P.A. HILTON LTD.

EXPERIMENTAL

OPERATING

AND

MAINTENANCE MANUAL

BOILING HEAT TRANSFER UNIT

H654

H654M/E/1/365

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POLICY STATEMENT

After Sales Service

We, P.A. Hilton Ltd., attach considerable importance in being able to retain the confidence and goodwill of our clients in offering an effective after sales service. Every effort is made to answer clients correspondence promptly and to provide a rapid follow up of spares and replacement parts by maintaining comprehensive stocks of components usually available ex-stock.

Should our clients encounter any difficulty in operating or maintaining a Hilton product we would ask that as a first step they contact the Hilton representative in their country or, in the absence of a local representative, write direct to P.A. Hilton Ltd.

In the extreme case a problem may arise in the operation of equipment which could seriously disrupt a teaching or research schedule. In such circumstances rapid advice from the manufacturers is desirable and we wish our clients to know that Hiltons' will accept from them a transfer charge telephone call from anywhere in the world.

We ask our clients to treat this service as an emergency service only and to use it sparingly and wisely. Please do be aware of the time differences that may exist and, before making a telephone call, make notes of the problem you wish to describe. English is a preferred language. Our telephone number is "Romsey (01794) 388382" and the telephone is normally manned between 0800 and 1700 hrs GMT every day. Advance notice of an impending telephone call by Fax would be appreciated.

Each product manufactured by P.A. Hilton Ltd., is tested under operating conditions in our permanent installations before despatch. Visitors to Horsebridge Mill are encouraged to operate and evaluate our equipment with initial guidance from a Hilton engineer.

CE

EDUCATION AND TRAINING EQUIPMENT

In accordance with the Electromagnetic Compatibility (Amendment) Regulations 1994 (SI No 3080) and EMC Directive 89/336/EEC and CE Marking Directive 93/68/EEC.

This apparatus complies with the above directives under the following clause:

> The use of the apparatus outside the classroom, laboratory, study area or similar such place invalidates conformity with the protection requirements of the Electromagnetic Compatibility Directive (89/336/EEC) and could lead to prosecution.

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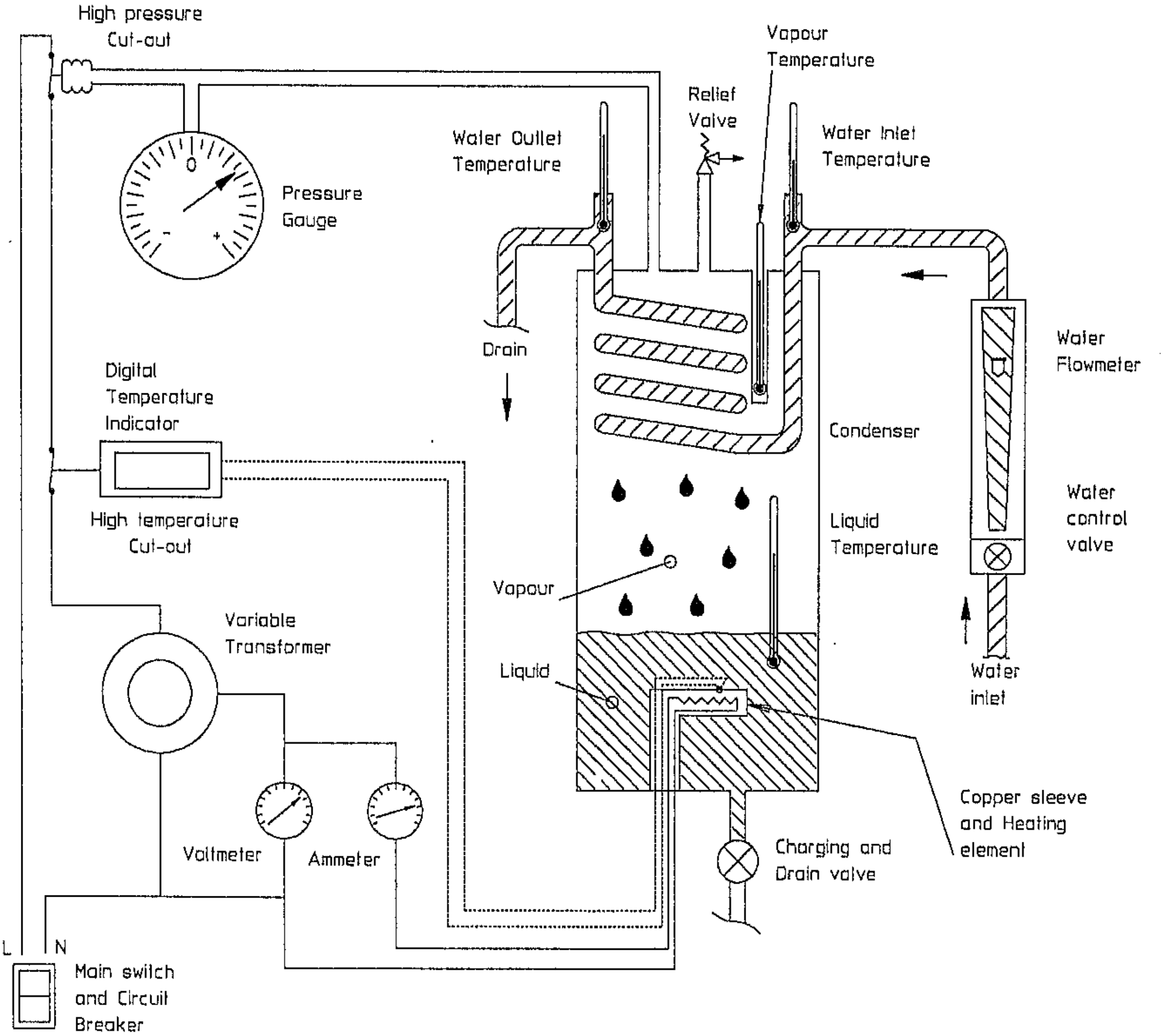
H654 Boiling Heat Transfer Unit



SYMBOLS AND UNITS

Symbol	Quantity	Fundamental Unit
A	Area	m^2
I	Current	Amps
ρ	Density	$kg\ m^{-3}$
ϕ	Heat Flux	$W\ m^{-2}$
$\dot{Q}$	Heat Transfer Rate	W
E	Potential Difference	Volts
$\dot{m}_w$	Mass Flow Rate (Water)	$kg\ s^{-1}$
l_n	Natural log	-
p	Pressure (absolute)	$N\ m^{-2}$*
C_p	Specific Heat Capacity $\frac{\Delta h}{\Delta t}$	$J\ kg^{-1}\ K^{-1}$
h	Specific Enthalpy	$J\ kg^{-1}$
h	Surface Heat Transfer Coefficient	$W\ m^{-2}\ K^{-1}$
Δt or θ	Temperature Difference	K
t	Temperature (Empirical)	°C
U	Overall Heat Transfer Coefficient	$W\ m^{-2}\ K^{-1}$

Presentation of Numerical Data

In this manual, numerical quantities obtained during experiments, etc., are expressed in a non-dimensional manner. That is, the physical quantity involved has been divided by the units in which it has been measured.

As an example:

Pressure	$\frac{p}{10^3\ Nm^{-2}}$	150

This indicates that $\frac{p}{10^3\ Nm^{-2}} = 150$

or $p = 150 \times 10^3\ N\ m^{-2}$

alternatively $p = 150\ kN\ m^{-2}$

*Absolute Pressure = Gauge Pressure + Atmospheric Pressure

Suffixes

f	A property of Saturated Liquid
g	A property of Saturated Vapour
fg	A change from Saturated Liquid to Saturated Vapour
l	Liquid Temperature
m	Metal Surface Temperature
i	Inlet Temperature of Water
o	Outlet Temperature of Water
s	Saturation Temperature

USEFUL DATA

Dimensions of heating surface: Effective length = 42mm
Diameter = 12.7mm
Surface area = $0.0018m^2$ (including area of end)

Condenser surface area: $0.032m^2$

Maximum permitted surface temperature: 220°C

Heater cut out temperature: 160°C

Fluid: 1,1-Dichloro-1-fluoroethane (R141b) $C\,Cl_2\,F\text{-}CH_3$

Quantity of fluid: Liquid level to be not less than 50mm above heating element.
Approximately 0.55 l.

Dimensions of glass chamber: Nominal internal diameter = 80mm
Length = 300mm
Volume = $0.0015m^3$

Specific heat capacity of water (C_{pw}): 4.18 kJ kg^{-1} K^{-1}

1 bar = 10^5 N m^{-2} = 100 kN m^{-2}

SPECIFICATION

Panel	High quality G.R.P. moulding, on which the following are mounted.
Chamber	Thick walled glass cylinder, approximately 80mm bore x 300mm long, with nickel plated brass end plates. The chamber houses the heating element and the condenser.
Heating Element	800W "high watt density" cartridge heater swaged into a thick walled copper sleeve to give a uniform surface temperature. Effective heating surface area approximately 18 cm^2.
Condenser	9 Coils nickel plated copper tube. Mean surface area approximately $0.032m^2$.
Variable Transformer	To give infinitely variable heat input to the heating element.
Charging and Drain Valve	Fitted to lower end plate - to charge or discharge the liquid.

INSTRUMENTATION

Voltmeter and Ammeter	To measure electrical input to the heating element. Ranges 0 to 250V and 0 to 3A respectively.
Temperature Indicator	Single point digital temperature indicator with 1.0°C resolution to indicate the temperature of the surface of the heating element.
Glass Thermometers	Four, 150mm long, to measure - (i) Water inlet and outlet temperatures (0 to 50°C) (ii) Liquid temperature (-10 to +110°C) (iii) Vapour temperature (-10 to +110°C)
Pressure Gauge	Range, -100 to +250kN m^{-2} gauge to indicate pressure in chamber.
Water Flow Meter	Tapered glass tube type with stainless steel float and control valve. Range 0 to 50 gm s^{-1}.

SAFETY

High Temperature Cut-Out	Set to switch off electrical input to the heater element if the element temperature (t_1) exceeds 160°C. Resets automatically.
High Pressure Cut-Out	Set to switch off electrical input to the heater element if the chamber pressure exceeds 220 kN m^{-2} gauge. Resets automatically.
Pressure Relief Valve	In the unlikely event of failure of the High Pressure Cut-Out Switch, or storage of the machine at very high ambient temperatures in tropical climates, a Pressure relief Valve is fitted to the chamber set to discharge vapour from the chamber when pressure exceeds 240 kN m^{-2} gauge. (This pressure is equivalent to an ambient temperature or vapour saturation temperature of approximately 72°C.)
Overload Cut-Out	Mains rocker switch operates as On/Off switch to overload cut-out in the event of a short to earth, or a short circuit.

<u>Residual Current Circuit Breaker</u>

Cuts off the power inside the unit should the current in and current out differ by more than 30mA, as in a leakage to earth situation.

<u>R141b</u>

R141b is non-flammable and should present no hazard under the conditions in which it is used in the H654. However, as with all solvents, inhalation should be avoided as a high concentration causes drowsiness, headaches and giddiness, and may lead to unconsciousness.

Full details of the limited hazards and safety data is given in the Chemical Safety Data Sheets at the rear of this manual.

SERVICES REQUIRED

<u>Electrical</u>

800 Watts, either, 240V 50Hz 1ph. (with earth/ground), or 110V 60Hz 1ph. (with earth/ground).

<u>Cold Water</u>

$50cm^3 s^{-1}$ (180 litre per hour) at 5m head (minimum)

INSTALLATION

Remove the unit from its packing case and carefully examine it for damage. If any is found, notify the insurers immediately.

Stand the unit on a table at a convenient height and close to an electrical supply, a water supply and a drain.

(i) Connect the mains water supply, using the hose supplied, to the 1/2" BSP fitting at the rear of the unit.

(ii) Connect the clear plastic drain tube supplied to the lower 1/2" BSP fitting at the rear of the unit. Place the other end of the tube into the drain and secure to ensure that it is not ejected at high flow rates.

(See Water Connections Diagram at the rear of the manual).

(iii) Check that the voltage stated on the rear panel of the unit agrees with that of the supply and is single phase.

220/240V Units

The power supply cable will be found emerging from the rear panel. Connect the cable to a suitable fixed power supply via a fused outlet which complies with the local regulations.

Brown cable	LIVE or LINE
Blue cable	NEUTRAL
Green/Yellow cable	EARTH or ground

Note that for safe operation a good earth is essential.

110/120V Units

The unit will have been supplied with a transformer. It is suitable for input voltages of between 110 and 130 Volts (110 to 130V in 5 volt steps).

Before connection to the transformer, the local mean voltage should be measured. When this has been determined, the Live input of the supply should be connected to the terminal having the nearest voltage label. The Neutral of the supply is connected to the 0V terminal and the Earth or Ground of the supply is connected to the terminal labelled "E" or ⏚ (see diagram TRAN100 at the rear of the manual).

The supply cable, cable gland and switched and fused outlet should be suitable for supplying 5A and be to a standard corresponding to the local regulations.

MAINTENANCE

High Pressure Cut-Out

At intervals not exceeding 3 months, the high pressure cut-out should be tested as follows:

Turn on the water supply to the condenser. Adjust the heater input to about 200W.

Gradually reduce the condenser water flow, thus increasing the condenser pressure. When the condenser pressure reaches 220 kN m^{-2} gauge, the high pressure cut out should operate and switch off the heater. Turn the condenser water to its maximum flow rate and when the pressure has fallen to about 120 kN m^{-2} gauge the heater should switch on.

If it is necessary to adjust the high pressure cut-out disconnect the unit from the electrical supply, then remove the rear panel from the unit.

The adjustment for the high pressure cut-out will be found on the top of the switch and this should be turned clockwise to increase the pressure at which the cut-out operates.

After adjustment, the rear cover should be replaced and the action of the cut-out retested.

Testing the RCCB

The Residual Current Circuit Breaker (RCCB) is situated inside the panel adjacent to the power cable entry point.

The RCCB should be tested by a competent person at intervals not exceeding 3 months.

Remove the rear panel and switch on the unit. Press the button marked 'Test' or 'T' on the RCCB, but DO NOT TOUCH ANYTHING ELSE INSIDE THE UNIT. The large lever on the RCCB should turn from the ON ('I') to OFF ('O') position immediately and the unit isolated from the supply. If this does not occur, the RCCB is faulty and needs to be repaired/replaced by a qualified electrician.

Return the lever to the ON ('I') position and the unit should be switched on again.

Replace the rear panel.

DESCRIPTION

(Please refer to the schematic diagram on Page 1).

A high "watt density" electric heating element in a copper sleeve submerged in R141b liquid is mounted horizontally in a vertical glass cylinder. The temperature of the copper sleeve is measured by a thermocouple and digital indicator.

The electrical input to the heater is controlled by a variable transformer, the actual heat transfer rate being obtained from the product of the voltmeter and ammeter readings.

A controller incorporated in the temperature indicator switches off the electrical input if the temperature of the heating surface exceeds a pre-set value.

At the upper end of the cylinder is a nickel plated coil of copper tube through which cooling water flows. This coil condenses the vapour produced by the heat input and the liquid formed returns to the bottom of the cylinder for re-evaporation.

A cooling water flow meter used in conjunction with glass thermometers measuring the cooling water temperatures, enables the rate of heat transfer at the condenser to be measured. The logarithmic mean temperature difference during condensation may also be determined.

Glass thermometers are also mounted inside the glass cylinder to indicate the temperature of the liquid and vapour.

SAFETY

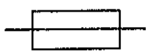
High Temperature Cut-Out

The digital temperature indicator incorporates a high temperature relay which is set to interrupt the electrical supply to the heater when its surface temperature rises above 160°C. Similarly, the electrical supply to the heater will be restored when its surface temperature falls below 160°C. This control is set in the factory before despatch and no further adjustment should be necessary or is recommended.

Due to variations in supplier, certain digital temperature indicators are internally fused in addition to being safeguarded by the main fuse on the front panel of the unit.

If the temperature indicator only should fail to operate, the internal fuse should be checked.

Fuse Examination and Replacement

1. Disconnect the unit from the mains supply.
2. Remove the rear panel from the unit.
3. Unscrew and remove the terminal block cover on the rear of the instrument housing.
4. Disconnect the wires from the 3 terminal blocks.
5. Pull off the 3 terminal blocks upward from their pins.
6. Lever off the red front cover with a screwdriver to reveal the display board.
7. Using a screwdriver on the pins, gently push the PCB module forward and remove it from the front of the housing.
8. On the PCB will be the fuse holder with the symbol  . Lift off the top and remove the fuse in its holder. Check and replace if necessary.
9. Reassemble the instrument in the reverse order.

If the fuse should repeatedly fail, or the indicator fails to operate, a competent engineer should be called to examine the unit.

Miniature Circuit Breaker (MCB)

The On/Off switch on the front of the panel is an MCB and will cut-out in the event of an overload caused by a short circuit or a short to earth. If this should cut-out, the unit should be disconnected from the supply and the cause of the overload determined.

Residual Current Circuit Breaker (RCCB)

This is situated inside the panel and will isolate the unit when the incoming and outgoing currents differ by more than 30mA, as in a leakage to earth situation.

High Pressure Cut-Out

This is set to interrupt the electrical input if the chamber pressure exceeds 220 kN m^{-2} gauge. See "Maintenance" on Page 8.

Pressure Relief Valve

In the unlikely event of failure of the High Pressure Cut-Out switch, or storage of the machine at very high ambient temperatures in tropical climates, a Pressure Relief Valve is fitted to the chamber set to discharge vapour from the chamber when pressure exceeds 240 kN m^{-2} gauge. (This pressure is equivalent to an ambient temperature or vapour saturation temperature of approximately 72°C).

CAUTION

Before starting any test check that:

(a) The cooling water is connected and ready for use.

(b) The pressure and temperature of the R141b agree with those at saturation conditions - if not, it is probable that air is present and the purging operation should be carried out.

(c) The electrical supply is correctly connected and that the unit is properly earthed.

(d) The digital temperature indicator is showing the same temperature as the liquid R141b thermometer. The instrument requires a few minutes to warm up.

This unit has been designed to operate on R141b and no other fluid should be charged into the system.

An important feature of this unit is the use of glass for the condenser shell. The shell has a safe working pressure of 300 kN m^{-2} and safety features are incorporated in the unit to ensure that this is not exceeded.

In all normal environments, R141b has a suitable pressure-temperature relationship.

R141b has been selected for use with the Boiling Heat Transfer Unit because of its saturation pressure at the temperatures envisaged. Its values of ρ_g and h_{fg} make it suitable for demonstrating the critical conditions at moderate heat fluxes.

CHECKING FOR LEAKS

If a leak of R141b is suspected, e.g. if there is a loss from the system, the following procedure should be adopted:

(A) **If there is liquid in the system:**
Place the unit in a warm place until its temperature reaches 40°C. The pressure throughout the system will now be above atmospheric and the leak may be located either by
- (i) Applying a strong soap or detergent solution to all joints,
- (ii) Using a Halogen leak detector,
- (iii) Using an electronic leak detector.

(B) **If there is no liquid in the system:**
Either
- (i) Introduce about 100ml of liquid R141b into the condenser (see Recharging, Page 13) and then proceed as in A,
- or (ii) Pressurise the system to 50 kN m^{-2} with air by applying a manual pump, e.g. motor car tyre pump, to the charging valve at the base of the condenser. The leak may then be located as in A (i).

CHARGING OR RECHARGING

The unit is shipped with the glass chamber containing R141b, and so is ready for use. If the liquid level falls below the heater block top fitting (where the thermocouple wires exit), then it is necessary to charge the chamber with R141b.

The one trip can of R141b as supplied has a small charge of Nitrogen, which can be used to assist charging, but after first use this will be lost. If the can has been used before, then stand it upright in water at about 40 to 45°C for about 5 minutes.

If the ambient temperature is below 32°C, then the chamber will be in partial vacuum. Should the chamber be above atmospheric pressure, then pass cooling water through the condenser coil to achieve a pressure of atmospheric or less.

Remove the nut from the charging adaptor and screw it onto the thread at the top of the can. Screw the cone end of charging adaptor into the straight end coupling of the flexible charging hose. (See diagram at the end of this manual).

Remove the nut from the charging/drain valve at the bottom of the chamber, and screw the angled end of the charging hose onto the cone fitting of the valve.

Invert the can and put the thread of the adaptor into the nut and then rotate the can to screw in the adaptor. This will open the self sealing valve of the can and allow the R141b to enter the charging hose.

Open the charging/drain valve on the bottom of the chamber, and so allow the liquid to rise into the chamber. It may be necessary to pull on the relief valve spindle to release back pressure if the chamber pressure rises above atmospheric to assist the flow of liquid.

When the level is about 50-60mm above the heater, rotate the can to unscrew the adaptor and so seal the can valve. Close the charging/drain valve at the bottom of the chamber. Remove the hose from the charging/drain valve, and replace the nut.

Store the charging hose, adaptor and can in a safe place, away from direct sunlight and other heat sources.

Discharging

The condenser may be emptied by lifting the relief valve spindle, opening the charging/drain valve, and directing the liquid into a suitable container.

Purging

Switch on electrical supply and adjust the heater power to about 150 Watts.

The liquid will start to boil vigorously and when the pressure reaches about 30 kN m^{-2} gauge, or liquid exceeds 40°C, pull on the pressure relief valve stem and release any air in the cylinder. It may be necessary to repeat this before all the air is expelled.

Turn on water supply (to reduce the pressure) then switch off the electrical supply.

INTRODUCTION

Boiling and condensation are vital links in the transfer of heat from a hot to a colder region in countless applications, e.g. thermal and nuclear power generation in steam plants, refrigeration, refining, heat transmission, etc.

Boiling

When a liquid at saturation temperature is in contact with the surface of a solid (usually metal) at a higher temperature, heat is transferred to the liquid and a phase change (evaporation) of some of the liquid occurs.

The nature and rate of this heat transfer changes considerably as the temperature difference between the metal surface and the liquid is increased.

Although "boiling" is a process familiar to everyone, the production of vapour bubbles is a very interesting and complex process.

Due to surface tension, the vapour inside a bubble must be at a higher pressure than the surrounding liquid. The pressure difference increases as the diameter of the bubble decreases, and is insignificant when the bubble is large.

However, when the bubble is minute, an appreciable pressure difference exists. (An analogy may be drawn with the inflation of a child's balloon - it is difficult to inflate when the balloon is small, but it becomes much easier as the diameter increases).

The pressure inside a bubble is the vapour pressure corresponding with the temperature of the surrounding liquid. Thus, when no bubbles exist (or are very small) it is possible for the liquid temperature in the region of the heat transfer surface to be well above the temperature of the bulk of the liquid. (This will be close to the saturation temperature corresponding with the pressure at the free liquid-vapour interface).

The formation of bubbles normally associated with boiling is influenced by the foregoing.

Convective Boiling

When the heating surface temperature is slightly hotter than the saturation temperature of the liquid, the excess vapour pressure is unlikely to produce bubbles. The locally warmed liquid expands and convection currents carry it to the liquid-vapour interface where evaporation takes place and thermal equilibrium is restored.

Thus, in this mode, evaporation takes place at small temperature differences and with no bubble formation.

Nucleate Boiling

As the surface becomes hotter, the excess of vapour pressure over local liquid pressure increases and eventually bubbles are formed. These occur at nucleating points on the hot surface where minute gas pockets, existing in surface defects form the nucleus for the formation of a bubble.

As soon as a bubble is formed, it expands rapidly as the warmed liquid evaporates into it. The buoyancy detaches the bubble from the surface and another starts to form.

Nucleate boiling is characterised by vigorous bubble formation and turbulence. Exceptionally high heat transfer rates and heat transfer coefficients with moderate temperature differences occur in nucleate boiling, and in practical applications, boiling is nearly always in this mode.

Film Boiling
Above a critical surface-liquid temperature difference, it is found that the surface becomes "vapour locked" and the liquid is unable to wet the surface. When this happens there is a considerable reduction in heat transfer rate and if the heat input to the metal is not immediately reduced to match the lower ability of the surface to transfer heat, the metal temperature will rise until radiation from the surface plus the limited film boiling heat transfer, is equal to the energy input.

If the energy input is in the form of work (including electrical energy) there is no limit to the temperature which could be reached by the metal and its temperature can rise until a failure or a "burn out" occurs. If the source is radiant energy from, for example, a combustion process, a similar failure can occur, and many tube failures in the radiant section of advanced boilers are attributed to this cause.

Immersion heaters must obviously be designed with sufficient area so that the heat flux never exceeds the critical value.

The consequences of a "burn out" in a nuclear power plant will be readily appreciated.

Condensing Heat Transfer
Condensation of a vapour onto a cold surface may be "filmwise" or "dropwise".

When filmwise condensation occurs, the surface is completely wetted by the condensate and condensation is onto the outer layer of the liquid film, the heat passing through the film and into the surface largely by conduction.

By treating a surface with a suitable compound it may be possible to promote "dropwise" condensation. When this occurs the surface is not wetted by the liquid and the surface becomes covered with beads of liquid which coalesce to form drops which then fall away leaving the surface bare for a repetition of the action.

Heat transfer coefficients with dropwise condensation are higher than with filmwise owing to the absence of the liquid film.

For a complete investigation of filmwise and dropwise condensation at high heat fluxes, the Hilton Film and Dropwise Condensation Unit H910 should be used.

Boiling and condensating heat transfer are indispensable links in the production of power, all types of refining and chemical processes, refrigeration, heating systems, etc.

There is a constant pressure for more compact heat transfer units with high heat transfer rates and a clear understanding of the boiling and condensing processes is essential for every mechanical and chemical engineer.

The Hilton Boiling Heat Transfer Unit has been designed to improve the understanding of boiling and condensing heat transfer and enables both a visual and analytical study of these processes.

During Use
Control the saturation pressure to the desired value by:
(a) Variation of the cooling water flow rate (or temperature)
(b) Variation of the power supplied to the heater.

After Use
Always:
(a) Switch off the electrical supply and disconnect from the mains.
(b) Circulate cooling water until pressure has fallen to atmospheric or below.

UNIT CAPABILITIES

(i) Visual demonstration of convective, nucleate and film boiling.

(ii) Determination of heat flux and surface heat transfer coefficient up to and beyond the critical condition at constant pressure.

(iii) Investigation of the effect of pressure on critical heat flux.

(iv) Demonstration of filmwise condensation and measurement of overall heat transfer coefficient.

(v) Demonstration of the cause of liquid carry over or priming in boilers.

(vi) Determination of the pressure temperature relationship of a pure substance.

(vii) Investigation of the effect of air in a condenser.

(viii) Demonstration of the law of partial pressures.

It should be appreciated that individual units may give results which are a little different from those given in the following pages.

(i) VISUAL DEMONSTRATION OF THE THREE MODES OF BOILING

Turn on the electrical and water supplies and adjust both to very low settings (<20 Watts). Allow the digital thermometer to stabilise. Observe this and the liquid temperature at frequent intervals.

Carefully watch the liquid surrounding the heater. Convection currents will be observed, and at the same time liquid will be seen to collect and drip on the condenser coils, indicating that evaporation is proceeding although at a low rate. Increase the wattage in increments, keeping the vapour pressure at any desired constant value by adjusting the cooling water flow rate.

Nucleate boiling will soon start and will increase until vigorous boiling is seen, the temperature difference between the liquid and metal being still quite moderate (<20K).

Increase the power input and at between 250 and 300 Watts the nature of the boiling will be seen to change dramatically and at the same time the metal-liquid temperature difference will rise quickly. The rate of evaporation falls to a low level and the water flow rate must be reduced to maintain a steady pressure. The electrical input should now be reduced to about 40 Watts. Careful examination of the heater surface will show that it is now enveloped in an almost unbroken film of vapour and this is the cause of the reduced heat transfer rate.

The electrical power input should now be reduced to zero. It will be found that as the metal-liquid temperature difference falls to about 40K the boiling suddenly becomes vigorous as film boiling reverts to nucleate boiling.

(ii) DETERMINATION OF HEAT FLUX AND SURFACE HEAT TRANSFER COEFFICIENT AT CONSTANT PRESSURE

Adjust the electric heater to about 30 Watts and adjust the water flow rate until the desired pressure is reached. Note the voltage, current, vapour pressure, liquid temperature and metal temperature. Increase the power to say 70 Watts, adjust the cooling water flow rate to give the desired pressure and when steady, wait 5 minutes then repeat the observation.

Repeat in similar increments until the transition from nucleate to film boiling is reached. By careful adjustment of voltage near this condition it is possible to make an accurate assessment of critical conditions. When film boiling is established the voltage should be reduced and the readings continued until the heater temperature reaches 160°C.

Typical results and graphs 1 and 2 are shown on Pages 19 and 27-28.

Typical results at a pressure of 175 kN m^{-2} absolute:

Voltage	$\frac{E}{Volts}$	50	75	100	120	130	135	140	145	50	55	60
Current	$\frac{I}{Amps}$	0.68	1.01	1.36	1.64	1.78	1.85	1.91	2.00	0.68	0.74	0.81
Liquid Temperature	$\frac{t_e}{°C}$	49	49	50	49	50	50	50	50	48	49	48
Metal Temperature	$\frac{t_m}{°C}$	56	59	62	64	65	66	67	80	140	150	170

From which:

Heat Transfer Rate = EI	$\frac{\dot{Q}}{W}$	34	76	136	197	213	250	267	290	34	41	49
Heat Flux = $\frac{\dot{Q}}{A}$	$\frac{\phi}{kW\ m^{-2}}$	19	42	76	109	118	139	148	161	19	23	27
Temperature Difference = $t_m - t_e$	$\frac{\Delta t}{K}$	7	10	12	15	15	16	17	30	92	101	122
Surface Heat Transfer Coefficient = $\frac{\phi}{\Delta t}$	$\frac{h}{kW\ m^{-2}\ K^{-1}}$	2.7	4.2	6.3	7.3	7.9	8.7	8.7	5.4*	0.21	0.23	0.22

Note: The effective area (A) of the heat transfer surface of the heater is 1.8×10^{-3} m^2

These results are most conveniently plotted on a log-log graph as shown in Graphs 1 and 2 (Pages 27 and 28).

*Transition Region

(iii) EFFECT OF PRESSURE ON CRITICAL HEAT FLUX

The method is similar to that given under (ii) but by careful adjustment of the power and water flow rate, the heat flux at transition from nucleate to film boiling at a variety of pressures may be established.

Typical results are:

Pressure	$\frac{p}{kN\ m^{-2}}$	60	100	125	150	175	200	225	250
Heat Input	$\frac{\dot{Q}}{W}$	241	267	281	292	309	328	338	349

From which:

Critical Heat Flux	$\frac{\phi}{kW\ m^{-2}}$	134	148	156	162	172	182	188	194

These results are shown graphically in Graph 3, Page 29.

(iv) FILMWISE CONDENSATION

The filmwise condensation which occurs with R141b can be clearly seen, and the resistance offered by the liquid is readily appreciated.

The overall heat transfer coefficient between the condensing vapour and the water may be found as follows:

> Adjust the voltage and water flow rate until the desired pressure and condensing rate is established. When conditions are stable, note the water flow rate, water inlet and outlet temperatures and the saturation temperature of the R141b.

Typical Results

Water flow rate	$\dot{m}_w$	= 5.5 gram s^{-1}
Water inlet temperature	t_i	= 20.5°C
Water outlet temperature	t_o	= 25.0°C
Saturation temperature of liquid	t_s	= 29.0°C
Voltage		95V
Current		1.3V

Heat transfer rate at cooling coil, $\dot{Q}_w = \dot{m}\,Cp(t_o - t_i)$
$= 5.5 \times 10^{-3} \times 4180(25.0 - 20.5)$ W
$= \underline{104\ W}$

Heat transfer rate from heater, $\dot{Q}_e$ = EI
$= 95 \times 1.3$ W
$= \underline{124\ W}$

Heat transfer to surroundings (by difference), $= \dot{Q}_e - \dot{Q}_w$
$= 124 - 104$ W
$= \underline{20\ W}$

$$\phi_1 = t_s - t_i = 29.0 - 20.5 = 8.5\ K$$
$$\phi_2 = t_s - t_o = 29.0 - 25.0 = 4.0\ K$$

Log mean temperature difference,

$$\phi_m = \frac{\phi_1 - \phi_2}{l_n \dfrac{\phi_1}{\phi_2}}$$

$$= \frac{8.5 - 4.0}{l_n \dfrac{8.5}{4.0}} K$$

$$= \underline{6.0\ K}$$

Overall heat transfer coefficient,

$$U = \frac{\dot{Q}_w}{\phi_m}$$

$$= \frac{104}{0.032 \times 6.0} \; W\,m^{-2}\,K^{-1}$$

$$= \underline{\underline{542}} \; W\,m^{-2}\,K^{-1}$$

This may be repeated at other water flow rates, other saturation temperatures and other condensation heat fluxes.

(v) CAUSES OF PRIMING IN BOILERS

Among the causes of "carry over" or "priming" in boilers are,

(a) Operating at a lower pressure than that for which the boiler is designed.

(b) Short term heavy demands in excess of the heat input, causing formation of flash steam.

The boiling action inside the glass cylinder is similar to that occurring in a boiler on load, and students readily appreciate the problem of liquid carry over if the following demonstration is made.

Apply about 200 W to the heater and pass a large water flow through the condenser so that the saturation temperature is low. When conditions are stable, observe the rate and degree of ebullition and turbulence. Now decrease the water flow rate so that the saturation pressure is approximately doubled and again observe the degree of ebullition. It will be seen that there is an appreciable reduction in this as the pressure is raised and the probability of carry over in a practical boiler is reduced. This is accounted for by the increase of vapour density and consequent reduction of the volume of vapour leaving the liquid.

If the cooling water flow rate is now suddenly increased, a short term heavy demand is simulated. The pressure will drop, and flash evaporation will occur, in addition to the boiling caused by the heat transfer. Violent ebullition will occur and the likelihood of carry over in a practical boiler will be appreciated.

(vi) PRESSURE-TEMPERATURE RELATIONSHIP

The relationship between the saturation pressure and temperature of a pure substance is readily demonstrated up to a maximum pressure of 220 kN m^{-2} gauge. The electrical supply is switched on and adjusted to about 100 W. Cooling water is circulated at the maximum rate and when conditions are stable the pressure and temperature are noted. The cooling water flow is reduced and the observations are repeated at a higher pressure, and so on.

Results may be compared with those on Graph 4, page 30.

If a supply of chilled water is available this may be circulated through the coil and the saturation pressure will then become less than atmospheric. This is a useful demonstration and helps to dispel the belief held by many students that a vacuum pump is necessary to produce the sub-atmospheric pressures in a steam plant.

(vii) EFFECT OF AIR IN A CONDENSER

Air may be deliberately admitted to the chamber by either:

(a) Pulling on the relief valve spindle (provided the pressure in the cylinder is below atmospheric), or

(b) Using an air pump or syringe to inject air through the charging/drain valve.

The overall heat transfer coefficient may be determined in the same manner as under section (iv). This value can be compared with the coefficient at a similar flow rate and saturation temperature when only R141b vapour is present.

It will be found that the heat transfer rate and coefficient is appreciably less when air is present and the detrimental effect of air is readily demonstrated.

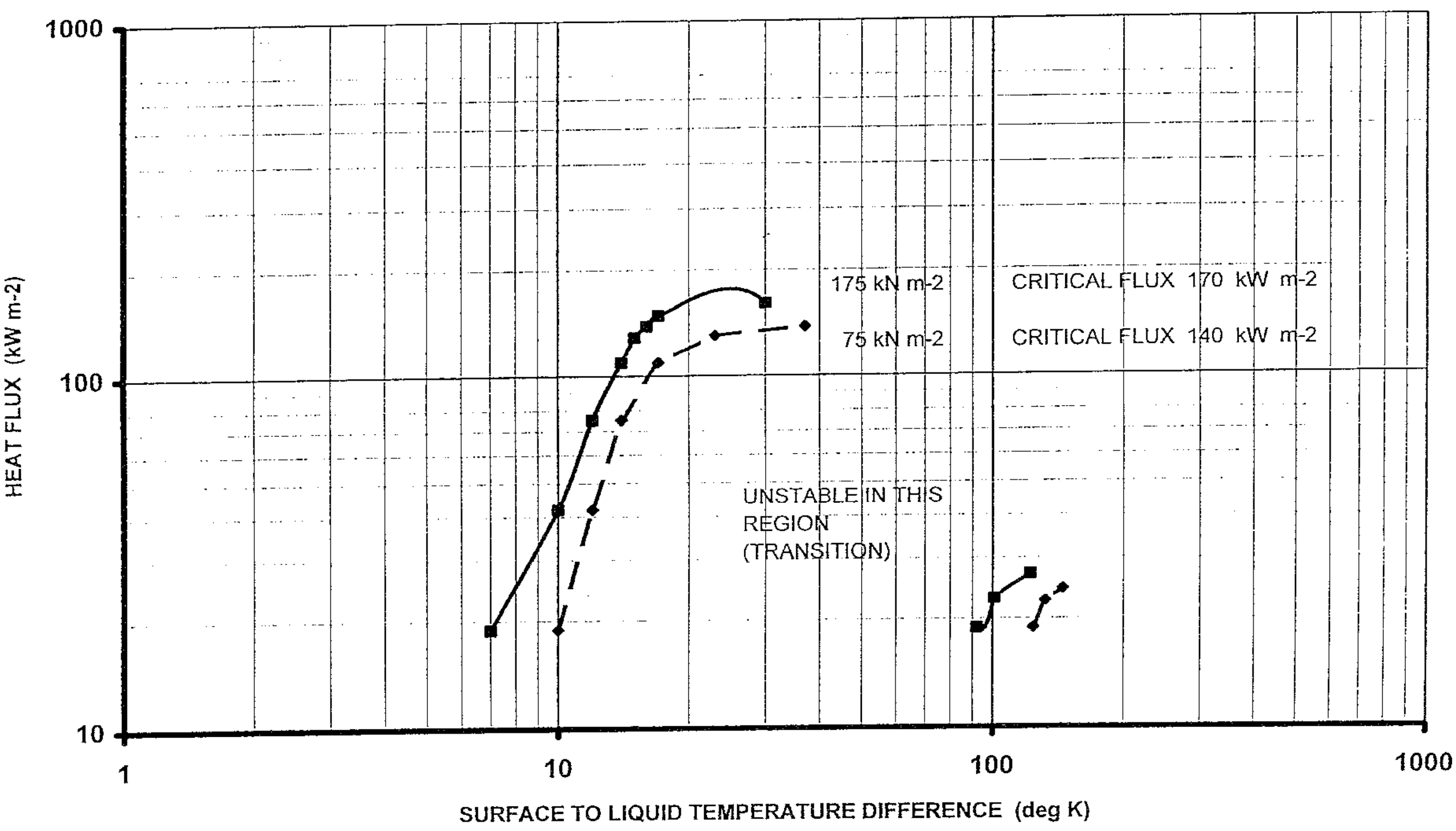
The effect of air blanketing can also be demonstrated visually. With air in the cylinder and at fairly high heat transfer rate it will be found that some of the condenser coils are quite dry. If the stem of the relief valve is lifted to release the air, vigorous condensation will be seen to take place on those coils, and the rate of condensation will show a marked increase.

(viii) DEMONSTRATION OF LAW OF PARTIAL PRESSURES

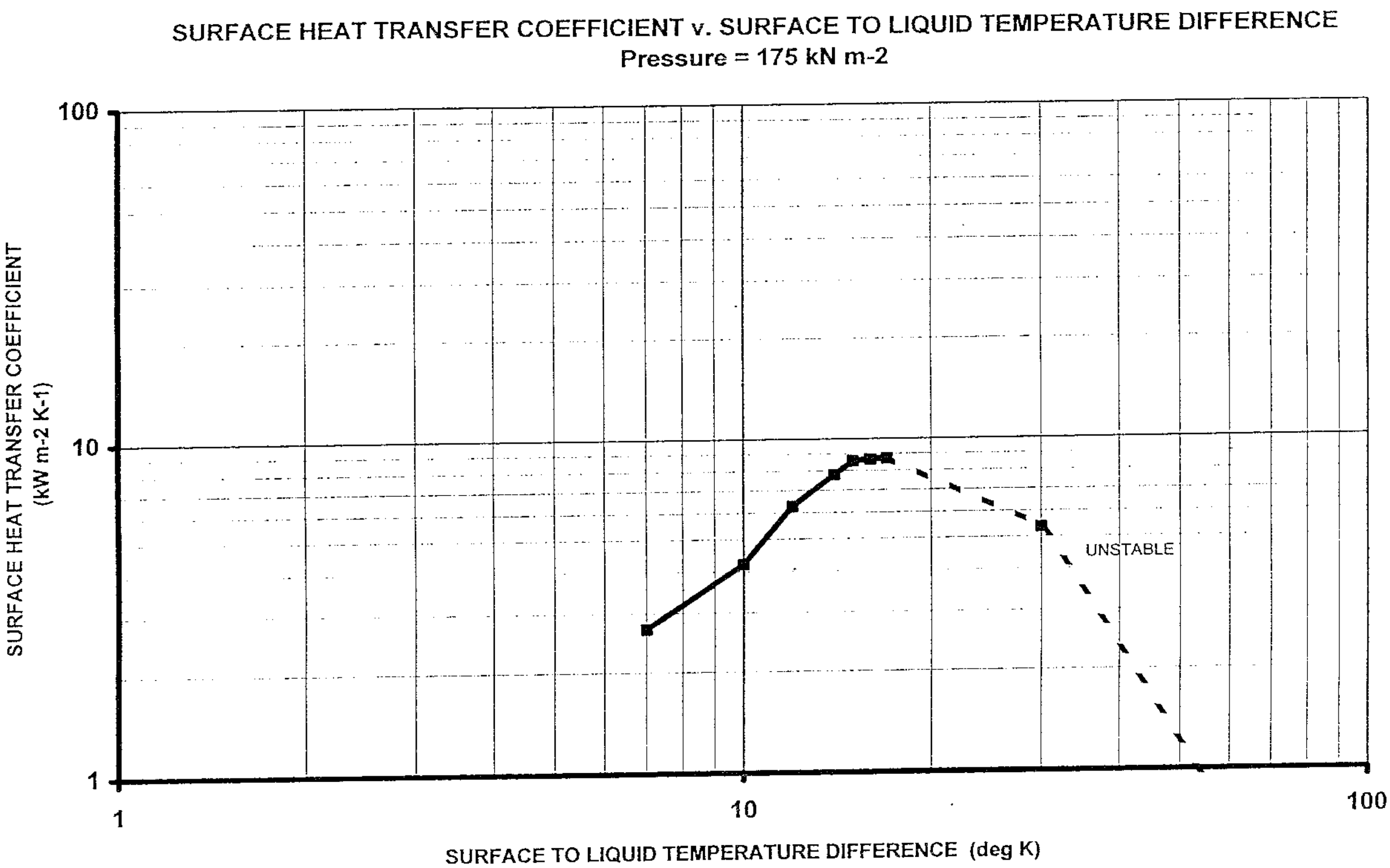
With the electrical power switched off, circulate cold (<20°C) water through the condenser and a partial vacuum will be produced. Open the charging valve allowing a measured quantity of air to enter the cylinder and then close the valve. (A measured quantity of air may be obtained by connecting a syringe to the charging valve or by connecting the charging valve to the air in an inverted measuring cylinder with its open end in water.) The volume of the space over the refrigerant liquid in the cylinder may be measured and the pressure of the admitted air calculated from the gas equation.

The total pressure of the air and R141b is indicated by the pressure gauge and this may be compared with the sum of the vapour and air pressures at a variety of temperatures.

HEAT FLUX v. SURFACE TO LIQUID TEMPERATURE DIFFERENCE

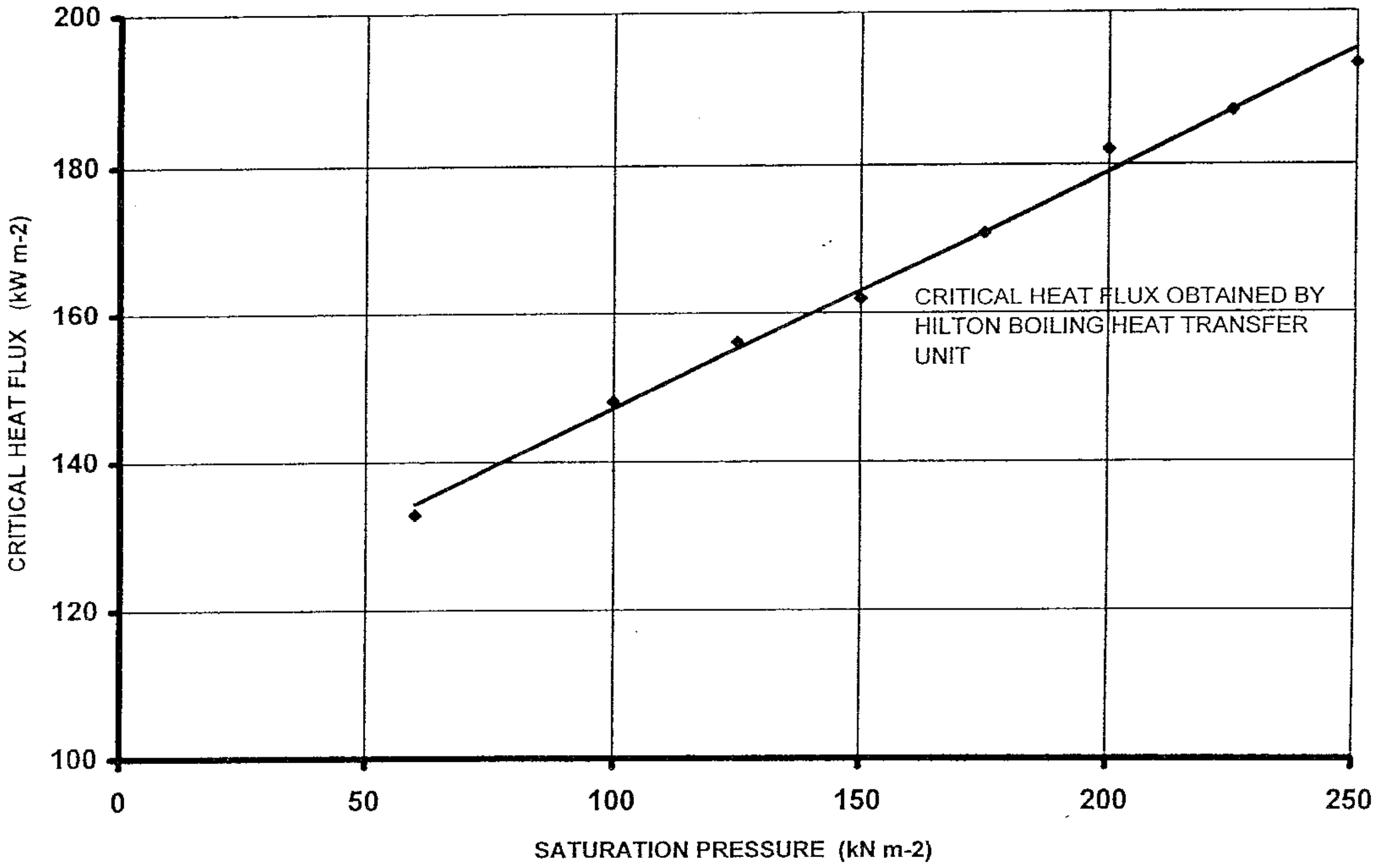


GRAPH 1


SURFACE HEAT TRANSFER COEFFICIENT v. SURFACE TO LIQUID TEMPERATURE DIFFERENCE
Pressure = 175 kN m-2
SURFACE HEAT TRANSFER COEFFICIENT
(kW m-2 K-1)
100
10
1
1
10
100
UNSTABLE
SURFACE TO LIQUID TEMPERATURE DIFFERENCE (deg K)

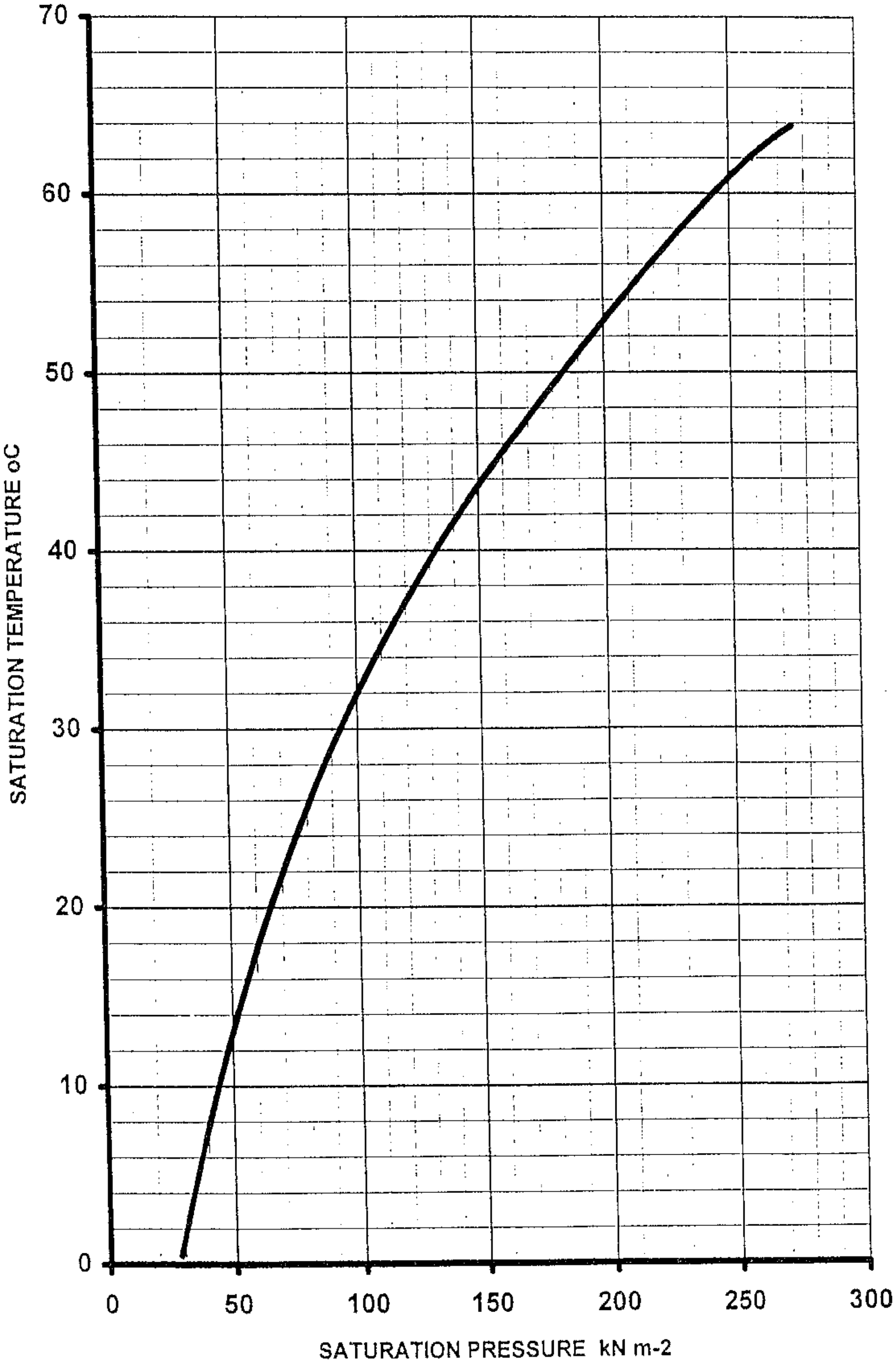
GRAPH 2

CRITICAL HEAT FLUX v. SATURATION PRESSURE



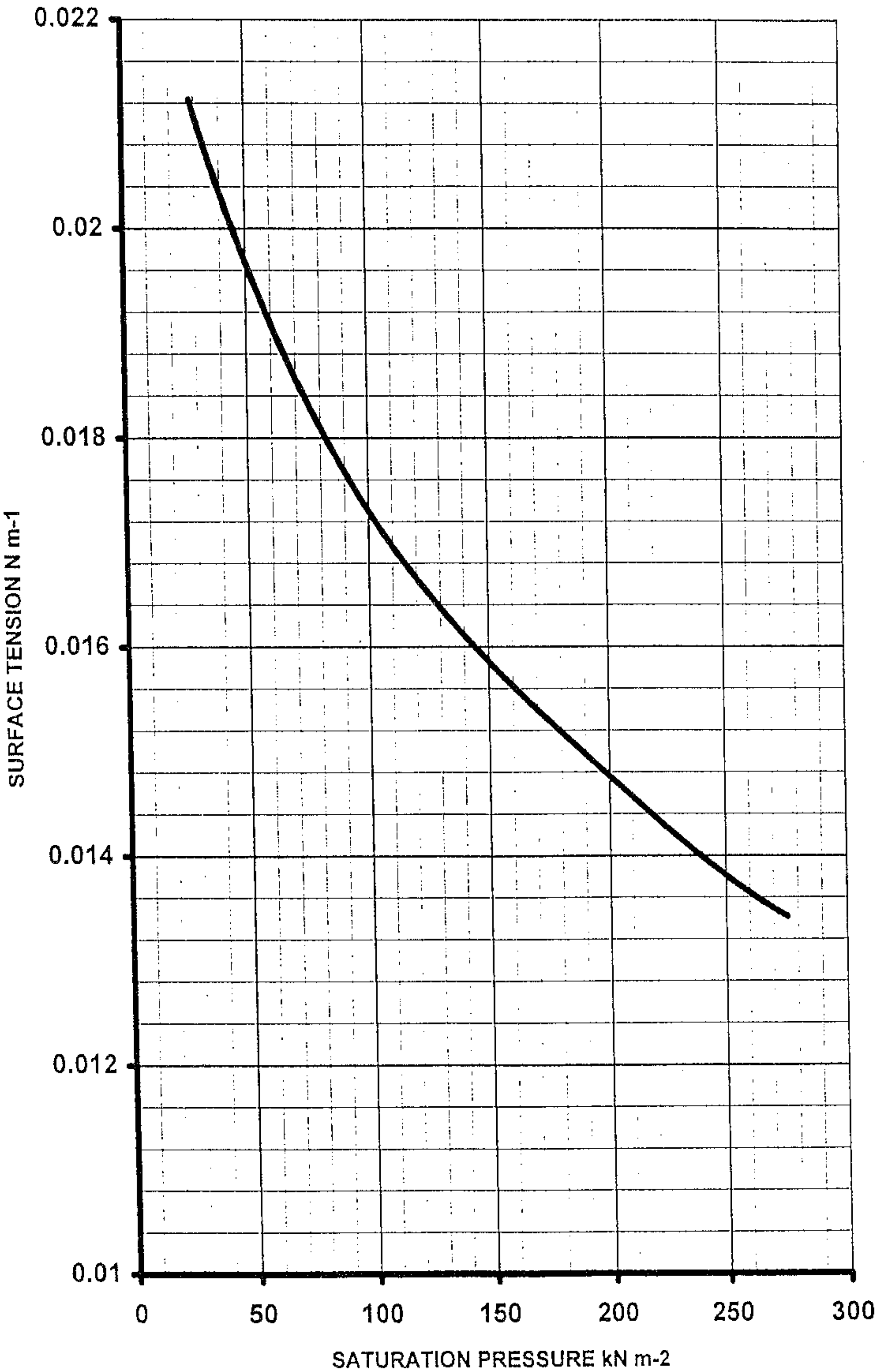
GRAPH 3

SATURATION TEMPERATURE v. SATURATION PRESSURE FOR R141b



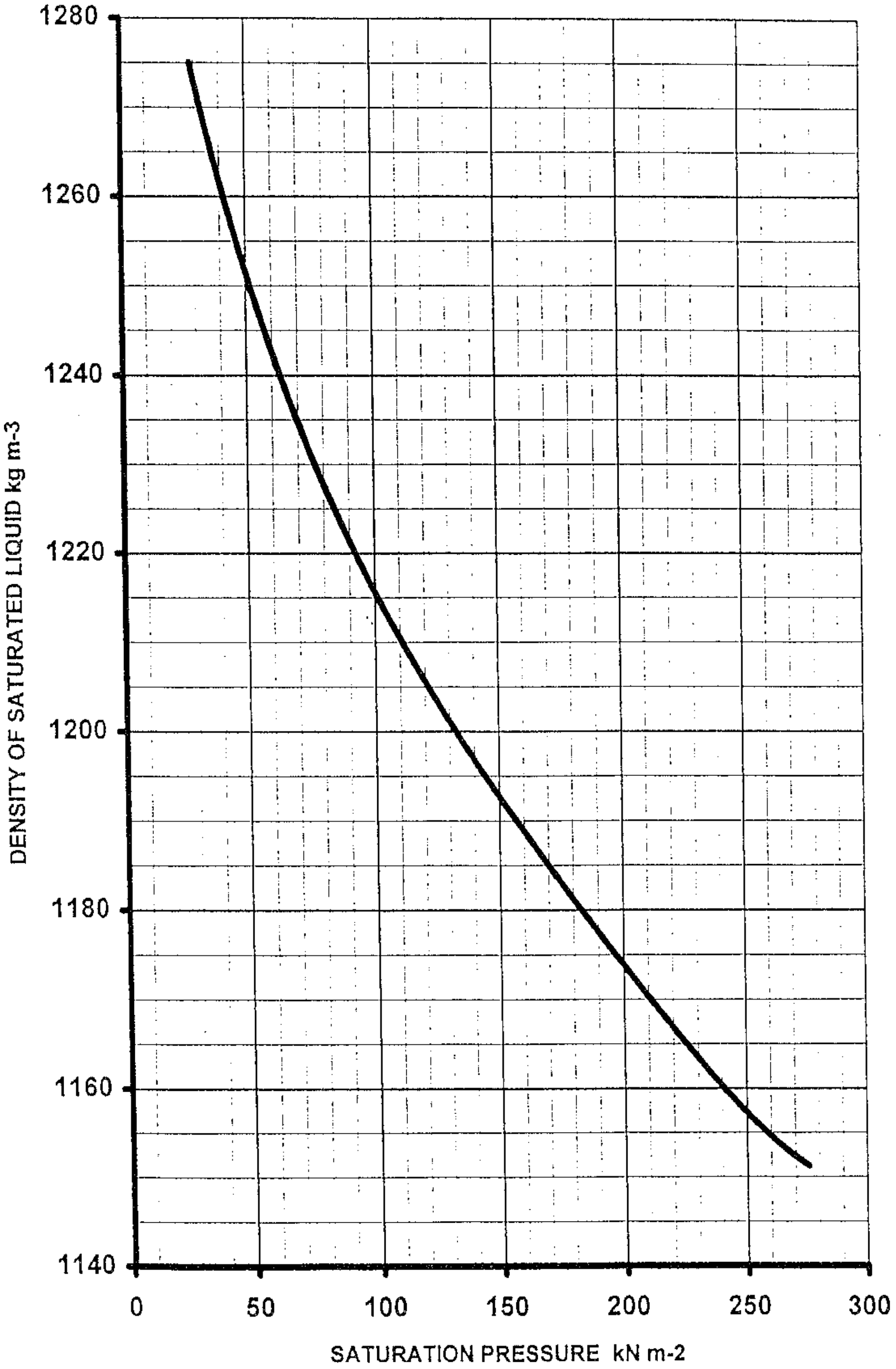
GRAPH 4

SURFACE TENSION v. SATURATION PRESSURE FOR R141b

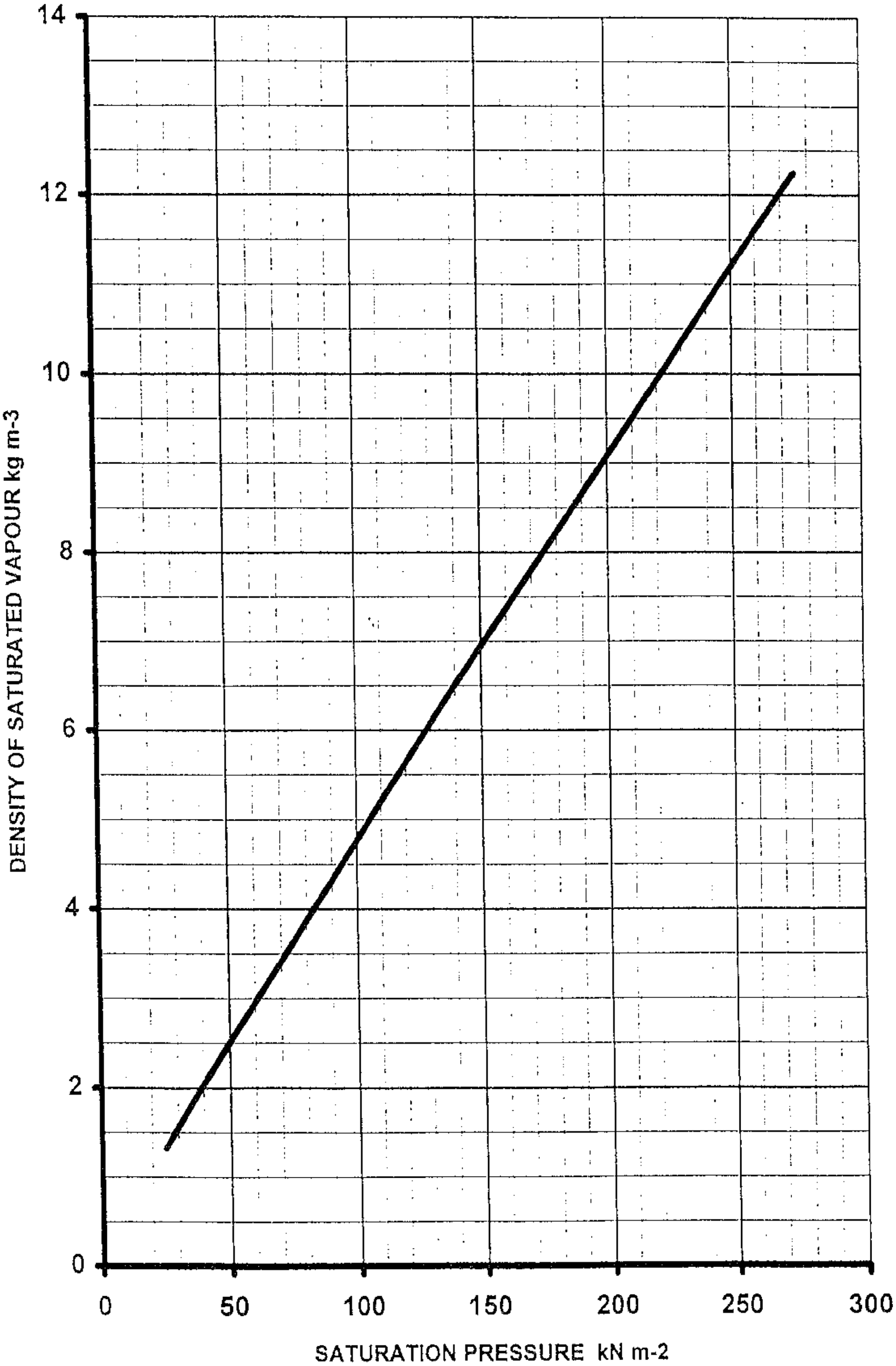


GRAPH 5

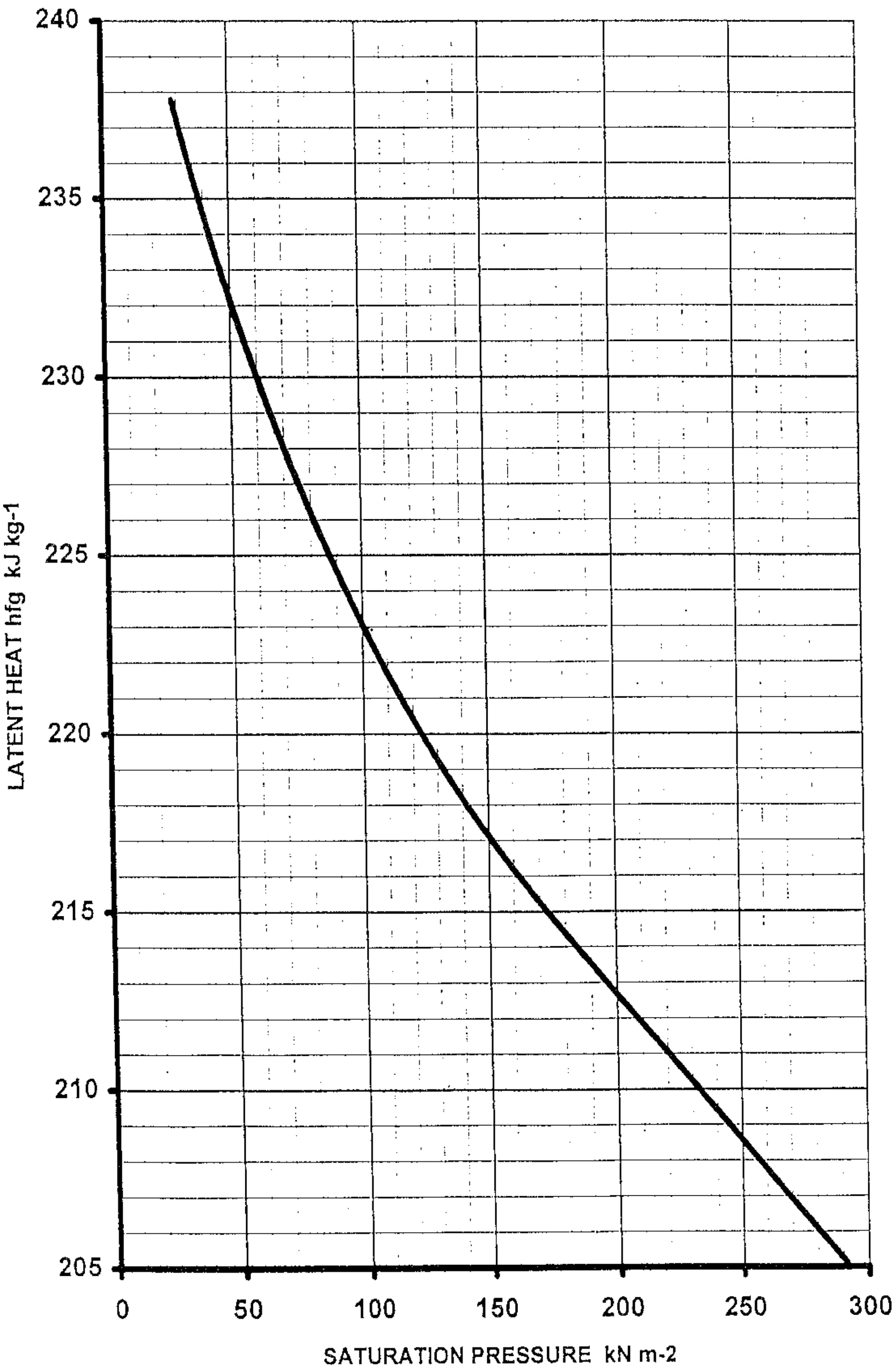
DENSITY OF SATURATED LIQUID v. SATURATION PRESSURE
FOR R141b



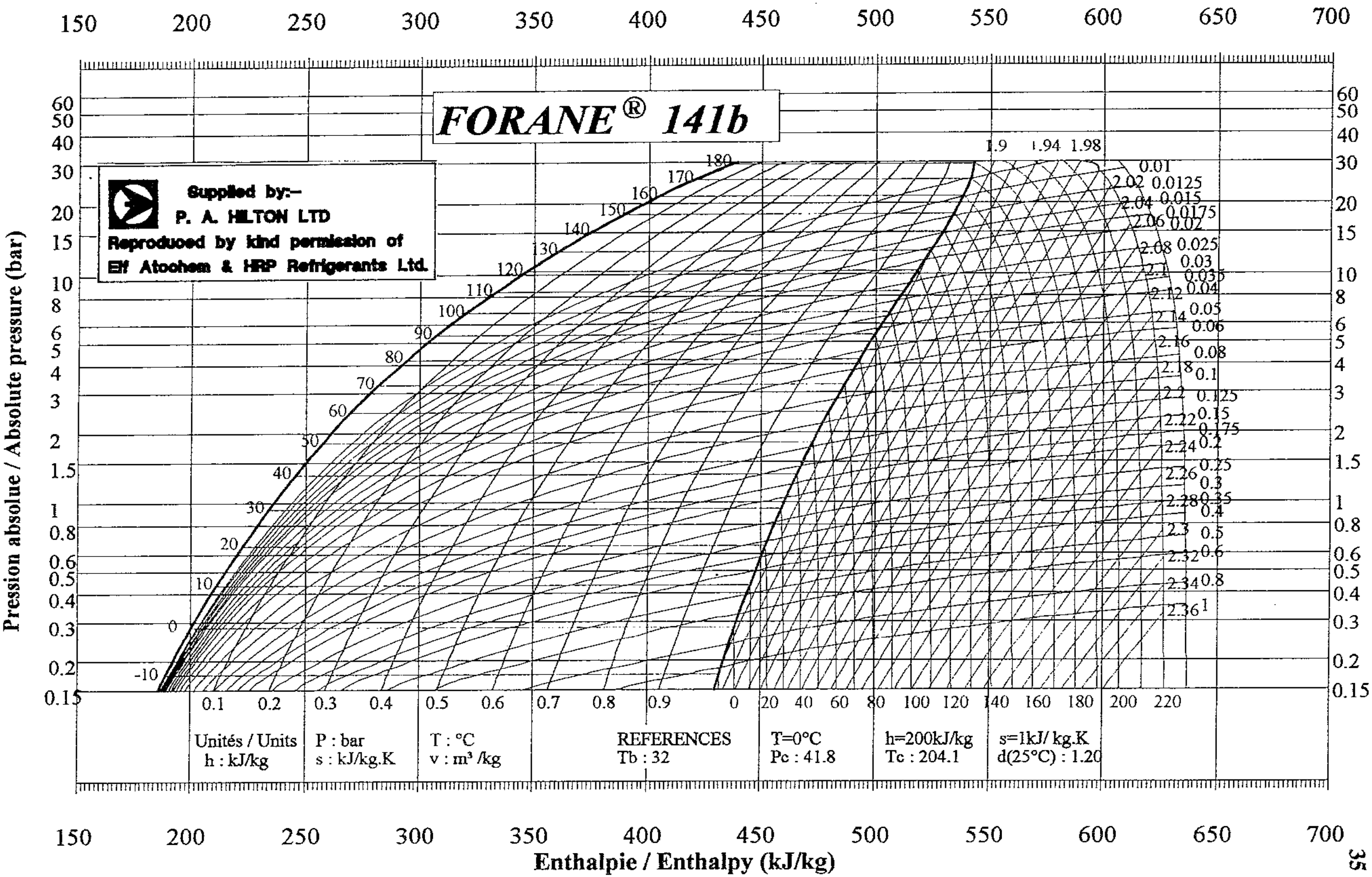
DENSITY OF SATURATED VAPOUR v. SATURATION PRESSURE FOR R141b



LATENT HEAT OF EVAPORATION v. SATURATION PRESSURE
FOR R141b



CENTRE D'APPLICATION DE LEVALLOIS



elf atochem

ATO

SPECIFIC RISKS

- Contact with liquid will cause severe frost bite
- Decomposes in a fire to give toxic and corrosive fumes
- Containers may burst if overheated
- Risk of asphyxiation at high concentration

1. *IDENTIFICATION*

1.1	**Synonyms**	1,1,-Dichloro-1-fluoroethane, R-141b
1.2	**Uses**	Plastic foam blowing agent,solvent

2. *COMPOSITION (substances or impurities giving a hazard)*

Substance	1,1,-dichloro-1-fluoroethane
Impurities	none

3. *PHYSICAL PROPERTIES*

	At 20°C	liquid
3.1	**Physical State**	colour: colourless odour: slightly etherial
3.2	**Temperatures**	melting point: -103.5°C boiling point: 32.0°C critical temperature: 205°C decomposition temperature: 500°C
3.3	**pH**	neutral
3.4	**Solubility**	in water at 20°C: 0.54% by weight in solvents: miscible with aliphatic hydrocarbons, aromatics, ketones, chlorinated derivatives and esters.
3.5	**Vapour pressure**	at 20°C: 0.81 bar at 50°C: 1.83 bar
3.6	**Density**	(liquid) at 25°C: 1.24 g/cm^3 (vapour) at 32°C: 5.018 kg/m^3
3.7	**Other data**	critical pressure: 43.4 bar

4. *STORAGE AND HANDLING*

4.1	**Special storage and handling precautions**	Store between 0° and 50°C in a well ventilated area. Product stored in specially reinforced drums.
4.2	**Packing materials**	Avoid alloys with 2% or more of magnesium or aluminium. Avoid plastics. Use steel or polyethylene drums.
4.3	**Decomposition products**	Stable at ambient temperature, but will undergo thermal decomposition at elevated temperatures to give off hydrochloric and hydrofluoric acids and possibly phosgene.
4.4	**Dangerous reactions**	With naked flame or hot metal surfaces.
4.5	**Individual prevention and protective measures**	Gloves and goggles recommended. Avoid liquid contact with skin and eyes and the inhalation of vapours.
4.6	**Special protective measures**	Ventilate the working area. No smoking. No naked flames.
4.7	**Measures after spillage or leakage**	If in an enclosed area, ventilate or wear self-contained breathing apparatus (risk of asphyxiation/anoxia). Allow to evaporate or pump into safe container. Prevent from entering sewers, basements etc.

FORANE® 141b

CAS	1717-00-6
EINCS	404-080-1

Health & Safety Data Sheet

If this material is redistributed for sale, details of its hazards and recommended methods of safe handling should be passed on to all users.

HRPR

HRP Refrigerants Ltd.
Gellihirion Industrial Estate
Pontypridd
Mid Glamorgan
CF37 5SX

In case of emergency telephone:

01443 842255

March 1995

JP160395D

SPECIFIC RISKS

- Contact with liquid will cause severe frost bite
- Decomposes in a fire to give toxic and corrosive fumes
- Containers may burst if overheated
- Risk of asphyxiation at high concentration

4.8	**Destruction of contaminated container**	Return to supplier.
4.9	**Other recommendations**	Store at a temperature below 50°C in a ventilated area, away from all sources of heat or ignition.

5. *IGNITION AND EXPLOSION*

5.1	**Flash point**	none
5.2	**Auto-ignition temperature**	none
5.3	**Special fire or explosion hazards**	Non-flammable product. Thermal decomposition gives off toxic fumes of hydrochloric and hydrofluoric acids and phosgene.
5.4	**Extinction**	Not applicable
5.5	**Particular measures during fire-fighting**	Wear self-contained breathing apparatus and full acid resistant protective clothing.
5.6	**Other recommendations**	Protect containers from heat sources. Cool with water to avoid over pressurisation. Ensure product does not come into contact with naked flames or hot metal surfaces.

6. *TOXICOLOGICAL INFORMATION*

Employers should be aware that this product is solvent abusable.

Vapour	2,500 ppm for 30-60 minutes will cause vertigo, drowsiness and respiratory problems. May cause increased sensitivity of myocardium above 12,500 ppm.
Liquid	Repeated and prolonged skin contact will produce dermatosis. Eye contact will lead to irritation, redness and moderate conjunctivitus.

7. *FIRST AID PROCEDURES*

Skin contact	Wash with copious amounts of water.
Inhalation	Remove to fresh air. Apply oxygen if breathing is difficult. Consult a doctor.
Eye Contact	Wash immediately with copious amounts of water. Consult an ophthalmologist.

8. *SPECIAL PRECAUTIONS FOR WASTE DISPOSAL*

This material is subject to the restrictions of the Environmental Protection Act and should not be vented to atmosphere. Waste material can be returned to HRPR. Movement of refrigerant for reclamation or destruction is subject to the Duty of Care and requires appropriate documentation for a controlled waste.

9. *SPECIFIC DATA*

Occupational exposure limits	500 ppm set by Elf Atochem.

FORANE®
141b

CAS	1717-00-6
EINCS	404-080-1

Health & Safety Data Sheet

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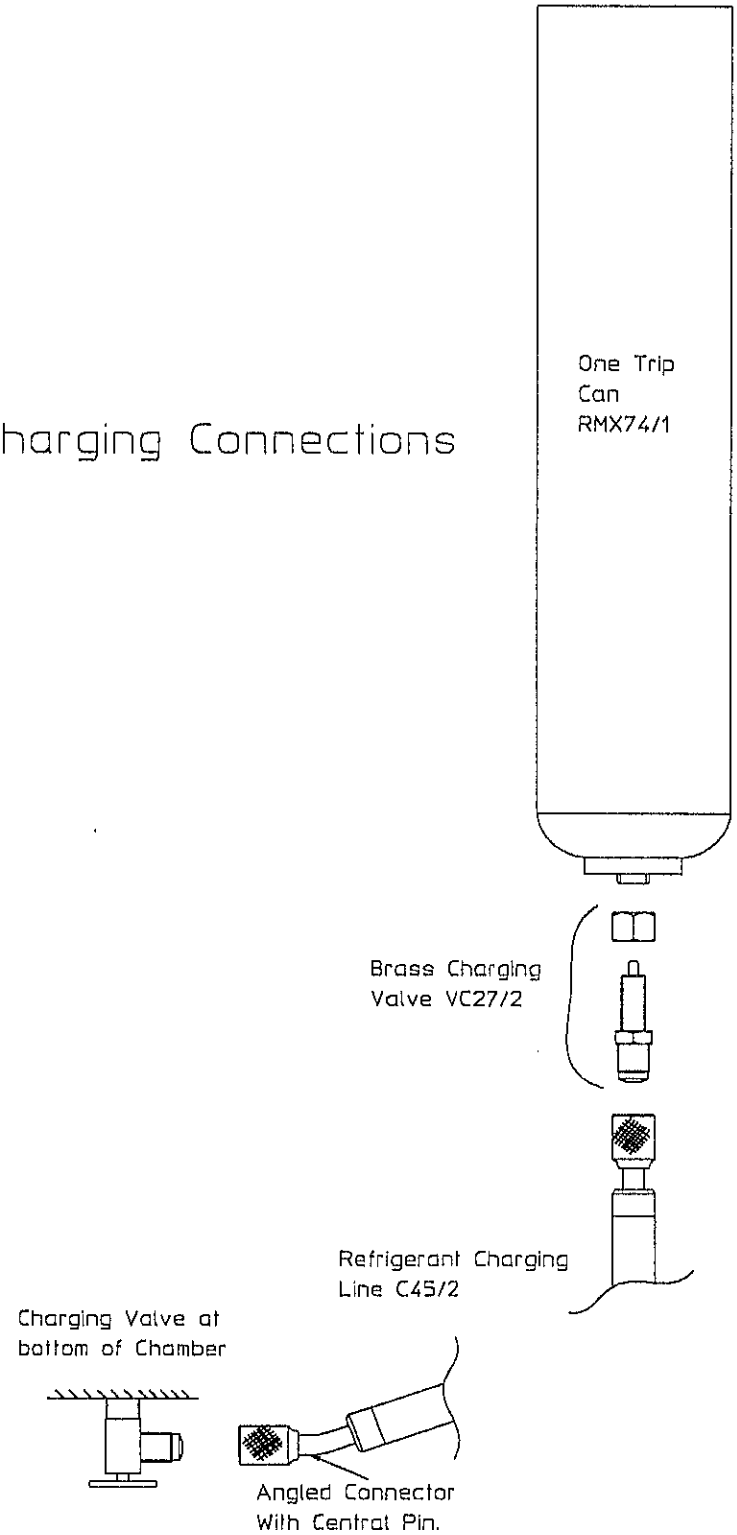
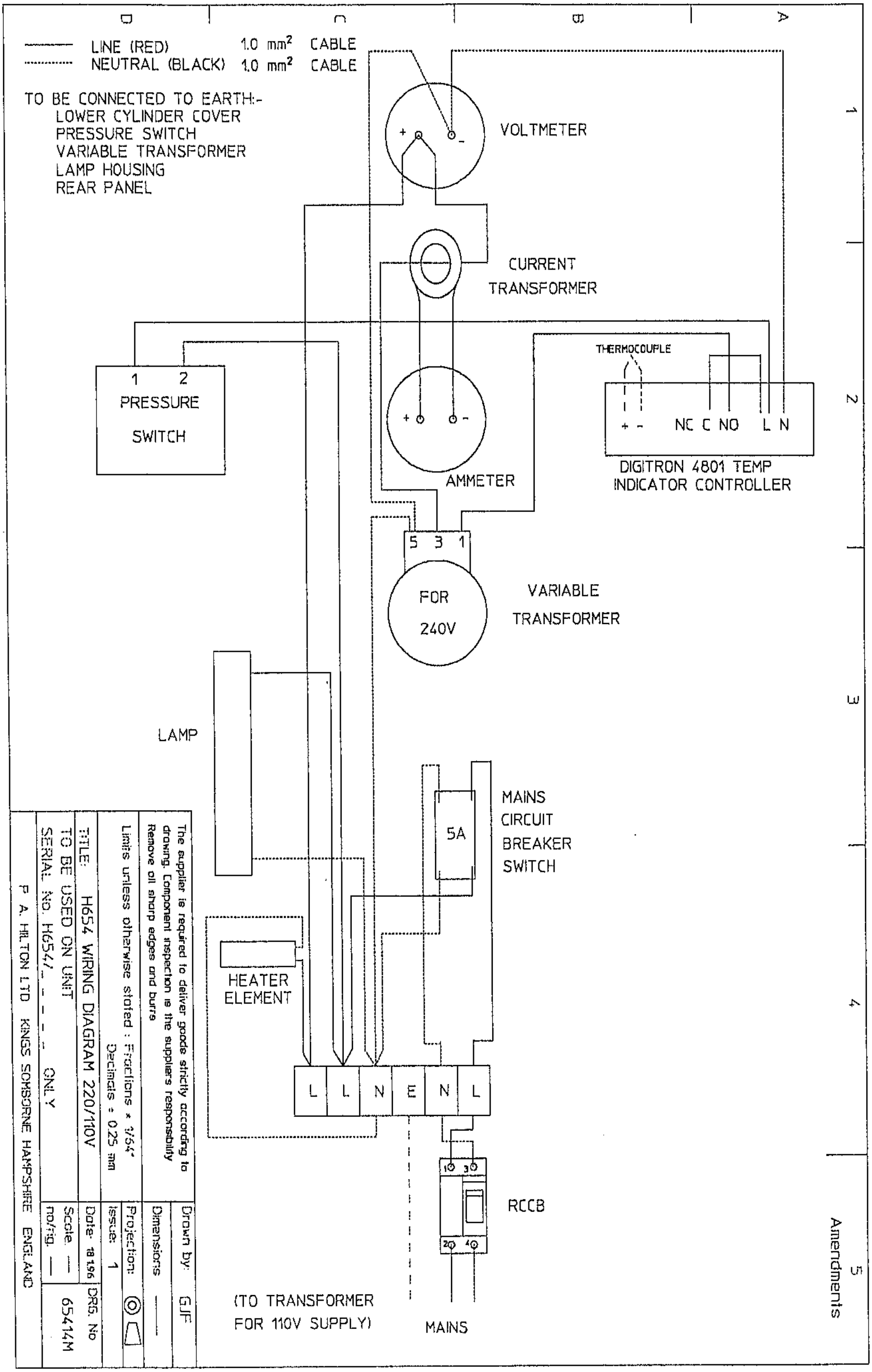
March 1995

JP160395D

R141b Charging Connections





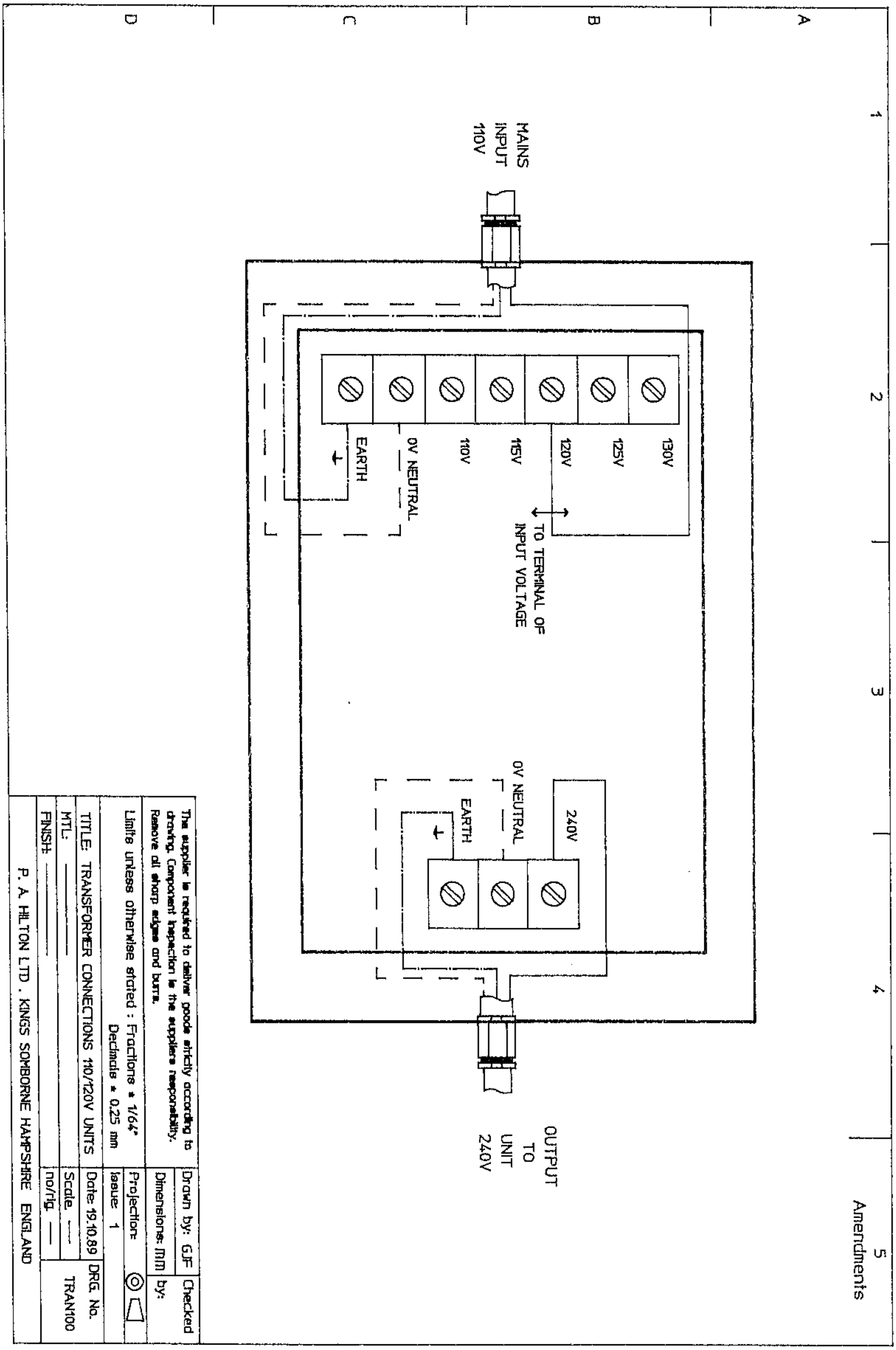
The supplier is required to deliver goods strictly according to drawing. Component inspection is the suppliers responsibility. Remove all sharp edges and burrs

Limits unless otherwise stated : Fractions ± 1/64" Decimals ± 0.25 mm

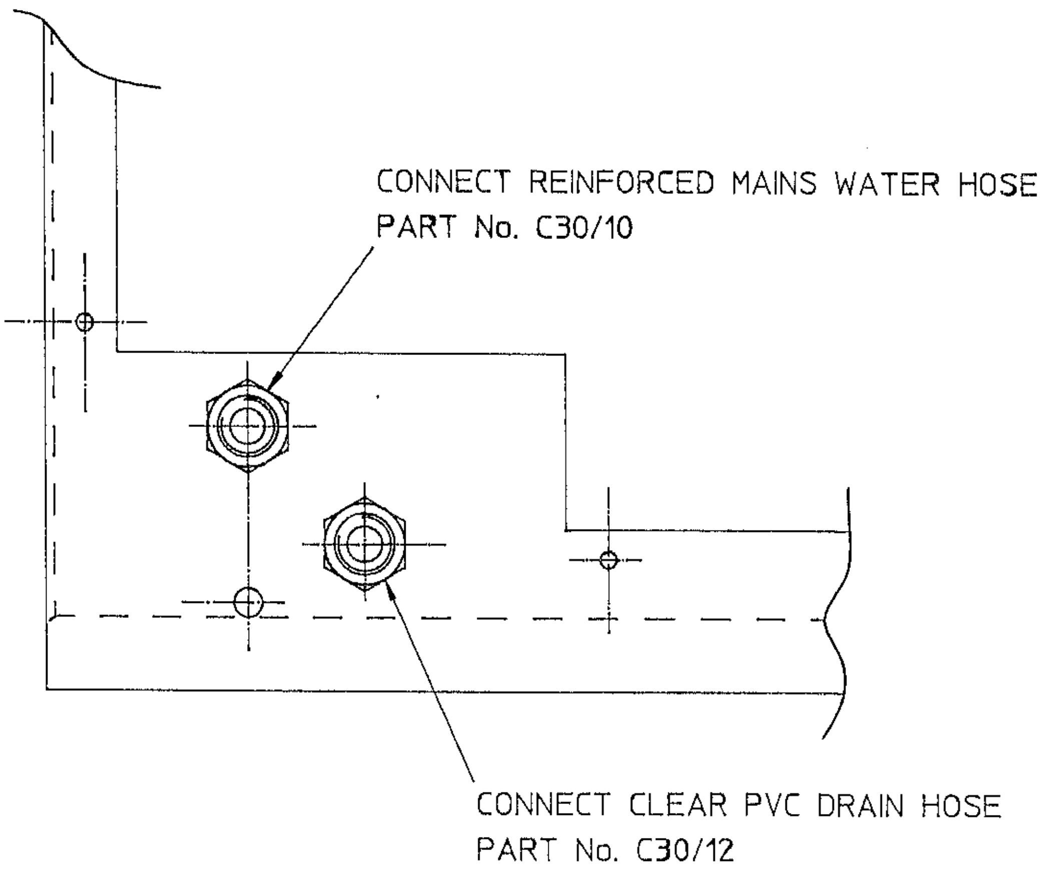
TITLE: H654 WIRING DIAGRAM 220/110V
TO BE USED ON UNIT
SERIAL No. H654/_ _ _ _ ONLY

P. A. HILTON LTD KINGS SOMBORNE HAMPSHIRE ENGLAND

Drawn by: GJF
Dimensions —
Projection:
Issue: 1
Date: 18 1 96
Scale: —
no/fig. —
DRG. No 65414M


MAINS
INPUT
110V
130V
125V
120V
115V
110V
0V NEUTRAL
EARTH
TO TERMINAL OF
INPUT VOLTAGE
240V
0V NEUTRAL
EARTH
OUTPUT
TO
UNIT
240V
Amendments
The supplier is required to deliver goods strictly according to drawing. Component inspection is the suppliers responsibility. Remove all sharp edges and burrs.
Limits unless otherwise stated : Fractions ± 1/64" Decimals ± 0.25 mm
TITLE: TRANSFORMER CONNECTIONS 110/120V UNITS
MTL.
FINISH
Drawn by: GJF
Checked by:
Dimensions: mm
Projection
Issue 1
Date 19.10.89
DRG. No.
TRAN100
Scale
no/rig
P. A. HILTON LTD . KINGS SOMBORNE HAMPSHIRE ENGLAND

WATER CONNECTIONS DIAGRAM



REAR VIEW OF PANEL