1988============
20    !
30    !   This is a program.to run a pool boiling experiment with a
40    !   HP 3421A data acquisition system
50    !
60    !=====================================================================
70    !    PARAMETERS
80    !
90    !------- EXPERIMENTAL
100   !
110   Limit=.001                       ! LIMIT FOR STABILITY CHECK
120   Stabtime=10                      ! TIME INCREMENT FOR STABILITY CHECK
130   Tubediameter=.75*.0254           ! TUBEDIAMETER [m]
140   Tubelength=4*.0254               ! TUBELENGTH [m]
150   Rr=1.5                           ! R(TUBESURFACE)/R(THERMOCOUPLES)
160   Kcopper=386                      ! THERMAL CONDUCTIVITY [W/Km] OF COPPE
170   Stabmode$="LIST"                 ! STAB.CHECK AS LIST/PLOT
180   Stabgraph$="N"                   ! SKIPS DATA READINGS IN DATAGRAPH
190   Check=.00044                     ! MAX. VOLT.INCR. FOR BURNOUT
200   Burncrit=.0018                   ! =68 C, START TO CHECK FOR BURNOUT
210   Burnout=0.                       ! STARTVALUE OF LOOP
220   Chf=0.                           ! STARTVALUE OF LOOP
230   Patmos=760                       ! ATMOSPHERIC PRESSURE [mm Hg]
240   Height=.17                       ! FREON ABOVE TUBE [m]
250   Gravity=9.81                     ! GRAVITY [N/kg]
260   Rhofreon=1507                    ! DENSITY OF FREON 113 [kg/m^3]
270   Media$="S"                       ! S=SCREEN/P=PRINTER
280   Rohm=28                          ! APPROX. RESIST OF THE HEATER
290   Graphstep=5                      ! # STEPS BETW 10^J TO 10^(J+1)
300   !
310   !---- GRAPHIC
320   !
330   Xmin=-2                          ! EXPONENT ON LEFT END OF X-LOG-AXIS
340   Xmax=2                           ! EXPONENT ON RIGHT END OF X-LOG-AXIS
350   Ymin=2                           ! EXPONENT ON LOWER END OF Y-LOG-AXIS
360   Ymax=5.3                         ! EXPONENT ON UPPER END OF Y-LOG-AXIS
370   Psize=.04                        ! SIZE OF POLYGON
380   Dx=1                             ! INCREMENT FOR THE LABEL OF X-AXIS
390   Dy=1                             ! INCREMENT FOR THE LABEL OF Y-AXIS
400   C_nc=.5064                       ! NATURAL CONVECTION
410   N_nc=.2507                       ! NATURAL CONVECTION
420   !
430   !---------------------------------------------------------------------
440   REAL Q(50),Delta(50)
450   !---------------------------------------------------------------------
460   !
470   !     PROGRAM START
480   !
490 Start:C$=CHR$(255)&"K"
500   OUTPUT 2 USING "#,K";C$
510   PRINT ""
520   PRINT "_____________________________________________________________"
530   PRINT ""
```

```
540   PRINT "   The time now is   ";TIME$(TIMEDATE);"  ";DATE$(TIMEDATE)
550   PRINT ""
560   PRINT "   This is a program to run a pool boiling experiment with a"
570   PRINT "   HP 3421A data acquisition system"
580   PRINT ""
590   PRINT "__________________________________________ CHRISTIAN JUNG _______"
600   PRINT ""
610   PRINT ""
620   PRINT ""
630   PRINT ""
640   PRINT ""
650   PRINT ""
660   PRINT ""
670   PRINT ""
680   PRINT ""
690   PRINT "   Start the program with F2 !"
700   PAUSE
710   !
720   Today$=DATE$(TIMEDATE)
730   Today$=UPC$(Today$)
740   !-----------------------------------------------------------------
750   !     MAIN MENU
760   !
770 Mnmenu:C$=CHR$(255)&"K"
780   OUTPUT 2 USING "#,K";C$
790   ASSIGN @Path TO *
800   OFF ERROR
810   Dfcheck=0
820   PRINT "    M A I N   M E N U   "
830   PRINT ""
840   PRINT "    Enter # to :"
850   PRINT ""
860   ON ERROR GOTO 910
870   ASSIGN @Path TO Today$
880   Dfcheck=1
890   Day$=Today$
900   GOTO 920
910   PRINT "    1      create a file with the name of today's date ?"
920   OFF ERROR
930   PRINT ""
940   PRINT "    2      use the file with the name of today's date ?"
950   PRINT ""
960   PRINT "    3      create a new file ?"
970   PRINT ""
980   PRINT "    4      use an old file ?"
990   PRINT ""
1000  PRINT "    5      list records ?"
1010  PRINT ""
1020  PRINT "    6      plot records ?"
1030  PRINT ""
1040  PRINT ""
1050  PRINT "    C      check topical data !"
1060  PRINT "    E      end !"
1070 Slect:LINPUT File$
1080  PRINT ""
```

```
1090  !
1100  !-----------------------------------------------------------------
1110  IF Dfcheck=1 AND File$="1" THEN Slect
1120  SELECT File$
1130  !-------------1-----
1140  CASE "1"
1150    Day$=Today$
1160    CREATE BDAT Day$,50
1170    ASSIGN @Path TO Day$
1180    PRINT ""
1190    PRINT "    The new file is created !"
1200    WAIT 1
1210    Nrun=1
1220    GOSUB Setparam
1230    GOTO Tubetype
1240  !-------------2-----
1250  CASE "2"
1260    Day$=Today$
1270    GOSUB Rcords
1280    GOSUB Setparam
1290    IF Tubetype$="no_tube_type" THEN Tubetype
1300    GOTO Datainput
1310  !-------------3-----
1320  CASE "3"
1330    LINPUT "   Put in the name of the file, you want to create : ",Day$
1340    Day$=UPC$(Day$)
1350    PRINT ""
1360    ON ERROR GOTO 1450
1370    CREATE BDAT Day$,50,200
1380    ASSIGN @Path TO Day$
1390    OFF ERROR                                    ! DAY$ DIDN'T EXIST
1400    PRINT "    A new file is created !"
1410    WAIT 1
1420    Nrun=1
1430    GOSUB Setparam
1440    GOTO Tubetype
1450    OFF ERROR                                    ! DAY$ ALREADY EXISTS
1460    PRINT "    The file already exists !      Press F2 to continue !"
1470    PAUSE
1480    GOSUB Rcords
1490    GOTO Mnmenu
1500  !-------------4-----
1510  CASE "4"
1520    LINPUT "   Which file you want to use ? ",Day$
1530    Day$=UPC$(Day$)
1540    GOSUB Rcords
1550    GOSUB Setparam
1560    IF Tubetype$="no_tube_type" THEN Tubetype
1570    GOTO Datainput
1580  !-------------5-----
1590  CASE "5"
1600    LINPUT "  Which file you want to list ?",Day$
1610    Day$=UPC$(Day$)
1620    LINPUT "  Enter  P  to print on the printer, RETURN to print on the sc
en !",Media$
```

```
1630   Arragenr=0
1640   IF Media$="P" THEN
1650      INPUT "  Enter arrangement #  (i.e., 9 for arrangement A9)",Arragenr
1660   END IF
1670   GOSUB Rcords
1680   GOTO Mnmenu
1690  !-------------6-----
1700  CASE "6"
1710   GOSUB Datashow
1720   GOTO Mnmenu
1730  !-------------C-----
1740  CASE "C"
1750   GOSUB Setparam
1760   GOSUB Datacheck
1770   GOTO Mnmenu
1780  !-------------E-----
1790  CASE "E"
1800   GOTO Ende
1810  !------------------
1820  CASE ELSE
1830   GOTO Slect
1840  END SELECT
1850  !------------------------------------------------------------
1860  !    TUBE TYPE
1870  !
1880 Tubetype: !
1890  C$=CHR$(255)&"K"
1900  OUTPUT 2 USING "#,K";C$
1910  PRINT ""
1920  PRINT "     T U B E   T Y P E "
1930  PRINT "     (change the subroutine 'Tubecheck:' for a new type !)"
1940  PRINT ""
1950  PRINT "     Enter # to select :"
1960  PRINT ""
1970  !----------------LIST TUBETYPES
1980  Tube=1
1990  LOOP
2000   GOSUB Tubecheck
2010  EXIT IF Tubetype$="no_tube_type"
2020   PRINT "   ";Tube;"        ";Tubetype$
2030   PRINT ""
2040   Tube=Tube+1
2050  END LOOP
2060  !---------------------------
2070  INPUT Tube
2080  GOSUB Tubecheck
2090  IF Tubetype$="no_tube_type" THEN Tubetype
2100  !---------------------------------------------------------------
2110  !     THE FILE, THE RECORD AND THE TUBE TYPE IS CHOSEN
2120  !
2130 Datainput:C$=CHR$(255)&"K"
2140  OUTPUT 2 USING "#,K";C$
2150  GOSUB Vstart12
2160  PRINT "__________________________________________________
__________"
```

```
2170  !
2180  PRINT ""
2190  PRINT "    NOW ALL DATA IS REFERED TO THE FILE :   ";Day$
2200  PRINT ""
2210  PRINT "                                THE RECORD :  ";Nrun
2220  PRINT ""
2230  PRINT "                             THE USED TUBE IS :   ";Tubetype$
2240  PRINT "________________________________________________________________________________
________"
2250  PRINT "    Enter :"
2260  PRINT ""
2270  PRINT "    OR                to choose another record !"
2280  PRINT "    M                 to go back to the main menu !"
2290  SELECT Stabmode$
2300  CASE "PLOT"
2310    PRINT "    L                 to list data during the stabilization check
!"
2320  CASE "LIST"
2330    PRINT "    P                 to plot data during the stabilization check
!"
2340  END SELECT
2350  PRINT "    S                 to start with the readings of the topical val
es !"
2360  PRINT ""
2370  PRINT "    any other key     to  adjust the voltage to ";Vstart1;"V or ";V
tart2;"V  and"
2380  PRINT "                      S T A R T  the readings then !"
2390  LINPUT Orstart$
2400  SELECT Orstart$
2410  CASE "M"
2420    GOTO Mnmenu
2430  CASE "OR"
2440    INPUT "    The new record number is :",Nrun
2450    GOTO Datainput
2460  CASE "L"
2470    Stabmode$="LIST"
2480    GOTO Datainput
2490  CASE "P"
2500    IF Nrun<>1 THEN Stabmode$="PLOT"
2510    GOTO Datainput
2520  CASE "S"," "
2530    GOTO Burnout
2540  CASE ELSE
2550    PRINT ""
2560    PRINT "  1.   Adjust the voltage until you hear a beep     or"
2570    PRINT "  2.   hit any alphabet                             to acquisit
ata !"
2580    PRINT ""
2590    !-----------------CHECK VOLTAGE AT THE DATAACQUISITION SYSTEM
2600    ON KBD GOTO 2730                            ! INTERRUPT
2610    OUTPUT 709;"CLS12"                          ! CHANNEL FOR VOLTAGE
2620    OUTPUT 709;"Z1F2N4"
2630    LOOP
2640      OUTPUT 709;"T2"
2650      ENTER 709;Vadj
```

```
2660      Vadjust=Vadj+.36668+8.9054*Vadj+.000743*Vadj^2
2670      PRINT "    Current voltage:  ";PROUND(Vadjust,-1);"V, Target voltage:
 ";Vstart1;"V or  ";Vstart2;"V"
2680      Adjcheck1=ABS(Vadjust-Vstart1)          ! VOLTAGE DIFFERENCE TO ADJUS
2690      Adjcheck2=ABS(Vadjust-Vstart2)
2700    EXIT IF Adjcheck1<.5 OR Adjcheck2<.5
2710    END LOOP
2720    BEEP
2730    OFF KBD
2740    !-----------------------
2750    GOTO Burnout
2760  END SELECT
2770  !
2780  !------------------------------------------------------------------------
2790  !    CHECK BURNOUT
2800  !
2810 Burnout:C$=CHR$(255)&"K"
2820  OUTPUT 2 USING "#,K";C$
2830  !
2840  OUTPUT 709;"CLS13"                       ! TOP OF TUBE IS CHECKED !
2850  OUTPUT 709;"Z0F1N4T2"
2860  ENTER 709;Chf
2870  !
2880  IF Chf<Burncrit THEN Stabcheck           ! NO BURNOUT CHECK NECESSARY
2890  !
2900  PRINT ""
2910  PRINT "    Check Burnout !                     Time: ";TIME$(TIMEDATE)
2920  PRINT ""
2930  PRINT ""
2940  !
2950  FOR I=1 TO 5
2960    OUTPUT 709;"T2"
2970    ENTER 709;Burnout
2980    Diff=Burnout-Chf
2990    IF Diff>Check THEN
3000      !----------------DATA ACQUISITION
3010      OUTPUT 709;"ACV12,19"
3020      ENTER 709;St1(1),St1(2)
3030      OUTPUT 709;"TEM13-18"
3040      ENTER 709;St1(3),St1(4),St1(5),St1(6),St1(7),St1(8)
3050      GOSUB Correct
3060      OUTPUT @Path,Nrun;Uv,Ia,Tav,T1,T2,T3,T4,St1(7),St1(8),Q(Nrun),Delta(
un),Tube,Tsat,Surfarea,Tubediameter,Rr
3070      Nrun=Nrun+1
3080      !---------------------------------
3090      BEEP
3100      PRINT ""
3110      PRINT "    B U R N O U T  !       shut power off !"
3120      PRINT ""
3130      PRINT "    The data was taken !   Press F2 to continue !"
3140      PAUSE
3150      GOTO Datataken
3160    END IF
3170    Chf=Burnout
```

```
3180  NEXT I
3190  PRINT "    No burnout.!"
3200  PRINT ""
3210  PRINT ""
3220  !
3230  !-------------------------------------------------------------
3240  !    CHECK STABILITY
3250  !
3260 Stabcheck: !
3270  Stabgraph$="Y"
3280  PRINT ""
3290  PRINT "    The program checks data of test run ";Nrun;" until stable conc
tions exist."
3300  PRINT "    The criteria is :  (D2-D1)/D1 < ";Limit
3310  !
3320  OUTPUT 709;"ACV12,19"
3330  ENTER 709;St1(1),St1(2)
3340  OUTPUT 709;"TEM13-18"
3350  ENTER 709;St1(3),St1(4),St1(5),St1(6),St1(7),St1(8)
3360  !
3370  SELECT Stabmode$
3380  !
3390  CASE "LIST"
3400    PRINT "    (Hit:       S                     to interrupt and show data
!"
3410    PRINT "                any other key         to force the data acquisit
on!)"
3420    PRINT ""
3430    PRINT "  Uv         Ia          Tav      T1       T2       T3       T4
pool     q    "
3440    PRINT "  ___________________________________________________________________
________________"
3450    PRINT "  [V]        [A]         [C]      [C]      [C]      [C]      [C]
C]     [W/m^2]"
3460    PRINT ""
3470  !
3480  CASE "PLOT"
3490    Ncurve=2
3500    Curverun=1
3510    Curve$(1)=Day$
3520    Pcurve(1)=3
3530    Lcurve$(1)=Day$
3540    Bolt$="ON"
3550    Natcurve$=""
3560    Stabgraph$="Y"
3570    CLEAR SCREEN
3580    GINIT
3590    PLOTTER IS CRT,"INTERNAL"
3600    GOSUB Datagraph
3610  END SELECT
3620  !
3630  ON KBD GOTO 4100
3640  Stable=1
3650  !
3660  LOOP
```

```
3670    GOSUB Correct
3680    SELECT Stabmode$
3690    CASE "LIST"
3700      PRINT USING 3710;Uv,Ia,Tav,T1,T2,T3,T4,St1(7),Q(Nrun)
3710      IMAGE   3X,DDD.DDD,X,DDD.DDD,5X,DDD.D,3X,DDD.D,3X,DDD.D,3X,DDD.D,3X,D
D.D,3X,DDD.D,3X,D.DESZ
3720    CASE "PLOT"
3730      IF Delta(Nrun)<=0 OR Q(Nrun)<=0 THEN 3790               ! LOG>0, Q>Q(D
TAAQUMIN)
3740      PDIR -150                                               ! GOING UP
3750      IF Q(Nrun)<Q(Nrun-1) THEN PDIR -90                      ! GOING DOWN
3760      MOVE LGT(Delta(Nrun)),LGT(Q(Nrun))
3770      POLYGON Psize,3,3
3780    END SELECT
3790  !
3800  EXIT IF Stable=0
3810  !
3820    WAIT Stabtime                               ! TIME INCREMENT
3830    FOR I=1 TO 8
3840      St2(I)=St1(I)
3850    NEXT I
3860    !
3870    OUTPUT 709;"ACV12,19"                       ! READ DATA FROM HP3421
3880    ENTER 709;St1(1),St1(2)                     ! Uv,Ia
3890    OUTPUT 709;"TEM13-18"
3900    ENTER 709;St1(3),St1(4),St1(5),St1(6),St1(7),St1(8)   !T1-T4,Tpool,Tbat
3910    !
3920    Stable=0
3930    FOR I=1 TO 7                                ! CHECK STABILITY
3940      IF St1(I)=0 THEN 4020
3950      Dst=(St1(I)-St2(I))/St1(I)
3960      Dst=ABS(Dst)
3970      IF Dst>Limit THEN
3980        Stable=Stable+1
3990        !               PRINT I,St1(I),St2(I),Tsat
4000      END IF
4010      !               PRINT I,St1(I),St2(I),Tsat,Dst,Stable
4020    NEXT I
4030      !
4040  END LOOP
4050  !
4060  BEEP
4070  PRINT ""
4080  PRINT "    Now all data was  S T A B L E  within a ";Limit*100;" % limit
4090  !
4100  IF KBD$="S" THEN                        ! INTERRUPT WITH S AND PLOT BOIL.CU
4110  !  Curvefile$=Day$
4120    Ncurve=2
4130    Curverun=1
4140    Curve$(1)=Day$
4150    Pcurve(1)=3
4160    Lcurve$(1)=Day$
```

```
4170     Bolt$="ON"
4180     Natcurve$=""
4190     CLEAR SCREEN
4200     GINIT
4210     PLOTTER IS CRT,"INTERNAL"
4220     GOSUB Datagraph
4230     CLEAR SCREEN
4240     GOTO Stabcheck
4250   END IF
4260   !
4270   OFF KBD
4280   IF Stabmode$="PLOT" THEN CLEAR SCREEN
4290   !------------------------------------------------------------------
4300   !     DATA ACQUISITION
4310   !OUTPUT @Path,Nrun;Uv(Nrun),Ia(Nrun),Tav(Nrun),T1(Nrun),T2(Nrun),T3(Nrun
4320   !                  ,T4(Nrun),Tpool(Nrun),Tbath(Nrun),Q(Nrun),Delta(Nrun)
4330   !                  ,Tube,Tsat,Surfarea,Tubediameter,R/r
4340   !
4350   OUTPUT @Path,Nrun;Uv,Ia,Tav,T1,T2,T3,T4,St1(7),St1(8),Q(Nrun),Delta(Nrun.
Tube,Tsat,Surfarea,Tubediameter,Rr
4360   !
4370   PRINT "     The data of test run  ";Nrun;"  was taken at  ";TIME$(TIMEDATE
4380   Nrun=Nrun+1
4390   !
4400   !------------------------------------------------------------------
4410   !     THE DATA WAS TAKEN
4420   !
4430 Dataken:PRINT ""
4440   PRINT ""
4450   PRINT "     Enter alphabet : "
4460   PRINT ""
4470   PRINT "     L           to list records !"
4480   PRINT "     S           to show data !"
4490   PRINT "     M           to go back to MAINMENU !"
4500   PRINT "     R           to repeat the last test run!"
4510   PRINT ""
4520   PRINT "     RETURN      to run next measurements !"
4530   LINPUT Dataken$
4540   SELECT Dataken$
4550   CASE "L"
4560     GOSUB Rcords
4570   CASE "S"
4580     GOSUB Datashow
4590   CASE "M"
4600     GOTO Mnmenu
4610   CASE "R"
4620     Nrun=Nrun-1
4630     GOTO Stabcheck
4640   CASE ""
4650     GOTO Datainput
4660   CASE ELSE
4670     GOTO Dataken
4680   END SELECT
4690   GOTO Dataken
```

```
4700  !
4710  !
4720  !
4730  !========================================================================
4740  !========================================================================
4750  !    SUBROUTINE VSTART12
4760  !
4770 Vstart12:!
4780  IF Nrun=1 THEN
4790    Vstart1=0
4800    Vstart2=0
4810    RETURN
4820  END IF
4830  !
4840  Qgraph=Q(Nrun-1)
4850  IF Qgraph<10^Ymin+100 THEN Qgraph=10^Ymin+100                ! START AND L
MIT
4860  !
4870  Vstart1=SQRT(Rohm*Surfarea*10^(LGT(Qgraph)+1/Graphstep))
4880  Vstart2=SQRT(Rohm*Surfarea*10^(LGT(Qgraph)-1/Graphstep))
4890  Decimal=0
4900  IF Vstart2<15 THEN Decimal=-1
4910  Vstart1=PROUND(Vstart1,Decimal)
4920  Vstart2=PROUND(Vstart2,Decimal)
4930  !
4940  RETURN
4950  !
4960  !----------------------------------------------------------------------
4970  !    SUBROUTINE RCORDS
4980  !
4990 Rcords:ON ERROR GOTO 5030
5000  ASSIGN @Path TO Day$
5010  GOTO 5070
5020  !
5030  PRINT "    This file is not on the disc.   Press F2 to continue !"
5040  PAUSE
5050  GOTO Mnmenu
5060  !
5070  OFF ERROR
5080  C$=CHR$(255)&"K"
5090  OUTPUT 2 USING "#,K";C$
5100  IF Media$="P" THEN PRINTER IS 9
5110  PRINT "I  Uv(I)     Ia(I)      Tav(I)  T1(I)   T2(I)   T3(I)   T4(I)   Tp
ol(I) q(I)"
5120  PRINT "______________________________________________________________________
______________"
5130  PRINT "   [V]       [A]        [C]     [C]     [C]     [C]     [C]     [C
   [W/m^2]"
5140  PRINT ""
5150  !
5160  FOR I=1 TO 50
5170    ON ERROR GOTO 5220
5180    ENTER @Path,I;Uv,Ia,Tav,T1,T2,T3,T4,Tpool,Tbath,Q(I),Delta(I),Tube,Tsat
Surfarea,Tubediameter,Rr
5190    PRINT USING 5200;I,Uv,Ia,Tav,T1,T2,T3,T4,Tpool,Q(I)
```

```
5200    IMAGE DD,2X,DDD.DDD,X,DDD.DDD,4X,DDD.D,3X,DDD.D,3X,DDD.D,3X,DDD.D,3X,DD
.D,3X,DDD.D,3X,D.DESZ
5210  NEXT I
5220  OFF ERROR
5230  Nrun=I
5240  PRINT ""
5250  PRINT ""
5260  GOSUB Tubecheck
5270  IF Rr<1 OR Rr>2 THEN Rr=1.5                              ! FOR OLD RECORDS
5280  IF Tubediameter<.01 OR Tubediameter>.025 THEN Tubediameter=.01905  ! FOR
LD RECORDS
5290  PRINT "    The file  ";Day$;"  contains  ";Nrun-1;"  records."
5300  PRINT "    A  ";Tubetype$;"  tube with a surface area of 0";PROUND(Surfar
a,-7);"m^2, an outer"
5310  PRINT "    diameter of 0";PROUND(Tubediameter,-5);"m  and a correction ra
io R/r of ";PROUND(Rr,-4);" was"
5320  PRINT "    tested in freon with a saturation temperature of  ";Tsat;" C."
5330  IF Arragenr<1 THEN 5380
5340  PRINT ""
5350  PRINT ""
5360  PRINT "                                   data A";Arragenr
5370  PRINT "                                   _________"
5380  PRINTER IS CRT
5390  PRINT "                                                        Press F2
o continue !"
5400  PAUSE
5410  C$=CHR$(255)&"K"
5420  OUTPUT 2 USING "#,K";C$
5430  RETURN
5440  !
5450  !-----------------------------------------------------------------
5460  !    SUBROUTINE TUBECHECK
5470  !
5480 Tubecheck:ON ERROR GOTO 5600
5490  ON Tube GOTO 5500,5520,5540,5560,5580          ! ADD LINE# FOR TTYPES
5500  Tubetype$="plain"                              ! TUBE 1
5510  GOTO 5620
5520  Tubetype$="plain WIELAND"                      ! TUBE 2
5530  GOTO 5620
5540  Tubetype$="Turbo-B, S"                         ! TUBE 3
5550  GOTO 5620
5560  Tubetype$="Turbo-B, M"                         ! TUBE 4
5570  GOTO 5620
5580  Tubetype$="Turbo-B, L"                         ! TUBE 5
5590  GOTO 5620
5600  Tubetype$="no_tube_type"
5610            !
5620  OFF ERROR
5630  RETURN
5640  !
5650  !-------------------------------------------------------------
5660  !    SUBROUTINE DATACHECK
5670  !
5680 Datacheck:C$=CHR$(255)&"K"
5690  OUTPUT 2 USING "#,K";C$
5700  PRINT "   Tsat   = ";Tsat;"  C"
```

```
5710  PRINT ""
5720  PRINT "   Uv          Ia           Tav      T1       T2       T3       T4       Tp
ol    q    "
5730  PRINT "  ________________________________________________________________________
__________"
5740  PRINT "   [V]         [A]          [C]      [C]      [C]      [C]      [C]      [C
     [W/m^2]"
5750  PRINT ""
5760 Morecheck: !
5770  OUTPUT 709;"ACV12,19"
5780  ENTER 709;St1(1),St1(2)
5790  OUTPUT 709;"TEM13-18"
5800  ENTER 709;St1(3),St1(4),St1(5),St1(6),St1(7),St1(8)
5810  !
5820  GOSUB Correct
5830  !
5840  IF Tav>10000 THEN
5850    PRINT USING 5900;Uv,Ia,0,0,0,0,0,Tpool,Q(Nrun)
5860    GOTO 5920
5870  END IF
5880  !
5890  PRINT USING 5900;Uv,Ia,Tav,T1,T2,T3,T4,Tpool,Q(Nrun)
5900  IMAGE   3X,DDD.DDD,X,DDD.DDD,5X,DDD.D,3X,DDD.D,3X,DDD.D,3X,DDD.D,3X,DDD.I
3X,DDD.D,3X,D.DESZ
5910  !
5920  LINPUT "    Enter  M  to go back to the main menu, any other key to checl
data once more !",Checkmore$
5930  IF Checkmore$<>"M" THEN Morecheck
5940  RETURN
5950  !
5960  !--------------------------------------------------------------------------
5970  !     SUBROUTINE CORRECT DATA
5980  !
5990 Correct: !------VOLTAGE AT THE HEATER Uv, 10:1 DIVIDOR IN DATA ACQU
6000  Corrv=-.36668-8.9054*St1(1)-.000743*St1(1)^2
6010  Uv=St1(1)-Corrv
6020  !--------------VOLTAGE SHUNT Ua
6030  Corra=-.001523-.001789*St1(2)-.0051955*St1(2)^2
6040  Ua=St1(2)-Corra
6050  !----------
6060  Ia=15*Ua                              ! SHUNT RESISTOR 1/15 OHM
6070  P=Ia*Uv                               ! POWER DISSIPATED
6080  Q(Nrun)=P/Surfarea                    ! HEAT FLUX
6090  !--------------TEMPERATURE GRADIENT BETW. THERMOCPLES AND TSURFACE
6100  T1=St1(3)-LOG(Rr)*Q(Nrun)*Tubediameter*.5/Kcopper
6110  T2=St1(4)-LOG(Rr)*Q(Nrun)*Tubediameter*.5/Kcopper
6120  T3=St1(5)-LOG(Rr)*Q(Nrun)*Tubediameter*.5/Kcopper
6130  T4=St1(6)-LOG(Rr)*Q(Nrun)*Tubediameter*.5/Kcopper
6140  !-----------
6150  Tav=(T1+T2+T3+T4)/4                   ! AVERAGE WALL TEMPERATURE AT SURFA
6160  Delta(Nrun)=Tav-Tsat              ! AVERAGE WALL SUPERHEAT
6170  Tpool=St1(7)
6180  RETURN
6190  !
```

```
6200  !-------------------------------------------------------------------
6210  !    SUBROUTINE SET PARAMETERS
6220  !
6230 Setparam:C$=CHR$(255)&"K"
6240  OUTPUT 2 USING "#,K";C$
6250  PRINT ""
6260  PRINT "    Enter :"
6270  PRINT ""
6280  PRINT "     - atmospheric pressure ,    default :  patmos = ";Patmos;" mm
g"
6290  INPUT Patmos
6300  PRINT "                                     new :  patmos = ";Patmos;" mm
g"
6310  PRINT "     - freon above tube ,        default :  height = ";Height;"  m
6320  INPUT Height
6330  PRINT "                                     new :  height = ";Height;"  m
6340  PRINT ""
6350  Ptube=Patmos*.0001333+Rhofreon*Gravity*Height*.000001              ! [ M
a ]
6360  Tsat=320+(Ptube-.09896)/(.10575-.09896)*2-273.16+.02          ! [C], COR
+.02
6370  Tsat=DROUND(Tsat,4)
6380  PRINT "                              ==>         Tsat  = ";Tsat;"  C"
6390  PRINT ""
6400  PRINT "     - tube diameter,             default:      D  = ";Tubediameter
" m"
6410  INPUT Tubediameter
6420  PRINT "                                     new:      D  = ";Tubediameter
"  m"
6430  PRINT "     - tube length                default:      L  = ";Tubelength;
m"
6440  INPUT Tubelength
6450  PRINT "                                     new:      L  = ";Tubelength;
 m"
6460  Surfarea=Tubediameter*PI*Tubelength                 ! SURFACE AREA [m^2]
6470  PRINT "     - tube o.r. / thermcpl.r.   default:      R/r= ";Rr
6480  INPUT Rr
6490  PRINT "                                     new:      R/r= ";Rr
6500  WAIT 1
6510  RETURN
6520  !
6530  !-------------------------------------------------------------------
6540  !    SUBROUTINE  SHOW DATA   Q VERSUS DELTA T
6550  !
6560 Datashow:C$=CHR$(255)&"K"
6570  OUTPUT 2 USING "#,K";C$
6580  Stabgraph$="N"
6590  Ncurve=1
6600  !-----------------------------------
6610  PRINT "    S H O W   D A T A"
6620  PRINT ""
6630  PRINT ""
6640  PRINT "    Enter :"
```

```
6650  PRINT ""
6660  !
6670  LOOP
6680    IF Ncurve=1 AND Day$<>"" THEN
6690      PRINT "    the name of the ";Ncurve;". file, you want to plot !  Defa
lt: ";Day$
6700      LINPUT Curvefile$
6710      Curvefile$=UPC$(Curvefile$)
6720      IF Curvefile$="" THEN
6730        Curvefile$=Day$
6740      END IF
6750      GOTO 6820
6760    END IF
6770    PRINT "    the name of the ";Ncurve;". file, you want to plot !"
6780    LINPUT "    RETURN   to finish the file selection !",Curvefile$
6790    Curvefile$=UPC$(Curvefile$)
6800  EXIT IF Curvefile$=""
6810    !------------------ CHECK EXISTENCE OF FILE
6820    ON ERROR GOTO 6860
6830    ASSIGN @Path TO *
6840    ASSIGN @Path TO Curvefile$
6850    GOTO 6900
6860    PRINT "    This file is not on the disc.   Press F2 to continue !"
6870    OFF ERROR
6880    PAUSE
6890    GOTO 7070
6900    OFF ERROR
6910    !-----------------------------------
6920    Curve$(Ncurve)=Curvefile$
6930    LINPUT "    the label of the plot !                    Default: filenam
",Lcurve$(Ncurve)
6940    IF Lcurve$(Ncurve)="" THEN
6950      Lcurve$(Ncurve)=Curvefile$
6960    END IF
6970    Pcurve(Ncurve)=Ncurve+2
6980    INPUT "    the number of sides of the polygon !      Default:   # plot
 2",Pcurve(Ncurve)
6990    LINPUT "    any alphabet to fill the polygon !       Default: not fil
d",Pfill$(Ncurve)
7000    IF Pfill$(Ncurve)<>"" THEN
7010      Pfill$(Ncurve)="filled"
7020    END IF
7030    PRINT ""
7040    PRINT "    ->     file : ";Curve$(Ncurve);",  label : ";Lcurve$(Ncurve
",  polygon : ";Pcurve(Ncurve);"    ";Pfill$(Ncurve)
7050    PRINT ""
7060    Ncurve=Ncurve+1
7070  END LOOP
7080  !--------------------- NATURAL CONVECTION CURVE
7090  Natcurve$=""
7100  LINPUT "    RETURN / N ,   to plot/not to plot    the natural convection
urve!",Natcurve$
7110  IF Natcurve$<>"N" THEN
7120    PRINT ""
7130    PRINT "    ->     Natural Convection Curve"
```

```
7140  END IF
7150  !--------------------.- FIGURE #
7160  Fignumber$=""
7170  LINPUT "    Enter figure# , or RETURN to plot no figure label!",Fignumber
7180  PRINT ""
7190  PRINT "    ->     Figure ";Fignumber$
7200  !--------------------- EXTENDS OF THE PLOT
7210  Plotwindow$=""
7220  LINPUT "    RETURN / N ,   to keep/to change    the default plotting winc
w !",Plotwindow$
7230  IF Plotwindow$<>"" THEN GOSUB Plotwindow
7240  !--------------------- CHOOSE MEDIA
7250  C$=CHR$(255)&"K"
7260  OUTPUT 2 USING "#,K";C$
7270  PRINT "    Enter # to show data :"
7280  PRINT ""
7290  PRINT "    1      on screen"
7300  PRINT ""
7310  PRINT "    2      on printer          ?"
7320  PRINT ""
7330  PRINT "    3      on plotter"
7340  PRINT ""
7350  PRINT ""
7360  PRINT "    Enter M to go back to MAIN MENU !"
7370  LINPUT "    Default :   1",Datanr$
7380  !
7390  Bolt$="ON"                                     ! PRINTS "POOL..." BOLT
7400  SELECT Datanr$
7410  CASE "2"
7420    CLEAR SCREEN
7430    GINIT
7440    PLOTTER IS 9,"INTERNAL"
7450    GOSUB Datagraph
7460  CASE "3"
7470    PRINT ""
7480    PRINT "    Turn plotter on !                            Press F2 to conti
ue !"
7490    PAUSE
7500    CLEAR SCREEN
7510    GINIT
7520    PLOTTER IS CRT,"INTERNAL"
7530    GOSUB Datagraph
7540    Bolt$="OFF"
7550    GINIT
7560    PLOTTER IS 705,"HPGL"
7570    OUTPUT 705;"VS10"
7580    GOSUB Datagraph
7590  CASE "M"
7600    GOTO Mnmenu
7610  CASE ELSE
7620    CLEAR SCREEN
7630    GINIT
7640    PLOTTER IS CRT,"INTERNAL"
7650    GOSUB Datagraph
```

```
7660  END SELECT
7670  !
7680  GRAPHICS OFF
7690  C$=CHR$(255)&"K"
7700  OUTPUT 2 USING "#,K";C$
7710  !
7720  RETURN                                        ! RETURN TO MNMENU
7730  !
7740  !++++++++++++++++++++++++++++++++++++++++ SUB-PROGRAM OF A SUBROUTINE
7750  !     SUBROUTINE DATAGRAPH,   GRAPHIC OF :    Q  VERSUS  DELTA T
7760  !
7770 Datagraph: !-----------------------
7780  Xrange=Xmax-Xmin
7790  Yrange=Ymax-Ymin
7800  !------------------- CORRECTION TO PLOT SQUARES
7810  Xstretchcorr=.82432*Xrange/3                ! NORMALIZED TO A SQUARE
7820  Ystretchcorr=Yrange/2.5                     ! NORMALIZED TO A SQUARE
7830  IF Xstretchcorr>Ystretchcorr THEN
7840    Ystretchcorr=Ystretchcorr/Xstretchcorr
7850    Xstretchcorr=1
7860  END IF
7870  IF Ystretchcorr>=Xstretchcorr THEN
7880    Xstretchcorr=Xstretchcorr/Ystretchcorr
7890    Ystretchcorr=1
7900  END IF
7910  !--------------- PLOT LABEL
7920  GRAPHICS ON
7930  X_gdu_max=100*MAX(1,RATIO)
7940  Y_gdu_max=100*MAX(1,1/RATIO)
7950  !
7960  IF Fignumber$<>"" THEN
7970    CSIZE 3
7980    LORG 3
7990    DEG
8000    LDIR 270
8010    MOVE .05*X_gdu_max,Y_gdu_max*.35
8020    Figure$="Figure "&Fignumber$
8030    LABEL Figure$
8040    LDIR 0
8050  END IF
8060  !
8070  CSIZE 4.5
8080  LORG 6
8090  !
8100  MOVE .5*X_gdu_max,Y_gdu_max*Ystretchcorr
8110  LABEL "Pool Boiling Experiment"
8120  IF Bolt$="OFF" THEN 8180
8130  FOR I=-.1 TO .1 STEP .2
8140    MOVE .5*X_gdu_max+I,Y_gdu_max*Ystretchcorr
8150    LABEL "Pool Boiling Experiment"
8160  NEXT I
8170  !
8180  DEG
8190  LDIR 90
8200  CSIZE 3.5
```

```
8210  MOVE (.5-.5*Xstretchcorr)*X_gdu_max,Y_gdu_max*Ystretchcorr/2
8220  LABEL "Heat Flux , W/m"
8230  CSIZE 2
8240  MOVE (.5-.5*Xstretchcorr)*X_gdu_max,.67*Y_gdu_max*Ystretchcorr
8250  LABEL "2"
8260  !
8270  CSIZE 3.5
8280  LORG 4
8290  LDIR 0
8300  MOVE .5*X_gdu_max,.01*Y_gdu_max*Stretchcorr
8310  LABEL "Wall Superheat , C"
8320  !
8330  LDIR 0
8340  !---------------- PLOT FRAME
8350  VIEWPORT (.5-.35*Xstretchcorr)*X_gdu_max,(.5+.49*Xstretchcorr)*X_gdu_max,
1*Y_gdu_max,.9*Y_gdu_max*Ystretchcorr
8360  FRAME
8370  WINDOW Xmin,Xmax,Ymin,Ymax
8380  !---------------- GRID
8390  FOR Xgrid=PROUND(Xmin+.501,0) TO Xmax-.001
8400    MOVE Xgrid,Ymin
8410    DRAW Xgrid,Ymax
8420  NEXT Xgrid
8430  FOR Ygrid=PROUND(Ymin+.501,0) TO Ymax-.001
8440    MOVE Xmin,Ygrid
8450    DRAW Xmax,Ygrid
8460  NEXT Ygrid
8470  !---------------- SCALE X-AXIS
8480  Xstart=PROUND(Xmin-.49,0)
8490  FOR Decade=Xstart TO Xmax
8500    FOR Units=1 TO 1+8*(Decade<Xmax)
8510      X=Decade+LGT(Units)
8520      MOVE X,Ymin
8530      DRAW X,Ymin+.02*Yrange
8540      MOVE X,Ymax-.02*Yrange
8550      DRAW X,Ymax
8560    NEXT Units
8570  NEXT Decade
8580  !---------------- SCALE Y-AXIS
8590  Ystart=PROUND(Ymin-.49,0)
8600  FOR Decade=Ystart TO Ymax
8610    FOR Units=1 TO 1+8*(Decade<Ymax)
8620      Y=Decade+LGT(Units)
8630      MOVE Xmin,Y
8640      DRAW Xmin+.01*Xrange,Y
8650      MOVE Xmax-.01*Xrange,Y
8660      DRAW Xmax,Y
8670    NEXT Units
8680  NEXT Decade
8690  !----------------- LABEL X-AXIS
8700  CLIP OFF
8710  Xstart=PROUND(Xmin+.49,0)
8720  FOR X=Xstart TO Xmax STEP Dx
8730    LORG 6
8740    CSIZE 3
```

```
8750      MOVE X,Ymin-Yrange*.01
8760      LABEL USING "#,K";"10"
8770      CSIZE 2
8780      LORG 1
8790      MOVE X+Xrange*.02,Ymin-Yrange*.03
8800      LABEL USING "#,K";X
8810    NEXT X
8820    !------------------ LABEL Y-AXIS
8830    Ystart=PROUND(Ymin+.49,0)
8840    FOR Y=Ystart TO Ymax STEP Dy
8850      CSIZE 3
8860      LORG 8
8870      MOVE Xmin-Xrange*.03,Y
8880      LABEL USING "#,K";"10"
8890      CSIZE 2
8900      LORG 1
8910      MOVE Xmin-Xrange*.025,Y+Yrange*.01
8920      LABEL USING "#,K";Y
8930    NEXT Y
8940    CLIP ON
8950    !--------------------------- PLOT DATA
8960    FOR Curverun=1 TO Ncurve-1
8970      !------------------------- READ DATA
8980      IF Stabgraph$="Y" THEN 9080         ! DATA ALREADY AVAILABLE, STABCHEC
8990      ASSIGN @Path TO *
9000      ASSIGN @Path TO Curve$(Curverun)
9010      FOR I=1 TO 50
9020        ON ERROR GOTO 9060
9030 !      ENTER @Path,I;Uv,Ia,Tav,T1,T2,T3,T4,Tpool,Tbath,Q(I),Delta(I),Tube,Ts
t,Surfarea,Tubediameter,Rr
9040        ENTER @Path,I;Ff,Ff,Ff,Ff,Ff,Ff,Ff,Ff,Ff,Q(I),Delta(I)
9050      NEXT I
9060      OFF ERROR
9070      Nrun=I
9080      !-------------------- PLOT LABEL OF CURVE
9090      LORG 2
9100      MOVE Xmin+.06*Xrange,.98*Ymax-.1*Yrange*Curverun
9110      PDIR -90-180/Pcurve(Curverun)
9120      SELECT Pfill$(Curverun)
9130      CASE ""
9140        POLYGON Psize,Pcurve(Curverun),Pcurve(Curverun)
9150      CASE ELSE
9160        POLYGON Psize,Pcurve(Curverun),Pcurve(Curverun),FILL
9170      END SELECT
9180      MOVE Xmin+.1*Xrange,.98*Ymax-.1*Yrange*Curverun
9190      CSIZE 3
9200      LABEL "incr., "&Lcurve$(Curverun)
9210      !
9220      MOVE Xmin+.06*Xrange,.98*Ymax-.1*Yrange*(Curverun+.4)
9230      PDIR -90
9240      SELECT Pfill$(Curverun)
9250      CASE ""
9260        POLYGON Psize,Pcurve(Curverun),Pcurve(Curverun)
9270      CASE ELSE
```

```
9280      POLYGON Psize,Pcurve(Curverun),Pcurve(Curverun),FILL
9290    END SELECT
9300    PDIR 0
9310    MOVE Xmin+.10*Xrange,.98*Ymax-.1*Yrange*(Curverun+.4)
9320    LABEL "decr."
9330    !--------------------- PLOT CURVE
9340    Plotstart=1
9350    LOOP                                            ! LOG>0, Q>Q(DATAAQUMIN
9360    EXIT IF Delta(Plotstart)>0 AND Q(Plotstart)>0 !10^Ymin    ! 1.POINT
9370      Plotstart=Plotstart+1
9380    END LOOP
9390    MOVE LGT(Delta(Plotstart)),LGT(Q(Plotstart))
9400    FOR I=Plotstart TO Nrun-1
9410      IF Delta(I)<=0 OR Q(I)<=0 THEN 9520               ! LOG>0, Q>Q(DATAAQU
IN)       .
9420      PLOT LGT(Delta(I)),LGT(Q(I)),-1
9430      PENUP
9440      PDIR -90-180/Pcurve(Curverun)                     ! GOING UP
9450      IF Q(I)<Q(I-1) THEN PDIR -90                      ! GOING DOWN
9460      SELECT Pfill$(Curverun)
9470      CASE ""
9480        POLYGON Psize,Pcurve(Curverun),Pcurve(Curverun)
9490      CASE ELSE
9500        POLYGON Psize,Pcurve(Curverun),Pcurve(Curverun),FILL
9510      END SELECT
9520    NEXT I
9530    PDIR 0
9540        !
9550  NEXT Curverun
9560  !------------------- PLOT NATURAL CONVECTION CURVE
9570  IF Natcurve$<>"" THEN 10110
9580  !
9590  LORG 2
9600  MOVE Xmin+.05*Xrange,.98*Ymax-.1*Yrange*Curverun
9610  PLOT Xmin+.08*Xrange,.98*Ymax-.1*Yrange*Curverun,-1
9620  PENUP
9630  MOVE Xmin+.1*Xrange,.98*Ymax-.1*Yrange*Curverun
9640  CSIZE 3
9650  LABEL "nat. Convection [9]"
9660  !
9670  Delta_nc=1                                    ! LOWER LIMIT OF THE CURV
9680  Q_nc=C_nc*3.7*6804901.4^N_nc*Delta_nc^(N_nc+1)
9690  MOVE LGT(Delta_nc),LGT(Q_nc)
9700  Delta_nc=30                                   ! UPPER LIMIT OF THE CURV
9710  Q_nc=C_nc*3.7*6804901.4^N_nc*Delta_nc^(N_nc+1)
9720  PLOT LGT(Delta_nc),LGT(Q_nc),-1
9730  PENUP
9740  !-----------------------------------------
9750  !
9760  IF Stabmode$="PLOT" AND Stabgraph$="Y" THEN RETURN
9770  !
9780  PAUSE
```

```
9790  LINPUT "          RETURN  to continue / W  to change the window !",Window$
9800  Window$=UPC$(Window$)
9810  IF Window$<>"W" THEN RETURN
9820  GRAPHICS OFF
9830  GOSUB Plotwindow
9840  CLEAR SCREEN
9850  GINIT
9860  GOTO Datagraph
9870  !++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
9880  !        SUBROUTINE PLOTWINDOW
9890  !
9900 Plotwindow: !
9910  C$=CHR$(255)&"K"
9920  OUTPUT 2 USING "#,K";C$
9930  PRINT "     The default plotting window is :"
9940  PRINT ""
9950  PRINT "     log(T-Tsat)_min = ";Xmin
9960  PRINT "     log(T-Tsat)_max = ";Xmax
9970  PRINT ""
9980  PRINT "     log(q'')_min    = ";Ymin
9990  PRINT "     log(q'')_max    = ";Ymax
10000 !
10010 PRINT ""
10020 PRINT ""
10030 PRINT "     The new plotting window is :"
10040 PRINT ""
10050 INPUT "     log(T-Tsat)_min =  ?                         , RETURN to keep the de
ault value !",Xmin
10060 PRINT "     log(T-Tsat)_min = ";Xmin
10070 INPUT "     log(T-Tsat)_max =  ?                         , RETURN to keep the de
ault value !",Xmax
10080 PRINT "     log(T-Tsat)_max = ";Xmax
10090 INPUT "     log(q'')_min    =  ?                         , RETURN to keep the de
ault value !",Ymin
10100 PRINT ""
10110 PRINT "     log(q'')_min    = ";Ymin
10120 INPUT "     log(q'')_max    =  ?                         , RETURN to keep the de
ault value !",Ymax
10130 PRINT "     log(q'')_max    = ";Ymax;"                             Press R
 to continue !"
10140 PAUSE
10150 RETURN
10160 !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
10170 !
10180 !-------------------------------------------------------------------
10190 !
10200 Ende:  !
10210 C$=CHR$(255)&"K"
10220 OUTPUT 2 USING "#,K";C$
10230 CAT
10240 !
10250 END
```

7. Data A1 to A9 (Pool-Boiling Experiment)

The data listed next refer to the pool-boiling tests with arrangements as explained in chapter II.1.4.

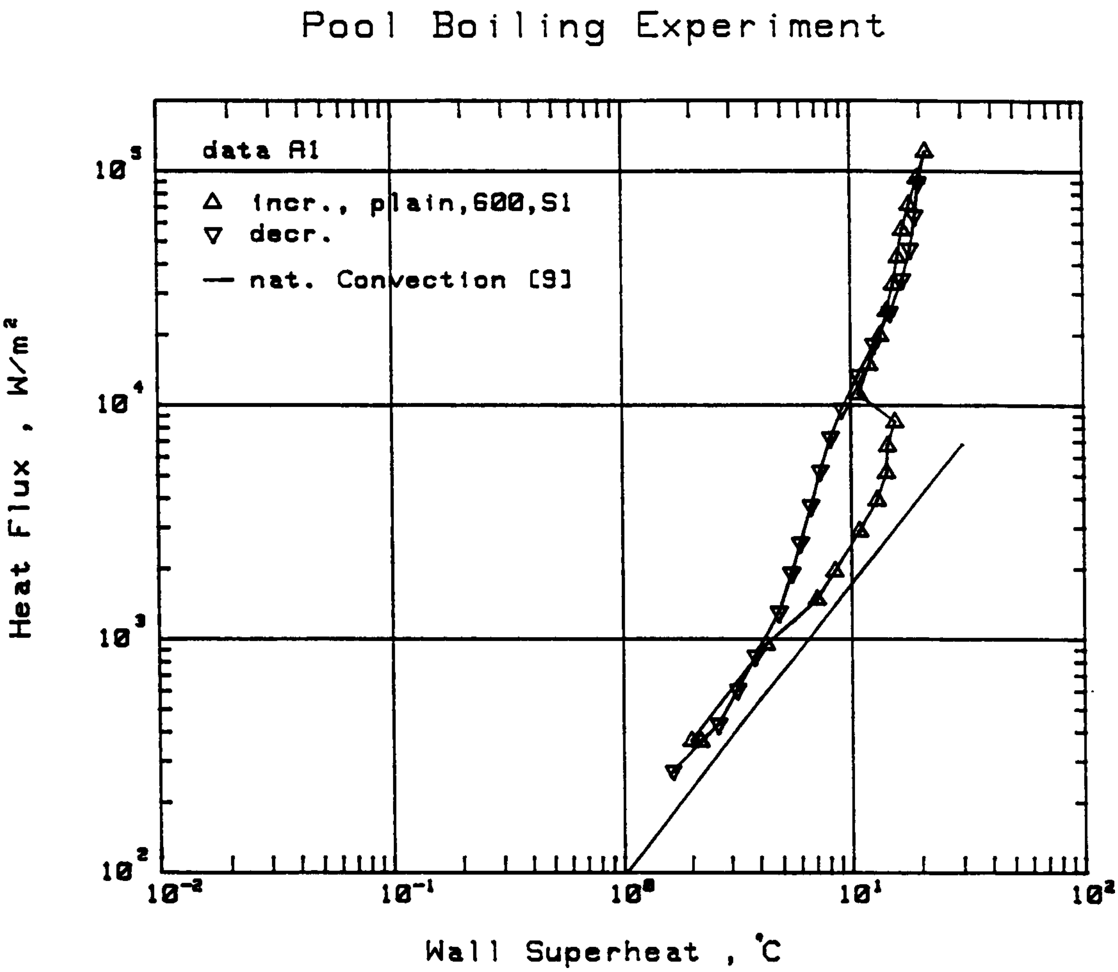
In the plots, a brief description of the arrangement is given with a code in the format: {tube type, surface quality, instrumentation}, where the parameters are denoted as follows:

- tube type: "plain", for a plain tube
  "plain-W", for a plain Wieland tube (wire-EDM)
  "Turbo-B", for a Wolverine Turbo-B tube
- surface quality: "100", for a surface polished with 100 paper
  "600", for a surface polished with 600 paper
  "Crocus", for a polishing with Crocus paper
- instrumentation: "S1", for a 1/8" o.d., 1/16" i.d., copper sleeve, which accommodates the thermocouple in a drilled well.
  "S2", for a 0.093" o.d., 0.036" i.d., copper sleeve, which accommodates the thermocouple in a drilled well.
  "sold.", for a plain Wieland tube, where the slots are soldered
  " ", if the thermocouple is accommodated in a 3/32" well without a sleeve, or in a slot which is not soldered.

I	Uv(I) [V]	Ia(I) [A]	Tav(I) [C]	T1(I) [C]	T2(I) [C]	T3(I) [C]	T4(I) [C]	Tpool(I) [C]	q(I) [W/m^2]
1	8.015	.275	50.6	50.7	50.7	50.6	50.5	47.9	3.6E+2
2	8.022	.277	50.4	50.5	50.5	50.4	50.3	48.0	3.7E+2
3	12.829	.450	52.7	52.7	52.8	52.7	52.6	48.0	9.5E+2
4	15.990	.562	55.5	55.5	55.6	55.5	55.4	48.1	1.5E+3
5	18.332	.647	56.9	57.0	57.0	56.9	56.8	48.1	1.9E+3
6	22.324	.788	59.3	59.4	59.4	59.2	59.2	48.1	2.9E+3
7	25.977	.920	61.4	61.5	61.4	61.4	61.3	48.0	3.9E+3
8	29.731	1.054	62.7	62.8	62.7	62.6	62.5	48.0	5.2E+3
9	34.054	1.195	62.8	62.9	62.9	62.9	62.7	48.1	6.7E+3
10	38.315	1.346	63.9	63.9	64.0	64.1	63.8	47.9	8.5E+3
11	43.866	1.541	59.3	59.3	59.5	59.4	59.0	48.0	1.1E+4
12	50.904	1.782	60.6	60.6	60.8	60.8	60.2	48.0	1.5E+4
13	58.735	2.053	62.0	61.9	62.3	62.3	61.5	48.0	2.0E+4
14	66.270	2.324	62.9	62.8	63.2	63.3	62.4	47.9	2.5E+4
15	75.492	2.640	63.9	63.7	64.1	64.3	63.4	47.9	3.3E+4
16	86.402	3.016	64.6	64.4	64.8	65.1	64.2	47.8	4.3E+4
17	98.999	3.453	65.3	65.2	65.3	65.9	65.0	47.8	5.6E+4
18	111.996	3.905	66.6	66.4	66.5	67.2	66.3	47.8	7.2E+4
19	127.972	4.447	68.1	67.9	67.9	68.8	67.8	47.8	9.4E+4
20	146.137	5.051	69.7	69.6	69.5	70.6	69.3	47.8	1.2E+5
21	125.193	4.342	68.4	68.3	68.2	69.0	67.9	47.8	8.9E+4
22	106.241	3.694	67.7	67.6	67.8	68.2	67.2	47.8	6.5E+4
23	90.171	3.137	66.7	66.6	67.0	67.2	66.1	47.8	4.7E+4
24	77.575	2.700	65.4	65.3	65.7	65.8	64.7	47.9	3.4E+4
25	65.973	2.294	63.4	63.4	63.7	63.6	62.9	47.9	2.5E+4
26	56.356	1.963	61.2	61.2	61.4	61.3	60.8	47.9	1.8E+4
27	48.524	1.677	59.4	59.4	59.6	59.4	59.0	47.9	1.3E+4
28	41.190	1.421	57.7	57.8	57.9	57.7	57.4	48.0	9.6E+3
29	35.639	1.241	56.7	56.8	56.8	56.7	56.5	48.0	7.3E+3
30	30.032	1.059	55.9	55.9	56.0	56.0	55.7	48.0	5.2E+3
31	25.372	.893	55.2	55.3	55.3	55.3	55.1	48.0	3.7E+3
32	21.149	.741	54.5	54.6	54.6	54.6	54.4	48.1	2.6E+3
33	18.254	.639	54.0	54.1	54.1	54.0	53.9	48.0	1.9E+3
34	15.086	.526	53.4	53.5	53.5	53.4	53.3	48.0	1.3E+3
35	12.205	.423	52.4	52.5	52.5	52.4	52.3	48.0	8.5E+2
36	10.369	.356	51.8	51.8	51.8	51.7	51.7	48.0	6.1E+2
37	8.785	.299	51.2	51.3	51.3	51.2	51.1	48.0	4.3E+2
38	6.992	.236	50.2	50.3	50.3	50.2	50.1	48.1	2.7E+2
39	.370	.023	48.6	48.7	48.7	48.6	48.5	48.0	1.4E+0

The file 15SEP1988 contains 39 records.
A plain tube with a surface area of 0 .0060805 m^2, an outer diameter of 0 .01905 m and a correction ratio R/r of 1.5 was tested in freon with a saturation temperature of 48.57 C.

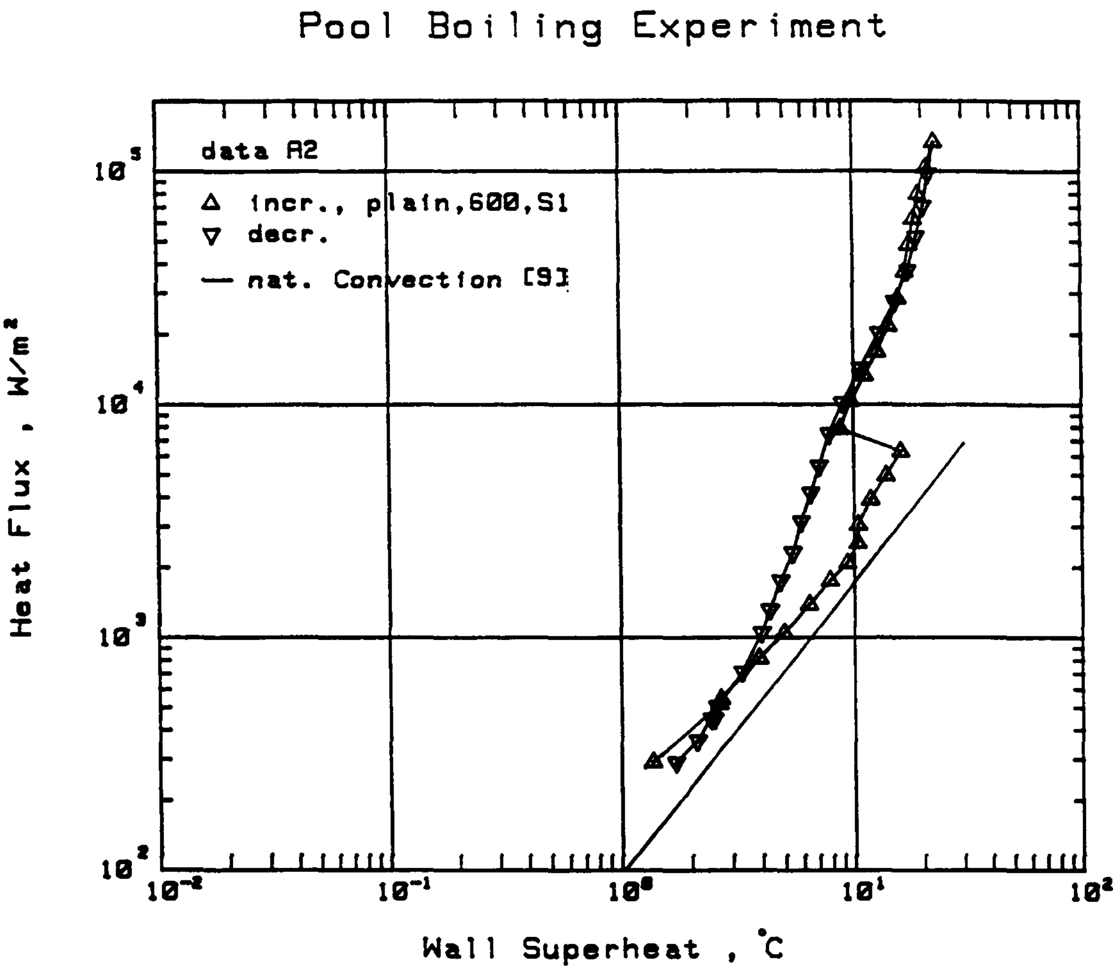
data A 1


Pool Boiling Experiment
data A1
△ incr., plain,600,S1
▽ decr.
— nat. Convection [9]
Heat Flux , W/m²
Wall Superheat , °C
10²
10³
10⁴
10⁵
10⁻²
10⁻¹
10⁰
10¹
10²

I	Uv(I) [V]	Ia(I) [A]	Tav(I) [C]	T1(I) [C]	T2(I) [C]	T3(I) [C]	T4(I) [C]	Tpool(I) [C]	q(I) [W/m^2]
1	.367	.023	48.1	48.2	48.2	48.1	48.0	47.9	1.4E+0
2	7.223	.245	49.7	49.6	49.8	49.7	49.6	47.9	2.9E+2
3	9.582	.329	50.9	50.7	51.1	51.0	50.9	47.8	5.2E+2
4	8.899	.305	50.8	50.6	50.9	50.9	50.8	47.8	4.5E+2
5	8.896	.305	50.7	50.5	50.9	50.8	50.7	47.8	4.5E+2
6	9.836	.338	51.0	50.7	51.1	51.1	51.0	47.8	5.5E+2
7	11.947	.415	52.2	51.9	52.3	52.3	52.2	47.8	8.2E+2
8	13.518	.471	53.3	53.0	53.4	53.4	53.2	47.9	1.0E+3
9	15.541	.543	54.7	54.4	54.8	54.8	54.6	47.9	1.4E+3
10	17.469	.612	56.1	55.9	56.3	56.2	56.1	47.8	1.8E+3
11	19.049	.668	57.6	57.4	57.8	57.7	57.6	47.8	2.1E+3
12	21.025	.738	58.7	58.5	58.8	58.8	58.6	47.8	2.6E+3
13	22.967	.807	58.8	58.6	58.9	58.9	58.7	47.8	3.0E+3
14	26.004	.917	60.1	60.0	60.3	60.2	60.0	47.8	3.9E+3
15	29.276	1.033	62.1	61.9	62.3	62.2	62.0	47.8	5.0E+3
16	33.261	1.150	64.3	64.2	64.5	64.4	64.3	47.8	6.3E+3
17	37.225	1.286	57.1	57.0	57.3	57.1	56.9	47.8	7.9E+3
18	42.676	1.481	58.1	58.0	58.4	58.2	57.9	47.8	1.0E+4
19	48.425	1.677	59.5	59.3	59.8	59.6	59.2	47.8	1.3E+4
20	54.175	1.887	61.0	60.9	61.4	61.2	60.7	47.8	1.7E+4
21	61.710	2.143	62.6	62.4	63.0	62.9	62.2	47.7	2.2E+4
22	70.534	2.459	64.0	63.7	64.4	64.4	63.5	47.7	2.9E+4
23	80.451	2.805	65.1	65.0	65.4	65.6	64.6	47.6	3.7E+4
24	92.055	3.197	65.8	65.6	66.0	66.3	65.4	47.6	4.8E+4
25	104.753	3.634	66.8	66.6	66.8	67.3	66.4	47.6	6.3E+4
26	118.346	4.101	67.6	67.5	67.5	68.2	67.4	47.6	8.0E+4
27	134.920	4.674	69.2	69.0	68.9	69.9	68.9	47.6	1.0E+5
28	153.384	5.292	71.0	71.0	70.5	71.7	70.5	47.5	1.3E+5
29	131.049	4.523	69.8	69.8	69.5	70.4	69.3	47.5	9.7E+4
30	111.599	3.860	68.7	68.8	68.7	69.2	68.2	47.5	7.1E+4
31	95.825	3.317	67.2	67.2	67.4	67.7	66.6	47.6	5.2E+4
32	80.947	2.805	65.6	65.6	65.9	65.9	65.1	47.6	3.7E+4
33	69.245	2.414	63.6	63.6	63.9	63.7	63.0	47.6	2.7E+4
34	59.528	2.068	61.3	61.3	61.6	61.4	60.8	47.7	2.0E+4
35	50.011	1.737	59.1	59.1	59.3	59.1	58.7	47.7	1.4E+4
36	42.280	1.466	57.3	57.3	57.4	57.3	57.0	47.8	1.0E+4
37	36.234	1.256	56.1	56.2	56.3	56.2	55.9	47.8	7.5E+3
38	30.783	1.075	55.4	55.4	55.5	55.3	55.2	47.8	5.4E+3
39	26.796	.947	54.8	54.8	54.9	54.8	54.7	47.7	4.2E+3
40	23.290	.822	54.2	54.2	54.3	54.2	54.1	47.8	3.2E+3
41	20.009	.705	53.7	53.8	53.8	53.7	53.6	47.7	2.3E+3
42	17.394	.612	53.1	53.1	53.1	53.1	53.0	47.8	1.8E+3
43	15.072	.529	52.6	52.7	52.7	52.6	52.5	47.8	1.3E+3
44	13.493	.472	52.3	52.3	52.3	52.3	52.2	47.8	1.0E+3
45	11.179	.388	51.6	51.7	51.7	51.6	51.5	47.8	7.1E+2
46	9.436	.326	50.9	50.9	50.9	50.9	50.8	47.8	5.1E+2
47	7.988	.274	50.3	50.5	50.5	50.4	50.3	47.8	3.6E+2
48	7.195	.245	50.0	50.1	50.1	50.0	49.9	47.8	2.9E+2

The file 19SEP1988 contains 48 records.
A plain tube with a surface area of 0 .0060805 m^2, an outer diameter of 0 .01905 m and a correction ratio R/r of 1.5 was tested in freon with a saturation temperature of 48.3 C.

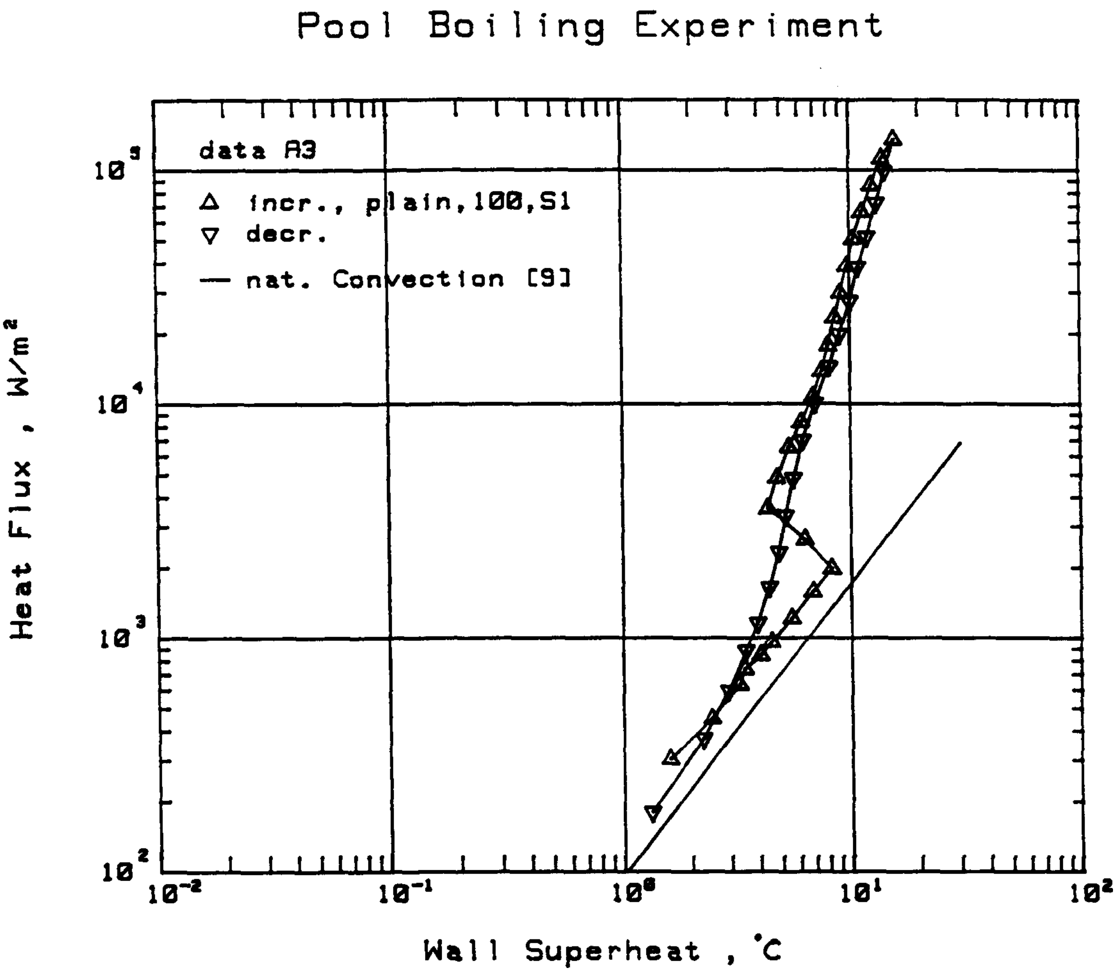
data A 2


Pool Boiling Experiment
data A2
incr., plain,600,S1
decr.
nat. Convection [9]
Heat Flux , W/m²
Wall Superheat , °C
10⁵
10⁴
10³
10²
10⁻²
10⁻¹
10⁰
10¹
10²

I	Uv(I)	Ia(I)	Tav(I)	T1(I)	T2(I)	T3(I)	T4(I)	Tpool(I)	q(I)
	[V]	[A]	[C]	[C]	[C]	[C]	[C]	[C]	[W/m^2]
1	.367	.023	48.2	48.2	48.2	48.1	48.1	48.0	1.4E+0
2	7.341	.251	49.8	49.8	49.9	49.8	49.7	47.9	3.0E+2
3	8.935	.308	50.6	50.5	50.8	50.7	50.6	47.9	4.5E+2
4	10.521	.365	51.4	51.3	51.6	51.5	51.4	47.9	6.3E+2
5	11.340	.396	51.6	51.4	51.8	51.7	51.6	47.9	7.4E+2
6	12.132	.424	52.2	52.0	52.4	52.3	52.2	47.9	8.5E+2
7	12.929	.453	52.7	52.5	52.8	52.8	52.6	47.9	9.6E+2
8	14.508	.510	53.7	53.5	53.9	53.8	53.7	47.9	1.2E+3
9	16.510	.582	55.0	54.8	55.2	55.2	55.0	47.9	1.6E+3
10	18.478	.651	56.4	56.2	56.6	56.5	56.4	47.8	2.0E+3
11	21.311	.753	54.5	54.5	54.6	54.5	54.5	47.7	2.6E+3
12	24.825	.878	52.6	52.5	52.7	52.6	52.4	47.7	3.6E+3
13	28.800	1.021	53.0	52.9	53.2	53.0	52.8	47.7	4.8E+3
14	33.657	1.180	53.6	53.5	53.9	53.7	53.4	47.7	6.5E+3
15	38.216	1.331	54.3	54.2	54.6	54.4	54.1	47.7	8.4E+3
16	43.271	1.511	55.1	55.0	55.4	55.2	54.8	47.7	1.1E+4
17	49.218	1.707	55.7	55.7	56.0	55.8	55.4	47.6	1.4E+4
18	55.860	1.933	56.3	56.2	56.6	56.2	56.0	47.6	1.8E+4
19	64.089	2.218	56.8	56.9	57.0	56.7	56.5	47.6	2.3E+4
20	72.319	2.504	57.3	57.4	57.5	57.2	57.1	47.6	3.0E+4
21	82.534	2.866	57.9	58.1	58.0	57.8	57.7	47.5	3.9E+4
22	94.138	3.272	58.6	58.8	58.5	58.5	58.4	47.5	5.1E+4
23	107.729	3.739	59.6	59.9	59.4	59.5	59.4	47.5	6.6E+4
24	123.109	4.252	60.7	61.1	60.5	60.6	60.5	47.4	8.6E+4
25	140.478	4.854	62.1	62.6	61.9	62.1	61.9	47.4	1.1E+5
26	154.675	5.322	64.0	64.7	63.7	64.1	63.5	47.4	1.4E+5
27	131.843	4.553	62.6	63.3	62.4	62.5	62.3	47.4	9.9E+4
28	112.690	3.890	61.4	61.9	61.2	61.3	61.1	47.5	7.2E+4
29	95.428	3.287	60.1	60.5	60.1	60.1	59.8	47.5	5.2E+4
30	82.038	2.836	59.1	59.4	59.1	59.0	58.8	47.5	3.8E+4
31	69.443	2.399	58.2	58.4	58.3	58.2	57.9	47.5	2.7E+4
32	59.033	2.038	57.2	57.4	57.4	57.2	56.9	47.6	2.0E+4
33	50.408	1.737	56.3	56.4	56.5	56.3	56.0	47.7	1.4E+4
34	42.082	1.451	55.2	55.3	55.4	55.2	54.9	47.7	1.0E+4
35	35.045	1.210	54.4	54.5	54.5	54.4	54.2	47.7	7.0E+3
36	28.845	1.012	53.8	53.9	53.9	53.8	53.6	47.7	4.8E+3
37	24.041	.842	53.4	53.5	53.5	53.4	53.2	47.7	3.3E+3
38	20.116	.702	53.1	53.1	53.1	53.1	52.9	47.7	2.3E+3
39	16.927	.589	52.6	52.6	52.7	52.6	52.5	47.7	1.6E+3
40	14.240	.495	52.1	52.1	52.2	52.1	52.0	47.8	1.2E+3
41	12.476	.432	51.7	51.7	51.7	51.7	51.5	47.8	8.9E+2
42	10.254	.352	51.1	51.2	51.2	51.1	51.0	47.8	5.9E+2
43	8.153	.277	50.4	50.5	50.5	50.4	50.3	47.8	3.7E+2
44	5.731	.191	49.5	49.6	49.6	49.5	49.4	47.8	1.8E+2

The file 19SEP2988 contains 44 records.
A plain tube with a surface area of 0 .0060805 m^2, an outer diameter of 0 .01905 m and a correction ratio R/r of 1.5 was tested in freon with a saturation temperature of 48.19 C.

data A 3

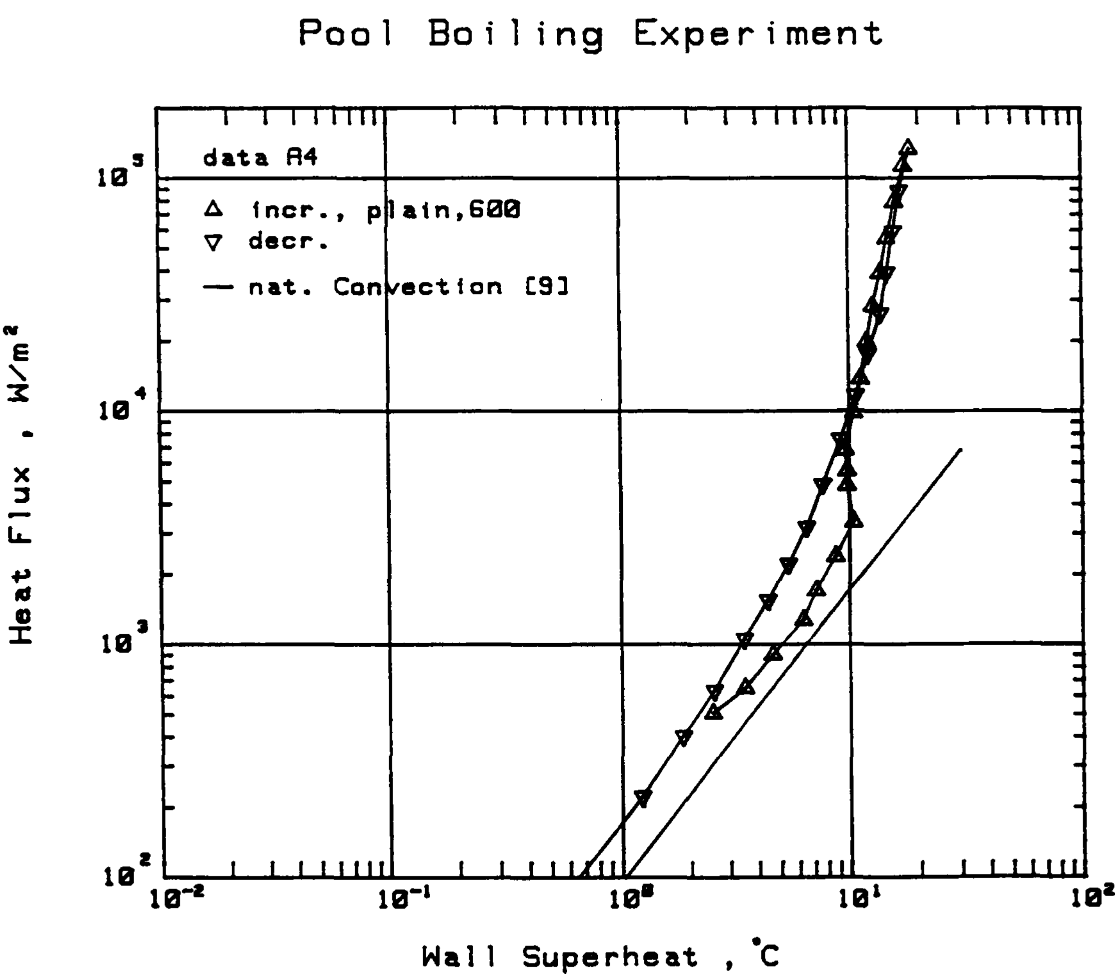


Pool Boiling Experiment
data A3
△ incr., plain,100,S1
▽ decr.
— nat. Convection [9]
Heat Flux , W/m²
Wall Superheat , °C
10²
10³
10⁴
10⁵
10⁻²
10⁻¹
10⁰
10¹
10²

I	Uv(I) [V]	Ia(I) [A]	Tav(I) [C]	T1(I) [C]	T2(I) [C]	T3(I) [C]	T4(I) [C]	Tpool(I) [C]	q(I) [W/m^2]
1	.368	.023	47.7	47.8	47.7	47.7	47.6	47.5	1.4E+0
2	9.522	.323	50.4	50.5	50.4	50.3	50.3	47.4	5.1E+2
3	10.776	.367	51.3	51.5	51.4	51.3	51.2	47.4	6.5E+2
4	12.670	.435	52.5	52.6	52.5	52.4	52.4	47.5	9.1E+2
5	14.995	.517	54.1	54.3	54.1	54.1	54.0	47.5	1.3E+3
6	17.336	.598	55.0	55.2	55.0	54.9	54.9	47.5	1.7E+3
7	20.478	.710	56.5	56.8	56.5	56.4	56.4	47.5	2.4E+3
8	24.262	.844	58.3	58.6	58.2	58.0	58.2	47.5	3.4E+3
9	29.027	1.010	57.6	57.8	57.6	57.5	57.6	47.4	4.8E+3
10	31.576	1.075	57.7	57.8	57.6	57.6	57.6	47.4	5.6E+3
11	34.747	1.195	57.5	57.8	57.5	57.3	57.4	47.3	6.8E+3
12	41.784	1.436	58.4	58.7	58.4	58.2	58.2	47.3	9.9E+3
13	49.516	1.692	59.1	59.5	59.0	58.8	59.0	47.3	1.4E+4
14	59.231	2.038	59.9	60.3	59.8	59.5	59.8	47.2	2.0E+4
15	70.534	2.429	60.6	61.1	60.5	60.3	60.5	47.2	2.8E+4
16	83.228	2.866	61.6	62.1	61.4	61.4	61.6	47.1	3.9E+4
17	98.801	3.408	62.6	63.0	62.3	62.5	62.5	47.1	5.5E+4
18	118.148	4.071	63.7	64.2	63.3	63.7	63.7	47.1	7.9E+4
19	141.570	4.854	65.2	65.9	64.7	65.1	65.1	47.0	1.1E+5
20	153.880	5.277	66.2	67.1	65.7	66.1	66.1	47.1	1.3E+5
21	124.995	4.297	64.5	65.1	64.1	64.4	64.4	47.1	8.8E+4
22	101.975	3.513	63.5	64.0	63.2	63.4	63.4	47.1	5.9E+4
23	83.228	2.866	62.6	63.1	62.4	62.3	62.5	47.1	3.9E+4
24	68.154	2.339	61.6	62.2	61.5	61.3	61.5	47.2	2.6E+4
25	55.761	1.917	60.0	60.5	59.9	59.7	59.8	47.2	1.8E+4
26	45.650	1.556	58.5	59.0	58.5	58.3	58.4	47.3	1.2E+4
27	36.730	1.256	57.0	57.4	57.0	56.8	56.9	47.3	7.6E+3
28	29.108	1.012	55.5	55.8	55.5	55.4	55.4	47.4	4.8E+3
29	23.655	.819	54.4	54.6	54.3	54.2	54.2	47.4	3.2E+3
30	19.732	.683	53.3	53.5	53.3	53.1	53.1	47.3	2.2E+3
31	16.537	.570	52.3	52.5	52.3	52.2	52.2	47.4	1.6E+3
32	13.681	.469	51.3	51.5	51.3	51.2	51.2	47.4	1.1E+3
33	10.633	.362	50.4	50.5	50.4	50.3	50.3	47.4	6.3E+2
34	8.523	.287	49.7	49.8	49.7	49.6	49.6	47.4	4.0E+2
35	6.367	.212	49.1	49.2	49.1	49.0	48.9	47.4	2.2E+2
36	3.647	.116	48.3	48.4	48.4	48.3	48.2	47.4	7.0E+1

The file 23SEP1988 contains 36 records.
A plain tube with a surface area of 0 .0060805 m^2, an outer diameter of 0 .01905 m and a correction ratio R/r of 1.5 was tested in freon with a saturation temperature of 47.84 C.

data A 4

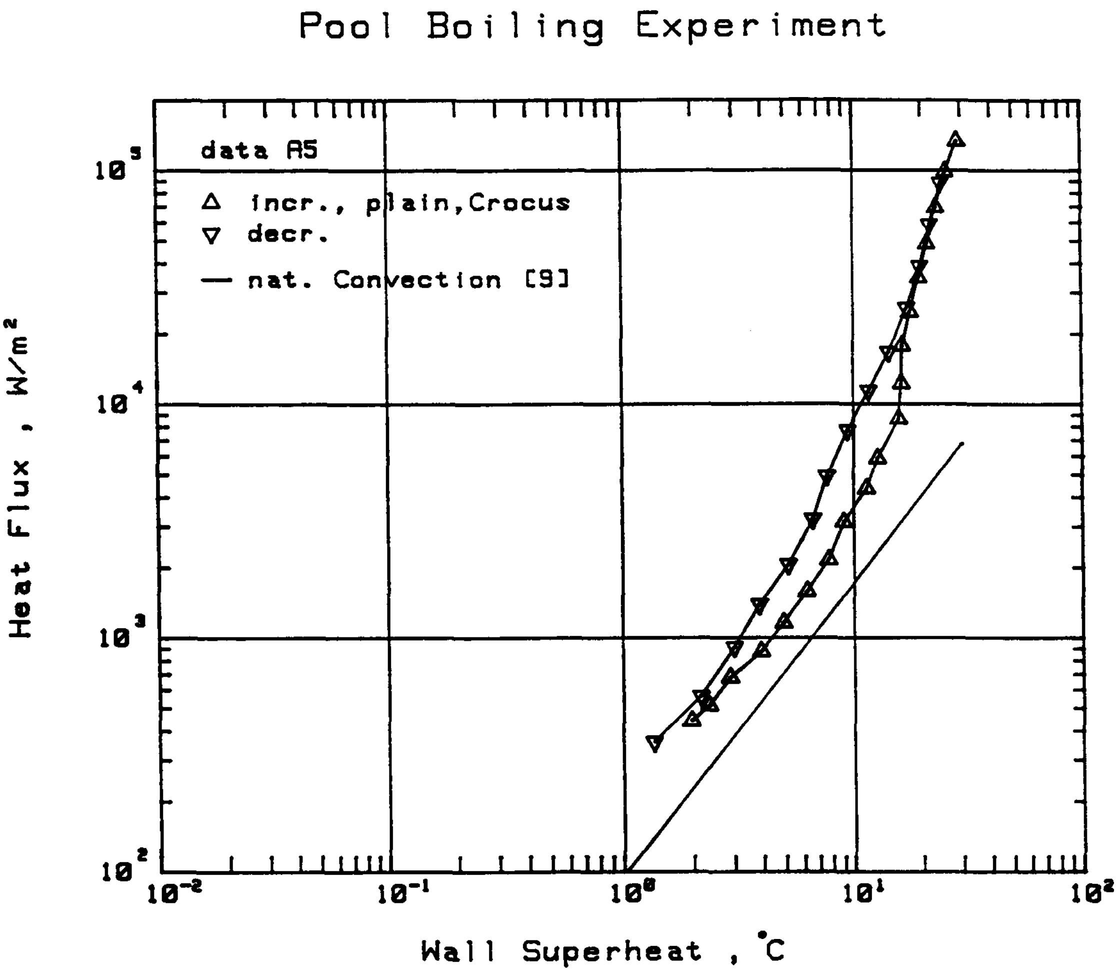


Pool Boiling Experiment
data A4
△ incr., plain,600
▽ decr.
— nat. Convection [9]
Heat Flux , W/m²
Wall Superheat , °C
10²
10³
10⁴
10⁵
10⁻²
10⁻¹
10⁰
10¹
10²

I	Uv(I)	Ia(I)	Tav(I)	T1(I)	T2(I)	T3(I)	T4(I)	Tpool(I)	q(I)
	[V]	[A]	[C]	[C]	[C]	[C]	[C]	[C]	[W/m^2]
1	.368	.023	48.1	48.1	48.1	48.1	48.0	47.9	1.4E+0
2	8.857	.302	50.2	50.4	50.3	50.0	50.1	47.9	4.4E+2
3	9.551	.326	50.6	50.8	50.7	50.4	50.5	47.9	5.1E+2
4	10.948	.376	51.1	51.4	51.3	50.9	51.0	47.8	6.8E+2
5	12.431	.429	52.2	52.5	52.4	51.8	52.1	47.9	8.8E+2
6	14.276	.495	53.2	53.6	53.4	52.6	53.2	47.9	1.2E+3
7	16.641	.579	54.4	54.9	54.8	53.7	54.5	47.9	1.6E+3
8	19.427	.677	56.0	56.6	56.4	55.0	56.0	47.9	2.2E+3
9	23.350	.816	57.3	57.6	57.4	57.2	57.0	47.8	3.1E+3
10	27.557	.964	59.7	60.0	59.8	59.7	59.4	47.8	4.4E+3
11	32.270	1.105	61.0	61.4	61.2	60.9	60.6	47.8	5.9E+3
12	39.108	1.346	64.1	64.5	64.3	64.0	63.7	47.7	8.7E+3
13	46.542	1.602	64.6	65.1	64.8	64.5	64.1	47.7	1.2E+4
14	55.959	1.933	64.8	65.4	64.9	64.6	64.2	47.6	1.8E+4
15	66.171	2.279	66.1	66.7	66.1	65.9	65.5	47.6	2.5E+4
16	78.269	2.700	67.8	68.5	67.7	67.5	67.3	47.5	3.5E+4
17	92.551	3.197	69.5	70.2	69.4	69.3	69.0	47.5	4.9E+4
18	110.904	3.815	71.5	72.2	71.3	71.4	70.9	47.4	7.0E+4
19	132.438	4.553	74.0	74.9	73.7	73.9	73.4	47.4	9.9E+4
20	153.880	5.277	77.2	78.6	76.9	76.8	76.5	47.3	1.3E+5
21	124.995	4.297	72.6	73.5	72.4	72.5	72.1	47.4	8.8E+4
22	101.876	3.498	70.1	70.9	70.0	69.9	69.7	47.4	5.9E+4
23	82.732	2.851	67.9	68.7	67.9	67.7	67.5	47.5	3.9E+4
24	67.361	2.324	65.5	66.2	65.5	65.2	65.0	47.6	2.6E+4
25	54.274	1.872	62.7	63.3	62.8	62.4	62.3	47.6	1.7E+4
26	44.857	1.541	60.0	60.5	60.1	59.8	59.6	47.6	1.1E+4
27	36.829	1.271	57.7	58.1	57.7	57.4	57.3	47.7	7.7E+3
28	29.268	1.022	55.9	56.2	56.0	55.7	55.6	47.7	4.9E+3
29	23.737	.826	54.8	55.2	54.9	54.7	54.6	47.7	3.2E+3
30	19.007	.659	53.4	53.7	53.5	53.3	53.2	47.7	2.1E+3
31	15.623	.541	52.1	52.3	52.2	52.0	51.9	47.7	1.4E+3
32	12.693	.438	51.3	51.4	51.3	51.2	51.1	47.7	9.1E+2
33	10.015	.341	50.4	50.6	50.5	50.3	50.3	47.8	5.6E+2
34	8.037	.271	49.6	49.8	49.7	49.4	49.5	47.8	3.6E+2

The file 22SEP1988 contains 34 records.
A plain tube with a surface area of 0 .0060805 m^2, an outer diameter of 0 .01905 m and a correction ratio R/r of 1.5 was tested in freon with a saturation temperature of 48.25 C.

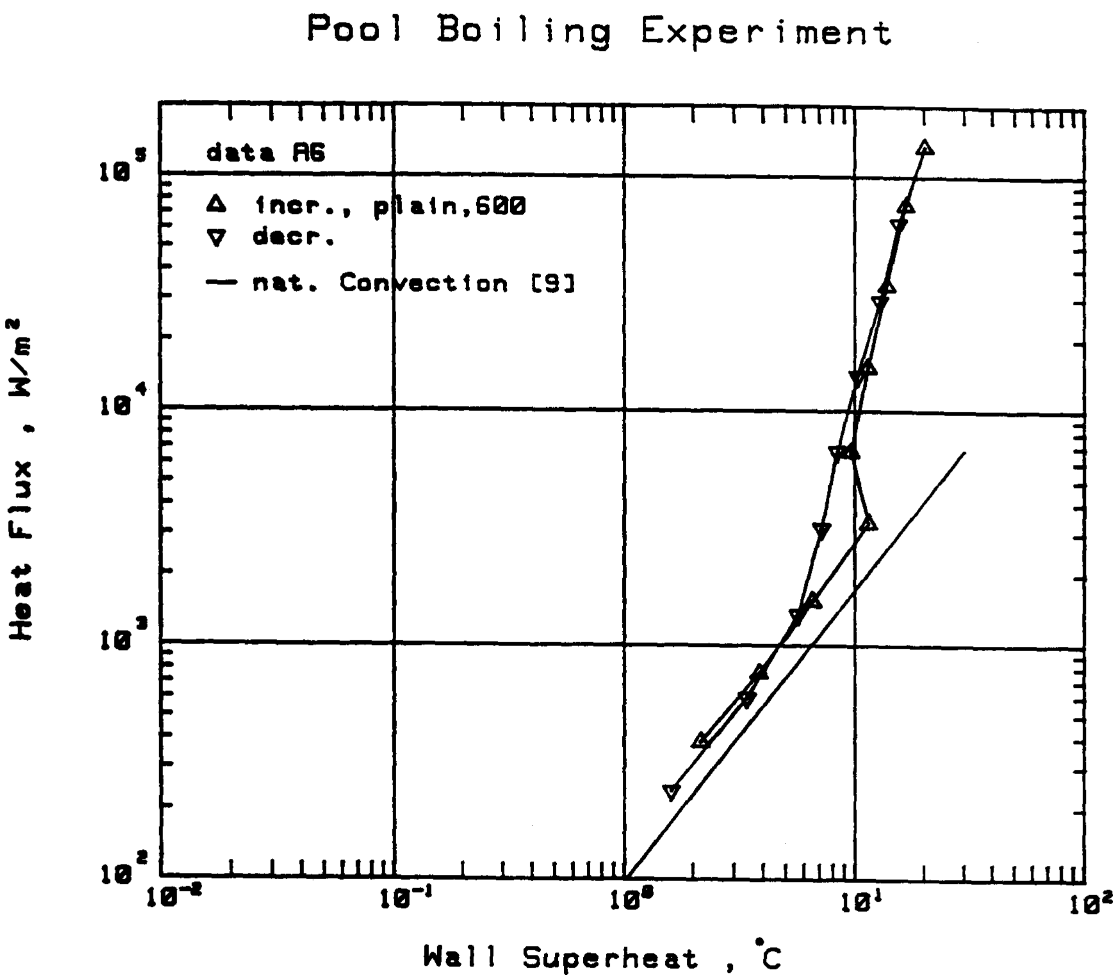
data A 5


Pool Boiling Experiment
data A5
△ incr., plain, Crocus
▽ decr.
— nat. Convection [9]
Heat Flux , W/m²
Wall Superheat , °C
10²
10³
10⁴
10⁵
10⁻²
10⁻¹
10⁰
10¹
10²

I	Uv(I)	Ia(I)	Tav(I)	T1(I)	T2(I)	T3(I)	T4(I)	Tpool(I)	q(I)
	[V]	[A]	[C]	[C]	[C]	[C]	[C]	[C]	[W/m^2]
1	.367	.023	48.5	48.6	48.6	48.5	48.4	48.1	1.4E+0
2	8.030	.292	50.7	50.8	50.7	50.7	50.6	48.2	3.9E+2
3	11.219	.414	52.4	52.5	52.4	52.4	52.3	48.2	7.6E+2
4	15.898	.591	55.1	55.2	55.1	55.1	55.0	48.2	1.5E+3
5	23.269	.871	60.0	60.1	60.1	60.0	60.0	48.1	3.3E+3
6	33.261	1.225	58.2	58.3	58.2	58.2	58.1	48.0	6.7E+3
7	50.111	1.857	60.0	60.1	59.9	60.1	59.9	48.0	1.5E+4
8	75.195	2.775	62.4	62.5	62.4	62.5	62.0	47.9	3.4E+4
9	112.293	4.101	65.3	65.4	65.7	65.6	64.4	47.8	7.6E+4
10	151.498	5.412	68.8	68.8	69.5	69.2	67.5	47.7	1.3E+5
11	103.463	3.709	64.1	64.2	64.4	64.3	63.4	47.8	6.3E+4
12	70.435	2.534	61.4	61.6	61.4	61.6	61.2	47.9	2.9E+4
13	48.822	1.752	58.8	58.9	58.8	58.9	58.7	48.0	1.4E+4
14	33.756	1.210	56.9	57.0	56.9	56.9	56.8	48.0	6.7E+3
15	22.928	.836	55.7	55.8	55.8	55.7	55.6	48.1	3.2E+3
16	15.075	.546	54.2	54.2	54.2	54.2	54.1	48.1	1.4E+3
17	10.081	.359	52.0	52.0	52.0	52.0	51.9	48.1	6.0E+2
18	6.444	.224	50.2	50.2	50.2	50.1	50.1	48.1	2.4E+2

The file 7OCT1988 contains 18 records.
A plain tube with a surface area of 0 .0060805 m^2, an outer diameter of 0 .01905 m and a correction ratio R/r of 1.5 was tested in freon with a saturation temperature of 48.54 C.

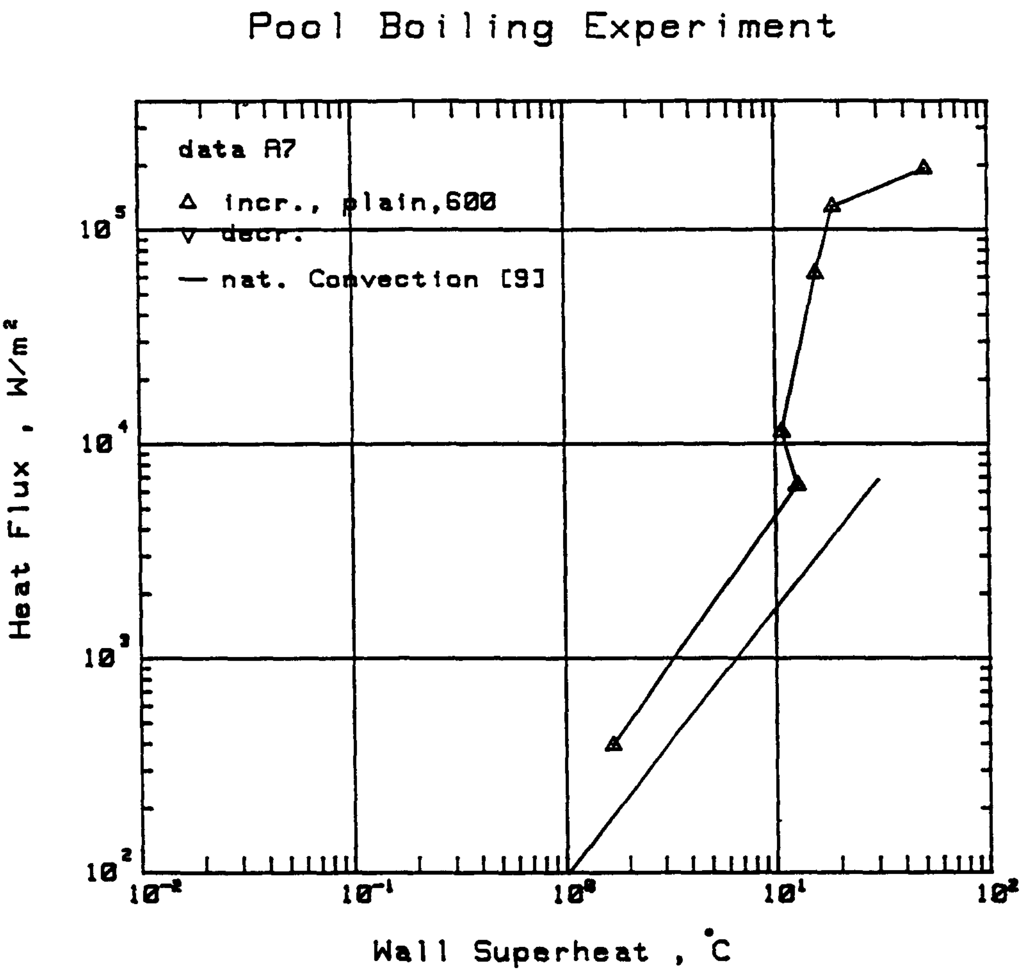
data A 6


Pool Boiling Experiment
data A6
incr., plain,600
decr.
nat. Convection [9]
Heat Flux , W/m²
Wall Superheat , °C
10²
10³
10⁴
10⁵
10⁻²
10⁻¹
10⁰
10¹
10²

I	Uv(I)	Ia(I)	Tav(I)	T1(I)	T2(I)	T3(I)	T4(I)	Tpool(I)	q(I)
	[V]	[A]	[C]	[C]	[C]	[C]	[C]	[C]	[W/m^2]
1	8.394	.284	50.0	50.1	50.1	50.0	49.9	47.9	3.9E+2
2	33.855	1.150	61.0	61.2	61.0	60.8	61.0	47.8	6.4E+3
3	44.857	1.541	59.1	59.4	59.1	58.8	59.0	47.7	1.1E+4
4	104.753	3.604	63.9	64.4	63.7	63.7	63.7	47.5	6.2E+4
5	150.703	5.171	67.0	67.9	66.5	66.9	66.9	47.5	1.3E+5
6	183.076	6.393	98.5	90.6	92.4	96.4	114.7	47.4	1.9E+5

The file 27SEP1988 contains 6 records.
A plain tube with a surface area of 0 .0060805 m^2, an outer diameter of 0 ..01905 m and a correction ratio R/r of 1.5 was tested in freon with a saturation temperature of 48.37 C.

data A 7

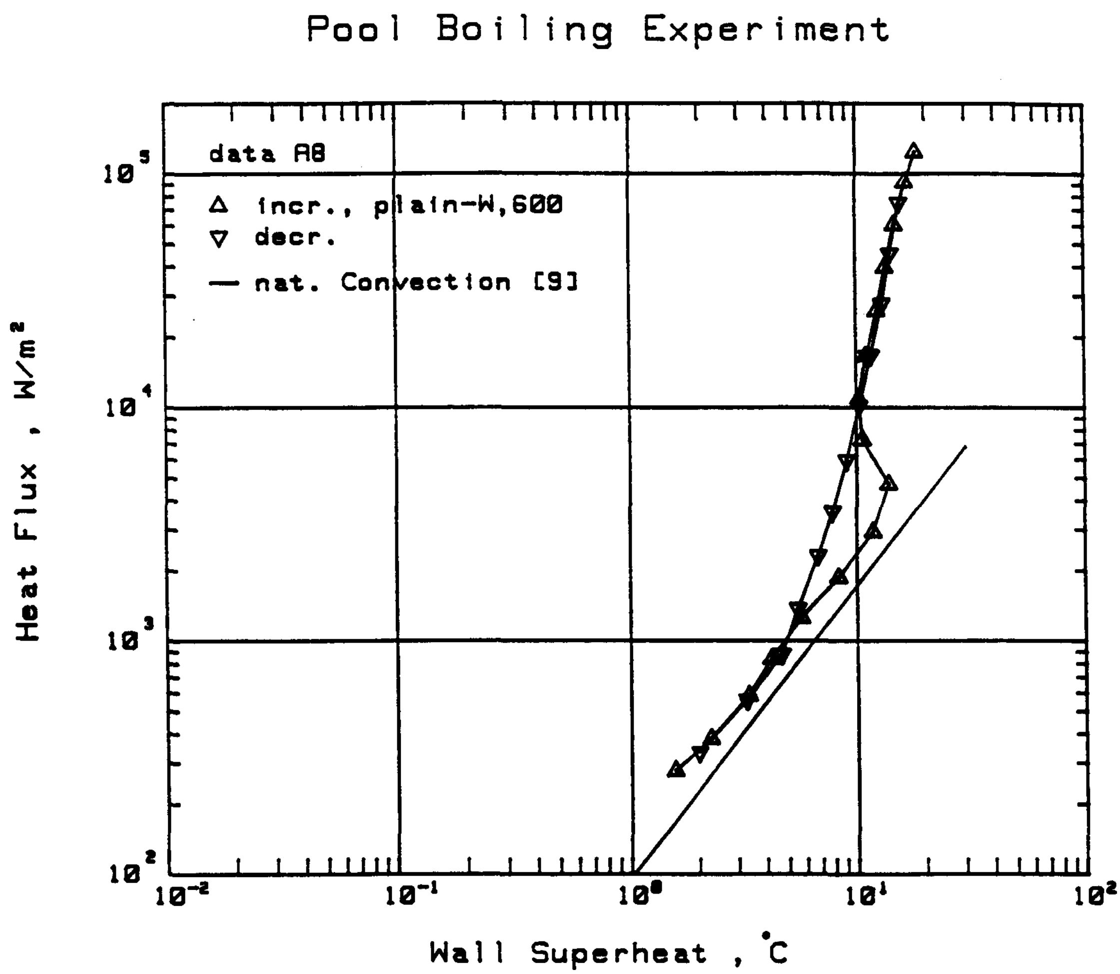


Pool Boiling Experiment
data A7
△ incr., plain,600
▽ decr.
— nat. Convection [9]
Heat Flux , W/m²
Wall Superheat , °C
10^5
10^4
10^3
10^2
10^-2
10^-1
10^0
10^1
10^2

I	Uv(I)	Ia(I)	Tav(I)	T1(I)	T2(I)	T3(I)	T4(I)	Tpool(I)	q(I)
	[V]	[A]	[C]	[C]	[C]	[C]	[C]	[C]	[W/m^2]
1	.367	.023	48.4	48.5	48.5	48.4	48.3	48.2	1.3E+0
2	7.163	.245	50.3	50.3	50.3	50.2	50.2	48.2	2.8E+2
3	8.336	.289	51.0	51.0	51.0	50.9	50.9	48.3	3.8E+2
4	10.286	.359	52.0	52.1	52.1	52.0	51.9	48.3	5.9E+2
5	12.300	.432	52.9	53.0	52.9	52.8	52.8	48.3	8.4E+2
6	14.992	.529	54.4	54.5	54.4	54.3	54.3	48.2	1.3E+3
7	18.235	.647	57.0	57.1	57.1	57.0	56.9	48.2	1.9E+3
8	22.858	.812	60.5	60.6	60.6	60.4	60.4	48.2	2.9E+3
9	28.889	1.028	62.5	62.6	62.6	62.4	62.3	48.2	4.7E+3
10	36.135	1.271	59.3	59.5	59.4	59.0	59.4	48.1	7.3E+3
11	44.361	1.556	59.0	59.1	58.8	58.7	59.2	48.1	1.1E+4
12	54.869	1.917	59.7	60.0	59.5	59.4	60.1	48.1	1.7E+4
13	54.770	1.917	59.9	60.2	59.6	59.5	60.3	48.1	1.7E+4
14	68.650	2.399	61.1	61.5	60.8	60.6	61.5	48.0	2.6E+4
15	85.311	2.956	62.2	62.7	62.0	61.6	62.4	48.0	4.0E+4
16	105.447	3.634	63.5	64.1	63.6	62.8	63.5	47.9	6.1E+4
17	130.751	4.463	65.2	66.2	65.3	64.3	65.1	47.9	9.2E+4
18	151.994	5.156	66.9	68.3	67.1	65.6	66.7	47.9	1.2E+5
19	118.148	4.010	64.3	65.0	64.3	63.5	64.2	48.0	7.5E+4
20	92.254	3.122	62.9	63.4	62.8	62.3	63.1	48.0	4.6E+4
21	71.823	2.444	61.7	62.1	61.5	61.2	62.1	48.1	2.8E+4
22	55.563	1.902	60.3	60.5	60.1	60.0	60.7	48.1	1.7E+4
23	43.271	1.481	59.0	59.1	58.9	58.9	59.2	48.1	1.0E+4
24	33.063	1.135	57.7	57.8	57.7	57.7	57.8	48.1	5.9E+3
25	25.498	.887	56.5	56.6	56.6	56.5	56.5	48.1	3.6E+3
26	20.529	.713	55.5	55.5	55.5	55.4	55.4	48.1	2.3E+3
27	15.835	.547	54.2	54.3	54.2	54.1	54.1	48.2	1.4E+3
28	12.686	.436	53.4	53.4	53.4	53.3	53.3	48.2	8.8E+2
29	10.187	.347	52.0	52.0	52.0	51.9	51.9	48.1	5.6E+2
30	7.909	.266	50.7	50.8	50.7	50.7	50.6	48.1	3.3E+2

The file 29SEP1988 contains 30 records.
A plain WIELAND tube with a surface area of 0 .0063199 m^2, an outer diameter of 0 .0198 m and a correction ratio R/r of 1.1 was tested in freon with a saturation temperature of 48.7 C.

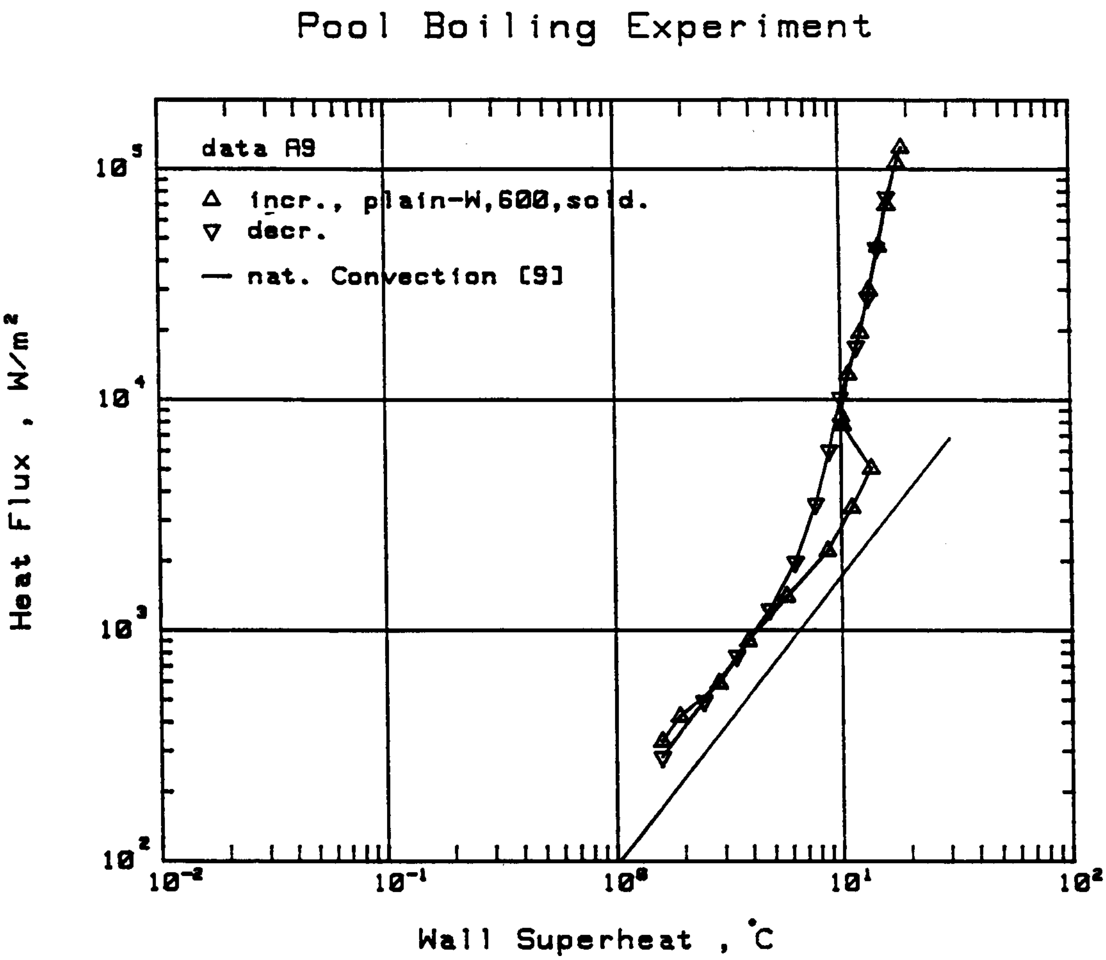
data A 8


Pool Boiling Experiment
data A8
incr., plain-W,600
decr.
nat. Convection [9]
Heat Flux , W/m²
Wall Superheat , °C
10²
10³
10⁴
10⁵
10⁻²
10⁻¹
10⁰
10¹
10²

I	Uv(I)	Ia(I)	Tav(I)	T1(I)	T2(I)	T3(I)	T4(I)	Tpool(I)	q(I)
	[V]	[A]	[C]	[C]	[C]	[C]	[C]	[C]	[W/m^2]
1	.367	.023	48.0	48.0	48.0	47.9	47.9	47.7	1.3E+0
2	7.845	.266	49.8	49.9	49.9	49.8	49.7	47.7	3.3E+2
3	8.874	.302	50.2	50.2	50.2	50.1	50.1	47.7	4.2E+2
4	10.416	.358	51.1	51.1	51.1	51.1	51.0	47.7	5.9E+2
5	12.807	.444	52.1	52.1	52.1	52.1	52.0	47.7	9.0E+2
6	15.928	.555	53.9	53.9	54.0	53.9	53.9	47.8	1.4E+3
7	19.994	.699	56.9	56.9	57.0	57.0	56.9	47.8	2.2E+3
8	24.767	.869	59.4	59.3	59.5	59.5	59.4	47.8	3.4E+3
9	30.103	1.059	61.9	61.8	62.0	61.9	61.8	47.7	5.0E+3
10	37.820	1.301	58.5	58.5	58.5	58.4	58.4	47.7	7.8E+3
11	39.505	1.361	58.3	58.2	58.4	58.3	58.3	47.7	8.5E+3
12	48.524	1.677	59.1	59.0	59.1	59.1	59.2	47.6	1.3E+4
13	59.826	2.068	60.6	60.4	60.7	60.6	60.7	47.7	2.0E+4
14	74.005	2.550	61.8	61.6	62.0	61.8	61.8	47.6	3.0E+4
15	92.254	3.167	63.2	63.1	63.6	63.2	62.9	47.6	4.6E+4
16	113.682	3.905	64.6	64.6	65.1	64.5	64.1	47.5	7.0E+4
17	140.875	4.809	66.4	66.3	67.1	66.4	65.6	47.4	1.1E+5
18	151.795	5.171	67.2	67.1	67.9	67.3	66.4	47.4	1.2E+5
19	118.247	4.041	64.6	64.5	65.1	64.6	64.1	47.4	7.6E+4
20	91.758	3.137	62.9	62.8	63.3	62.9	62.7	47.5	4.6E+4
21	71.427	2.444	61.6	61.4	61.8	61.6	61.7	47.6	2.8E+4
22	55.959	1.917	60.0	59.9	60.1	60.0	60.2	47.6	1.7E+4
23	43.469	1.481	58.2	58.0	58.3	58.2	58.3	47.7	1.0E+4
24	33.459	1.135	57.1	57.0	57.2	57.1	57.1	47.8	6.0E+3
25	25.331	.880	55.9	55.9	56.0	55.9	55.9	47.7	3.5E+3
26	18.973	.657	54.5	54.4	54.6	54.5	54.4	47.7	2.0E+3
27	15.023	.517	53.0	53.0	53.1	53.0	53.0	47.7	1.2E+3
28	11.931	.411	51.6	51.7	51.7	51.6	51.6	47.7	7.8E+2
29	9.579	.326	50.7	50.7	50.7	50.7	50.6	47.8	4.9E+2
30	7.289	.245	49.8	49.9	49.9	49.8	49.7	47.8	2.8E+2

The file 3OCT1988 contains 30 records.
A plain WIELAND tube with a surface area of 0 .0063199 m^2, an outer diameter of 0 .0198 m and a correction ratio R/r of 1.1 was tested in freon with a saturation temperature of 48.25 C.

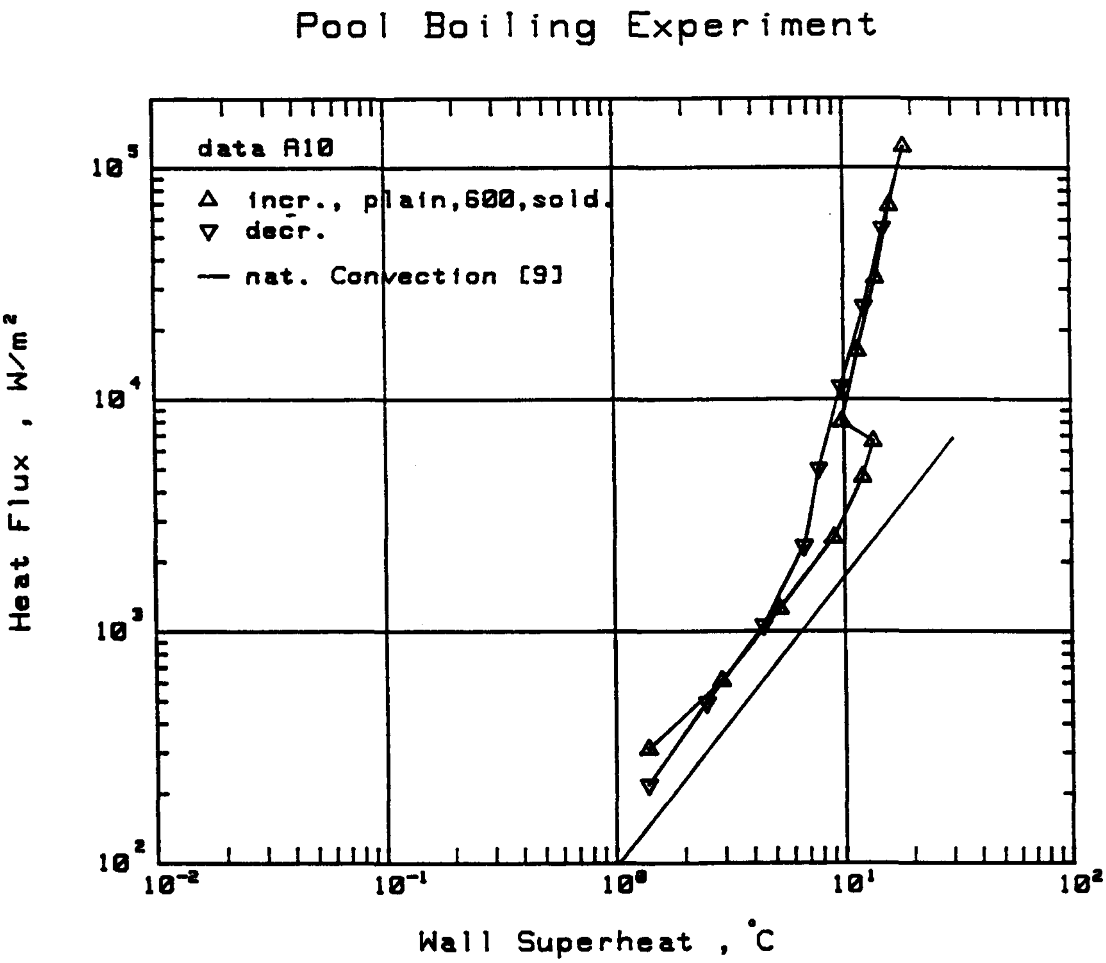
data A 9


Pool Boiling Experiment
data A9
△ incr., plain-W,600,sold.
▽ decr.
— nat. Convection [9]
Heat Flux , W/m²
Wall Superheat , °C
10²
10³
10⁴
10⁵
10⁻²
10⁻¹
10⁰
10¹
10²

I	Uv(I)	Ia(I)	Tav(I)	T1(I)	T2(I)	T3(I)	T4(I)	Tpool(I)	q(I)
	[V]	[A]	[C]	[C]	[C]	[C]	[C]	[C]	[W/m^2]
1	.368	.023	48.1	48.2	48.1	48.0	48.0	47.9	1.3E+0
2	7.631	.257	49.6	49.7	49.7	49.6	49.5	47.8	3.1E+2
3	10.638	.364	51.2	51.2	51.2	51.2	51.1	47.7	6.1E+2
4	15.096	.523	53.5	53.4	53.6	53.5	53.4	47.8	1.3E+3
5	21.408	.746	57.2	57.1	57.4	57.2	57.2	47.8	2.5E+3
6	28.917	1.010	60.3	59.9	60.5	60.4	60.3	47.7	4.6E+3
7	34.846	1.195	61.7	61.2	61.9	61.9	61.7	47.7	6.6E+3
8	38.414	1.316	58.1	57.9	58.3	58.1	57.9	47.8	8.0E+3
9	54.571	1.872	59.8	59.5	60.1	59.9	59.5	47.7	1.6E+4
10	78.368	2.685	62.1	61.7	62.5	62.3	61.9	47.6	3.3E+4
11	112.492	3.845	64.2	63.7	64.5	64.6	64.3	47.5	6.8E+4
12	151.299	5.156	66.8	66.0	67.0	67.3	66.8	47.4	1.2E+5
13	100.685	3.438	63.1	62.7	63.4	63.4	63.0	47.5	5.5E+4
14	68.055	2.339	60.6	60.2	60.9	60.7	60.4	47.6	2.5E+4
15	45.749	1.571	57.9	57.8	58.2	58.0	57.7	47.7	1.1E+4
16	30.387	1.045	56.0	55.9	56.2	56.0	55.9	47.8	5.0E+3
17	20.597	.717	54.9	54.9	55.0	54.9	54.8	47.7	2.3E+3
18	13.942	.483	52.7	52.7	52.8	52.7	52.6	47.8	1.1E+3
19	9.549	.326	50.8	50.8	50.8	50.7	50.7	47.8	4.9E+2
20	6.410	.215	49.6	49.7	49.7	49.6	49.6	47.8	2.2E+2

The file 5OCT1988 contains 20 records.
A plain WIELAND tube with a surface area of 0 .0063199 m^2, an outer diameter of 0 .0198 m and a correction ratio R/r of 1.1 was tested in freon with a saturation temperature of 48.26 C.

data A 10

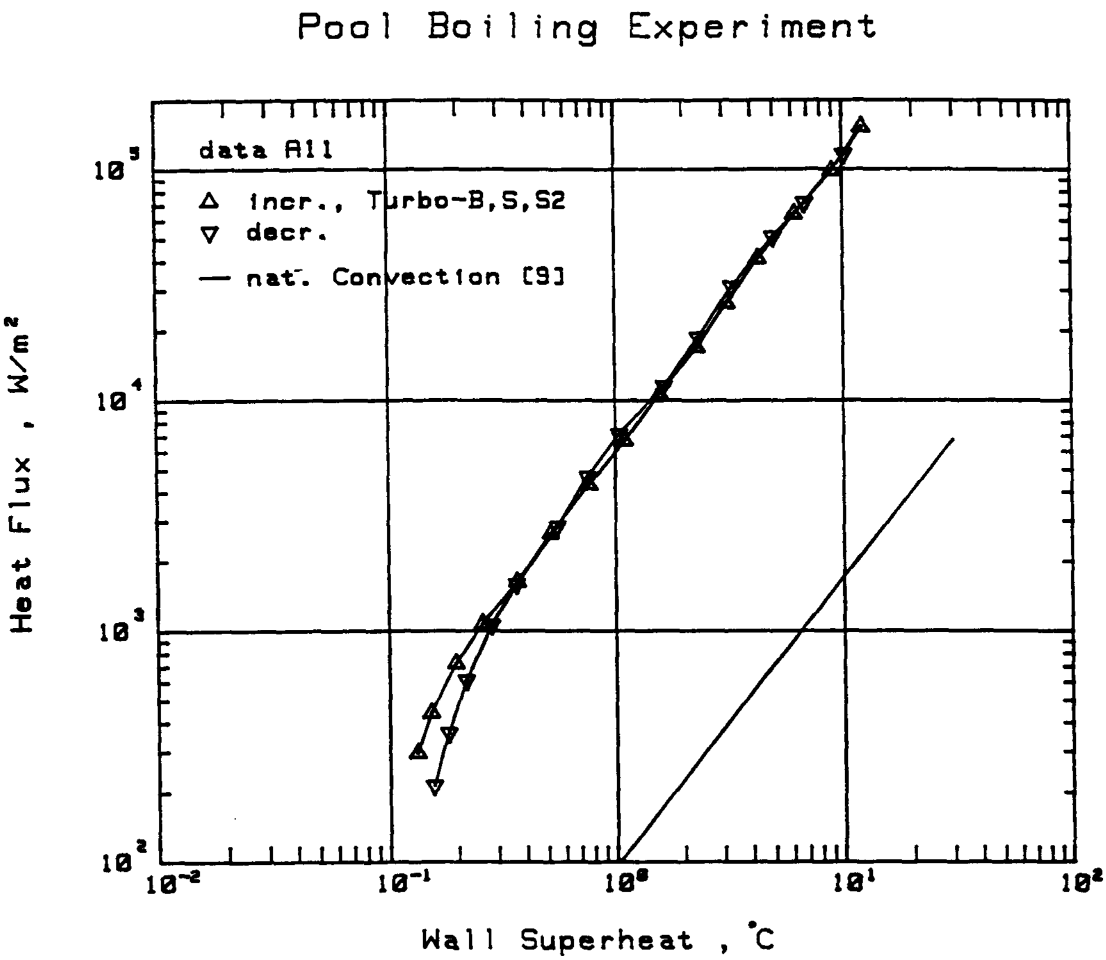


Pool Boiling Experiment
data A10
△ incr., plain,600,sold.
▽ decr.
— nat. Convection [9]
Heat Flux , W/m²
Wall Superheat , °C
10²
10³
10⁴
10⁵
10⁻²
10⁻¹
10⁰
10¹
10²

I	Uv(I)	Ia(I)	Tav(I)	T1(I)	T2(I)	T3(I)	T4(I)	Tpool(I)	q(I)
	[V]	[A]	[C]	[C]	[C]	[C]	[C]	[C]	[W/m^2]
1	.368	.023	47.9	48.0	47.9	47.9	47.8	47.7	1.4E+0
2	7.251	.250	48.1	48.2	48.2	48.1	48.0	47.6	3.0E+2
3	8.803	.307	48.2	48.2	48.2	48.1	48.1	47.6	4.4E+2
4	11.210	.394	48.2	48.3	48.2	48.2	48.1	47.5	7.2E+2
5	13.635	.481	48.3	48.3	48.3	48.3	48.2	47.5	1.1E+3
6	16.805	.595	48.4	48.4	48.4	48.4	48.3	47.4	1.6E+3
7	21.309	.758	48.5	48.5	48.6	48.5	48.4	47.4	2.6E+3
8	27.222	.970	48.8	48.7	48.8	48.8	48.7	47.4	4.3E+3
9	34.252	1.195	49.1	49.1	49.2	49.1	49.0	47.4	6.7E+3
10	43.271	1.511	49.6	49.6	49.7	49.6	49.5	47.5	1.1E+4
11	54.671	1.902	50.3	50.3	50.4	50.3	50.3	47.5	1.7E+4
12	68.154	2.369	51.1	51.2	51.2	51.0	51.1	47.5	2.6E+4
13	85.410	2.941	52.3	52.4	52.3	52.2	52.4	47.4	4.1E+4
14	106.936	3.649	54.2	54.3	54.2	54.0	54.2	47.4	6.4E+4
15	133.133	4.523	57.0	57.2	57.3	56.7	56.9	47.3	9.9E+4
16	163.909	5.669	60.2	60.4	60.5	59.7	60.3	47.2	1.5E+5
17	143.655	4.915	58.2	58.4	58.5	57.7	58.2	47.2	1.2E+5
18	112.988	3.860	54.9	55.1	55.1	54.5	54.8	47.4	7.2E+4
19	95.329	3.257	53.0	53.2	53.2	52.7	52.9	47.4	5.1E+4
20	74.203	2.550	51.3	51.3	51.4	51.2	51.3	47.5	3.1E+4
21	57.645	1.978	50.3	50.3	50.4	50.3	50.3	47.5	1.9E+4
22	45.055	1.556	49.6	49.6	49.7	49.6	49.6	47.5	1.2E+4
23	35.441	1.225	49.0	49.0	49.1	49.0	49.0	47.4	7.1E+3
24	28.412	1.001	48.8	48.8	48.8	48.8	48.7	47.5	4.7E+3
25	22.185	.780	48.6	48.6	48.6	48.6	48.5	47.5	2.8E+3
26	16.670	.583	48.4	48.4	48.4	48.4	48.3	47.5	1.6E+3
27	13.607	.474	48.3	48.3	48.3	48.3	48.2	47.5	1.1E+3
28	10.388	.358	48.2	48.3	48.3	48.2	48.1	47.6	6.1E+2
29	8.030	.274	48.2	48.2	48.2	48.2	48.1	47.6	3.6E+2
30	6.238	.209	48.2	48.2	48.2	48.1	48.1	47.6	2.1E+2

The file 25OCT2988 contains 30 records.
A Turbo-B, S tube with a surface area of 0 .0060972 m^2, an outer diameter of 0 .01914 m and a correction ratio R/r of 1.42 was tested in freon with a saturation temperature of 48 C.

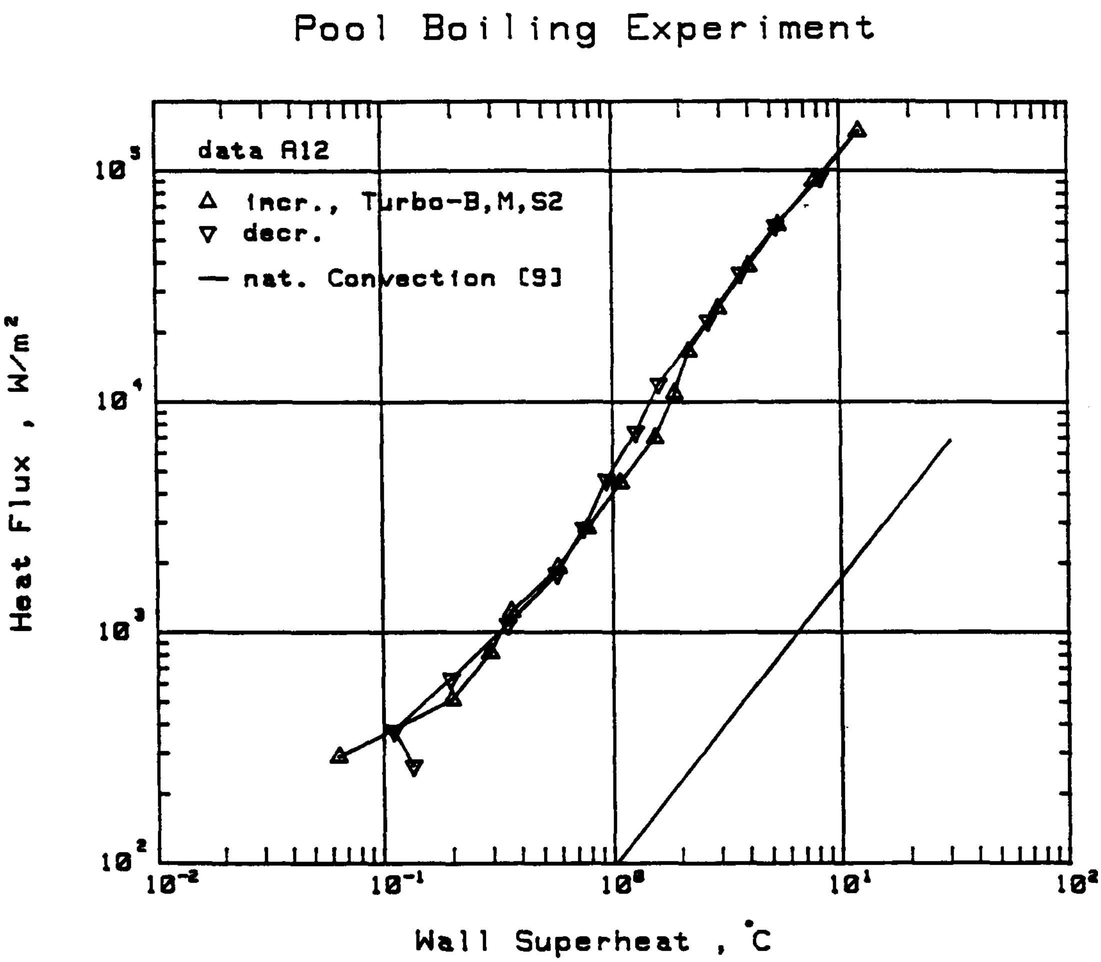
data A 11


Pool Boiling Experiment
data A11
△ incr., Turbo-B,S,S2
▽ decr.
— nat. Convection [9]
Heat Flux , W/m²
Wall Superheat , °C
10²
10³
10⁴
10⁵
10⁻²
10⁻¹
10⁰
10¹
10²

I	Uv(I)	Ia(I)	Tav(I)	T1(I)	T2(I)	T3(I)	T4(I)	Tpool(I)	q(I)
	[V]	[A]	[C]	[C]	[C]	[C]	[C]	[C]	[W/m^2]
1	.368	.023	47.8	47.9	47.9	47.8	47.7	47.6	1.4E+0
2	7.258	.244	48.0	48.1	48.0	48.0	47.9	47.5	2.9E+2
3	9.587	.326	48.1	48.2	48.2	48.1	48.0	47.5	5.1E+2
4	12.052	.414	48.2	48.3	48.3	48.2	48.1	47.5	8.2E+2
5	14.747	.510	48.3	48.3	48.3	48.3	48.2	47.4	1.2E+3
6	18.341	.636	48.5	48.5	48.6	48.5	48.4	47.3	1.9E+3
7	22.339	.776	48.7	48.8	48.8	48.7	48.6	47.4	2.8E+3
8	27.979	.976	49.0	49.1	49.1	49.0	48.9	47.4	4.5E+3
9	35.243	1.210	49.5	49.5	49.5	49.5	49.4	47.4	7.0E+3
10	44.064	1.511	49.8	49.9	49.8	49.8	49.7	47.4	1.1E+4
11	54.571	1.857	50.1	50.2	50.1	50.1	50.0	47.4	1.7E+4
12	67.559	2.294	50.9	51.1	50.8	50.8	50.8	47.3	2.5E+4
13	83.426	2.821	51.9	52.3	51.9	51.8	51.8	47.3	3.9E+4
14	102.670	3.468	53.4	53.9	53.2	53.2	53.1	47.3	5.8E+4
15	126.980	4.327	55.7	56.6	55.7	55.3	55.3	47.2	9.0E+4
16	156.859	5.744	60.1	61.4	60.2	59.4	59.4	47.1	1.5E+5
17	127.178	4.463	56.3	57.2	56.2	55.8	55.8	47.2	9.3E+4
18	100.685	3.513	53.2	53.8	53.2	53.0	52.9	47.2	5.8E+4
19	79.360	2.760	51.6	52.0	51.6	51.5	51.4	47.3	3.6E+4
20	62.701	2.188	50.6	50.8	50.6	50.5	50.4	47.4	2.2E+4
21	45.551	1.602	49.5	49.6	49.6	49.6	49.4	47.4	1.2E+4
22	36.036	1.256	49.2	49.3	49.3	49.2	49.1	47.4	7.4E+3
23	28.077	1.000	48.9	48.9	48.9	48.9	48.8	47.5	4.6E+3
24	22.101	.785	48.7	48.7	48.7	48.7	48.6	47.4	2.8E+3
25	17.618	.623	48.5	48.5	48.6	48.5	48.4	47.5	1.8E+3
26	13.719	.481	48.3	48.3	48.3	48.3	48.2	47.4	1.1E+3
27	10.515	.367	48.1	48.2	48.2	48.1	48.0	47.4	6.3E+2
28	8.150	.281	48.1	48.1	48.1	48.1	48.0	47.4	3.8E+2
29	6.891	.235	48.1	48.1	48.1	48.1	48.0	47.5	2.6E+2

The file 25OCT1988 contains 29 records.
A Turbo-B, M tube with a surface area of 0 .0061092 m^2, an outer diameter of 0 .01914 m and a correction ratio R/r of 1.41 was tested in freon with a saturation temperature of 47.94 C.

data A 12

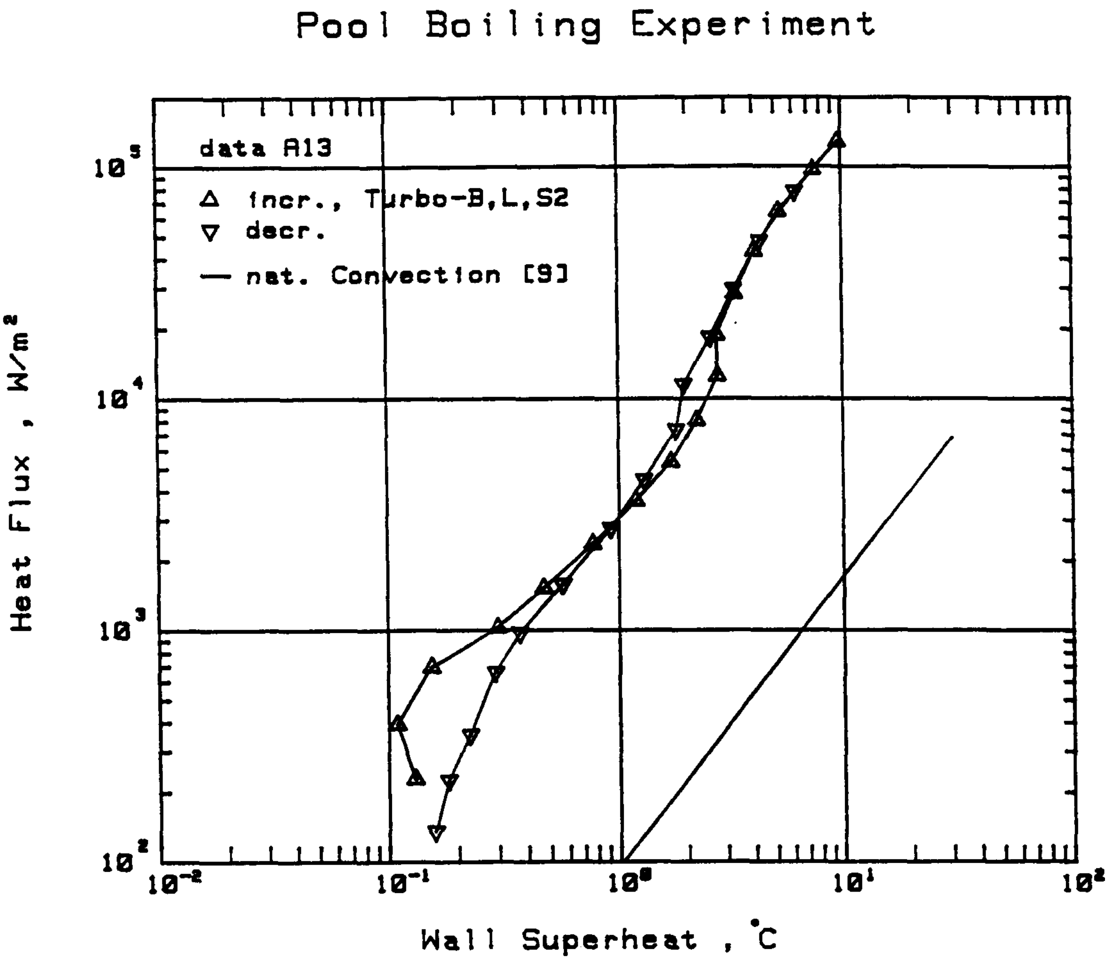


Pool Boiling Experiment
data A12
△ incr., Turbo-B,M,S2
▽ decr.
— nat. Convection [9]
Heat Flux , W/m²
Wall Superheat , °C
10²
10³
10⁴
10⁵
10⁻²
10⁻¹
10⁰
10¹
10²

I	Uv(I)	Ia(I)	Tav(I)	T1(I)	T2(I)	T3(I)	T4(I)	Tpool(I)	q(I)
	[V]	[A]	[C]	[C]	[C]	[C]	[C]	[C]	[W/m^2]
1	.367	.023	48.0	48.1	48.1	48.0	47.9	47.8	1.4E+0
2	6.474	.217	48.2	48.3	48.3	48.2	48.1	47.7	2.3E+2
3	8.437	.286	48.2	48.3	48.2	48.2	48.1	47.6	3.9E+2
4	11.159	.382	48.3	48.3	48.3	48.3	48.2	47.6	7.0E+2
5	13.531	.466	48.4	48.4	48.4	48.4	48.3	47.6	1.0E+3
6	16.429	.568	48.6	48.6	48.6	48.6	48.5	47.6	1.5E+3
7	20.432	.710	48.9	48.9	49.0	48.9	48.8	47.6	2.4E+3
8	25.321	.881	49.3	49.3	49.3	49.3	49.2	47.6	3.6E+3
9	30.882	1.060	49.8	49.8	49.9	49.8	49.8	47.6	5.3E+3
10	38.018	1.301	50.4	50.3	50.4	50.4	50.4	47.6	8.1E+3
11	47.434	1.617	50.9	50.9	51.0	50.9	50.9	47.6	1.3E+4
12	58.240	1.978	50.9	50.8	50.8	50.9	51.0	47.5	1.9E+4
13	71.427	2.429	51.5	51.4	51.4	51.5	51.7	47.5	2.8E+4
14	88.385	2.986	52.3	52.2	52.2	52.3	52.5	47.5	4.3E+4
15	108.325	3.619	53.6	53.6	53.4	53.6	53.7	47.5	6.4E+4
16	132.835	4.478	56.1	56.2	55.8	56.1	56.3	47.5	9.7E+4
17	150.405	5.231	58.6	58.7	58.2	58.6	58.8	47.5	1.3E+5
18	118.644	4.025	54.6	54.7	54.4	54.6	54.8	47.4	7.8E+4
19	92.452	3.152	52.5	52.5	52.4	52.5	52.7	47.5	4.8E+4
20	72.815	2.489	51.5	51.4	51.4	51.5	51.7	47.5	3.0E+4
21	57.248	1.963	50.7	50.6	50.7	50.7	50.8	47.5	1.8E+4
22	45.253	1.556	50.1	50.0	50.1	50.1	50.1	47.6	1.1E+4
23	36.234	1.241	49.9	49.9	49.9	49.9	49.9	47.6	7.3E+3
24	27.976	.980	49.4	49.4	49.4	49.4	49.3	47.6	4.5E+3
25	22.022	.770	49.0	49.0	49.1	49.0	49.0	47.6	2.8E+3
26	16.685	.580	48.7	48.7	48.7	48.7	48.6	47.7	1.6E+3
27	13.122	.454	48.5	48.5	48.5	48.5	48.4	47.7	9.7E+2
28	10.826	.373	48.4	48.4	48.4	48.4	48.3	47.7	6.6E+2
29	8.005	.271	48.3	48.4	48.4	48.3	48.2	47.7	3.5E+2
30	6.431	.215	48.3	48.3	48.3	48.3	48.2	47.7	2.3E+2
31	5.026	.166	48.3	48.3	48.3	48.3	48.2	47.8	1.4E+2

The file 28OCT1988 contains 31 records.
A Turbo-B, L tube with a surface area of 0 .0061288 m^2, an outer diameter of 0 .01916 m and a correction ratio R/r of 1.45 was tested in freon with a saturation temperature of 48.09 C.

data A 13

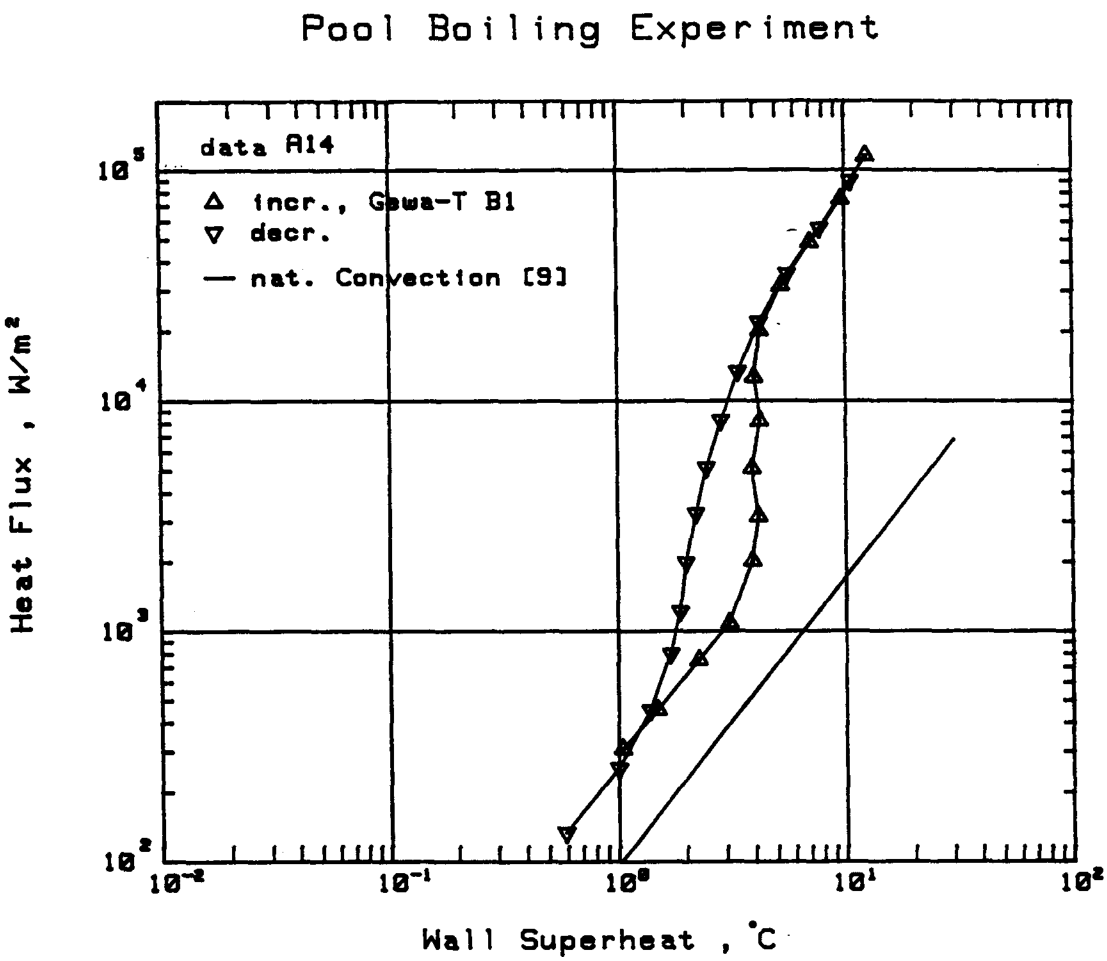


Pool Boiling Experiment
data A13
△ incr., Turbo-B,L,S2
▽ decr.
— nat. Convection [9]
Heat Flux , W/m²
Wall Superheat , °C
10²
10³
10⁴
10⁵
10⁻²
10⁻¹
10⁰
10¹
10²

I	Uv(I) [V]	Ia(I) [A]	Tav(I) [C]	Ti(I) [C]	T2(I) [C]	T3(I) [C]	T4(I) [C]	Tpool(I) [C]	q(I) [W/m^2]
1	.424	.023	47.6	47.7	47.7	47.6	47.5	47.4	1.6E+0
2	7.314	.250	48.7	48.8	48.8	48.7	48.6	47.3	3.1E+2
3	8.868	.305	49.2	49.2	49.2	49.2	49.1	47.3	4.6E+2
4	11.338	.394	49.9	50.0	50.0	49.9	49.9	47.4	7.5E+2
5	13.590	.475	50.8	50.9	50.8	50.7	50.7	47.4	1.1E+3
6	18.475	.650	51.6	51.6	51.6	51.6	51.5	47.3	2.0E+3
7	23.080	.813	51.8	51.9	51.9	51.8	51.8	47.3	3.2E+3
8	29.287	1.035	51.6	51.6	51.6	51.6	51.5	47.2	5.1E+3
9	37.423	1.301	51.9	51.9	52.0	52.0	51.9	47.2	8.2E+3
10	46.542	1.617	51.7	51.7	51.8	51.7	51.6	47.2	1.3E+4
11	58.735	2.038	51.9	52.0	52.0	51.9	51.8	47.2	2.0E+4
12	73.410	2.550	52.9	53.2	52.9	52.8	52.8	47.2	3.2E+4
13	91.361	3.152	54.8	55.2	54.6	54.5	54.7	47.1	4.9E+4
14	113.385	3.920	57.4	57.9	57.1	57.0	57.4	47.1	7.5E+4
15	140.578	4.854	60.1	60.9	59.6	59.4	60.5	47.0	1.2E+5
16	124.102	4.282	58.3	59.1	58.0	57.8	58.6	47.0	9.0E+4
17	97.809	3.393	55.5	56.0	55.2	55.1	55.5	47.1	5.6E+4
18	77.872	2.700	53.3	53.6	53.2	53.1	53.2	47.1	3.5E+4
19	61.115	2.128	51.9	52.1	51.9	51.8	51.8	47.2	2.2E+4
20	47.731	1.662	51.1	51.2	51.1	51.0	51.0	47.2	1.3E+4
21	37.423	1.301	50.6	50.6	50.6	50.6	50.5	47.3	8.2E+3
22	29.326	1.036	50.1	50.2	50.2	50.1	50.0	47.3	5.1E+3
23	23.392	.824	49.9	49.9	49.9	49.9	49.8	47.3	3.3E+3
24	18.293	.642	49.7	49.7	49.7	49.7	49.6	47.3	2.0E+3
25	14.373	.502	49.6	49.6	49.6	49.5	49.5	47.4	1.2E+3
26	11.669	.406	49.4	49.4	49.4	49.4	49.3	47.4	8.0E+2
27	8.833	.304	49.1	49.1	49.1	49.0	49.0	47.3	4.5E+2
28	6.657	.226	48.7	48.8	48.7	48.6	48.6	47.3	2.5E+2
29	4.874	.163	48.3	48.4	48.3	48.3	48.1	47.3	1.3E+2

The file 2NOV2988 contains 29 records.
A Gewa-T, B1 tube with a surface area of 0 .005929 m^2, an outer diameter of 0 .01888 m and a correction ratio R/r of 1.36 was tested in freon with a saturation temperature of 47.68 C.

data A 14



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