P.A. HILTON LTD.

EXPERIMENTAL

OPERATING

AND

MAINTENANCE MANUAL

REFRIGERATION CYCLE DEMONSTRATION UNIT

R633

R633M/E/1/580

FEB 96

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.

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.

P.A. HILTON LIMITED

Horsebridge Mill, King's Somborne,
Stockbridge, Hampshire, SO20 6PX,
England.

Tel No. National Romsey (01794) 388382
International +44 1794 388382

Fax No. +44 1794 388129

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Refrigeration Cycle Demonstration Unit R633

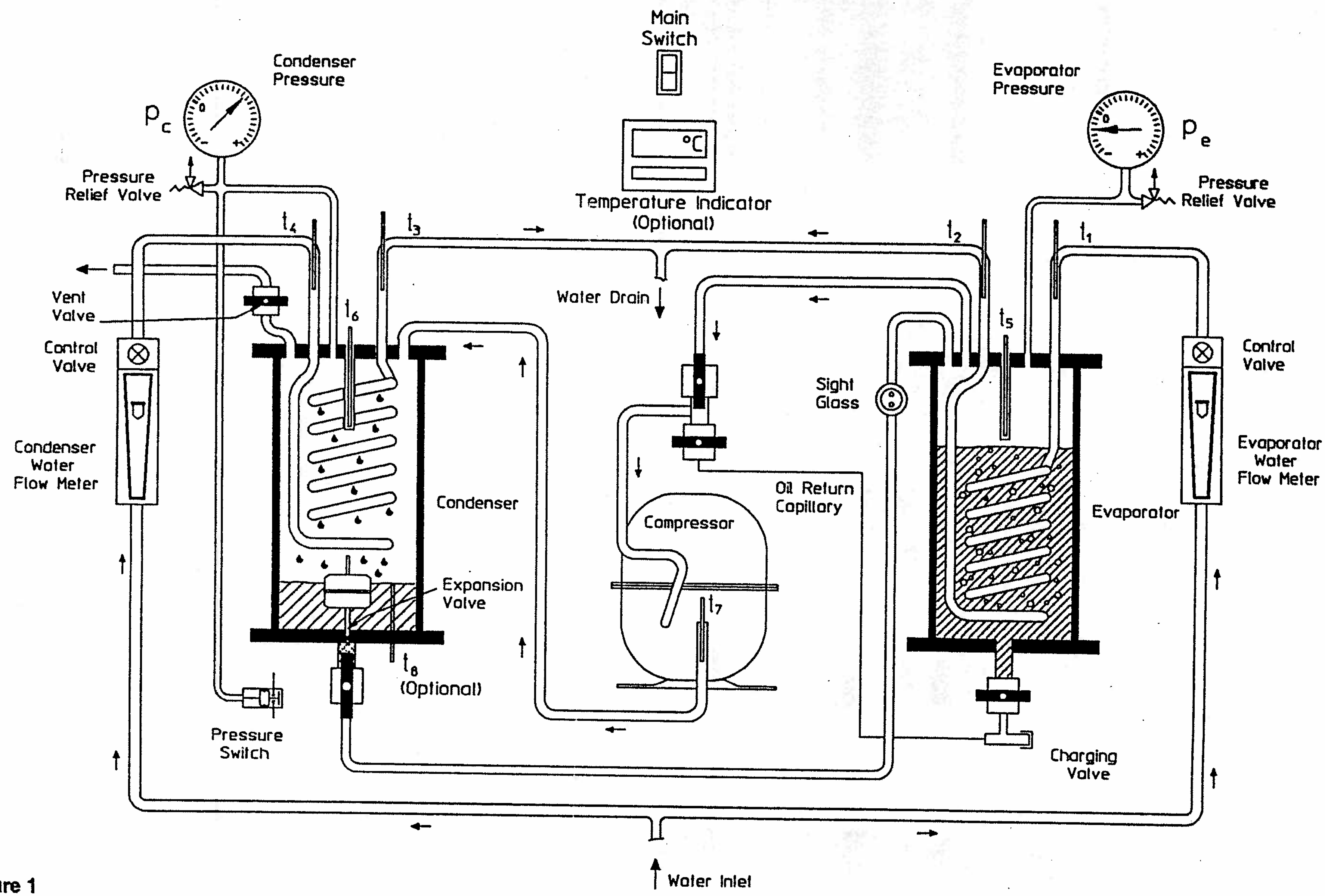
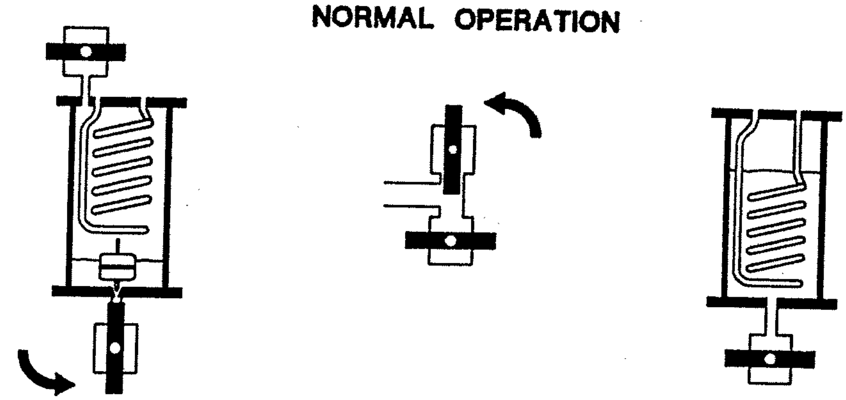


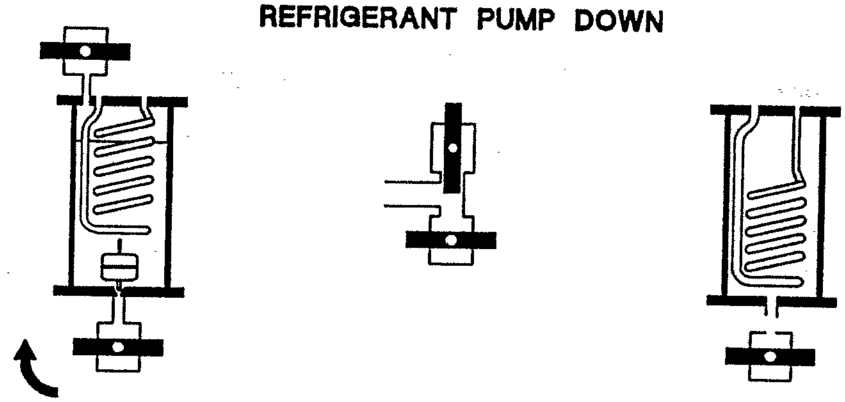
Figure 1

R633 Valve Positions

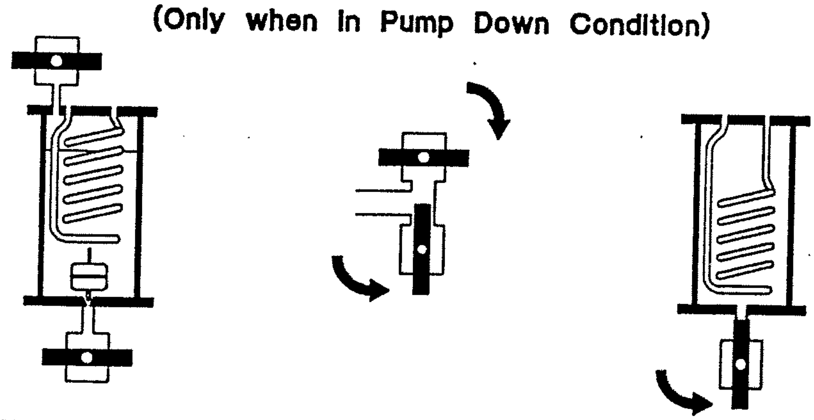
NORMAL OPERATION



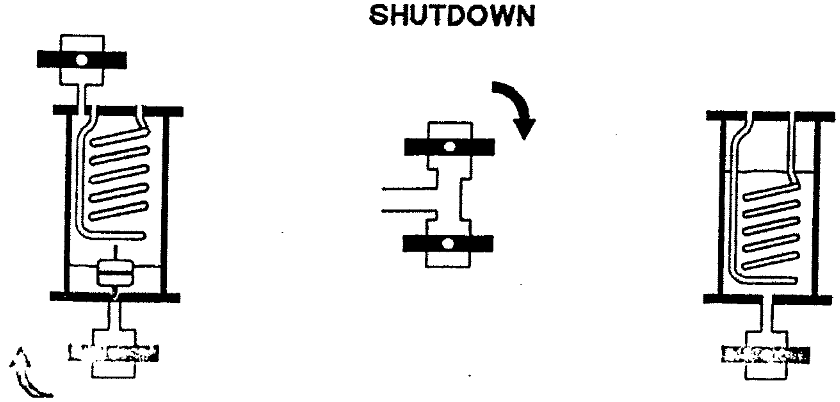
REFRIGERANT PUMP DOWN



OIL RETURN
(Only when in Pump Down Condition)



SHUTDOWN



SYMBOLS AND UNITS

Symbol		Unit
p_c	Pressure of Refrigerant in Condenser	$kN\ m^{-2}$ *
p_e	Pressure of Refrigerant in Evaporator	$kN\ m^{-2}$ *
$\dot{m}_c$	Water Mass Flow Rate through Condenser	$kg\ s^{-1}$
$\dot{m}_e$	Water Mass Flow Rate through Evaporator	$kg\ s^{-1}$
t_1	Temperature of Water entering Evaporator	°C
t_2	Temperature of Water leaving Evaporator	°C
t_3	Temperature of Water leaving Condenser	°C
t_4	Temperature of Water entering Condenser	°C
t_5	Evaporating Temperature	°C
t_6	Temperature in Condenser	°C
t_7	Compressor Discharge Temperature	°C
t_8	Condensed Liquid Temperature	°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 $\dfrac{p}{10^3\ Nm^{-2}}$	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 reading + atmospheric pressure

INTRODUCTION

The Refrigeration or Heat Pump Cycle:
A refrigerator is defined as a machine whose prime function is to remove heat from a low temperature region. Since energy cannot be destroyed, the heat taken in at a low temperature plus any other energy input must be dissipated to the surroundings. If the temperature at which the heat is dissipated is high enough to be useful, e.g. for space heating, the machine is then called a heat pump.

By selective design of the components the cycle may be optimised either for heat pump applications or for refrigeration applications. Indeed under certain applications both useful functions may be performed by one machine where circumstances permit. For example, in a dairy where refrigeration is required for milk cooling and storage and hot water is required for bottle or tank washing.

The Clausius Statement of the Second Law of Thermodynamics states that heat will not pass from a cold to a hotter region without the aid of an "external agency". Thus, a refrigerator will require an "external agency", i.e. an input of high grade energy, for it to operate.

This energy input may be in the form of work, or a heat transfer at a high temperature.

The most common type of refrigerator or heat pump uses a WORK INPUT and operates on the VAPOUR COMPRESSION CYCLE.

The Vapour Compression Cycle
The work input to the Vapour Compression Cycle drives a compressor which maintains a low pressure in an EVAPORATOR and a higher pressure in CONDENSER.

The temperature at which a liquid will evaporate (or a vapour will condense) is dependent on the pressure, thus if a suitable fluid is introduced it will evaporate at a low temperature in the low pressure evaporator (taking in heat) and will condense at a higher temperature in the high pressure condenser (rejecting heat).

The high pressure liquid formed in the condenser must then be returned to the evaporator at a controlled rate.

Thus, the simple vapour compression refrigeration cycle has four main components,

(1) An evaporator where heat is taken in at a low temperature as a liquid evaporates at a low pressure.

(2) A compressor which uses a work input to reduce the pressure in the evaporator and increase the pressure of the vapour being transferred to the condenser.

(3) A condenser where the high pressure vapour condenses, rejecting heat to its surroundings.

(4) A flow control device which controls the flow of liquid back to the evaporator and which brings about the pressure reduction.

The refrigeration cycle is most interesting from the thermodynamic view point. It is one of the few practical plants which operates on a true thermodynamic cycle and involves

(a) Nucleate boiling and filmwise condensation.

(b) Steady flow processes, i.e. throttling, compression and heat exchange.

(c) Flow control.

(d) The thermodynamic properties, i.e. pressure, specific volume, temperature, specific enthalpy and specific entropy, of a pure substance at all conditions between sub-cooled liquid and super-heated vapour.

Although the vapour compression cycle is simple to those who are familiar with it many students find great difficulty in visualising and understanding the events occurring within the various components.

With this in mind P.A. Hilton Ltd., designed the Refrigeration Cycle Demonstration Unit in which the major part of the cycle takes place inside glass chambers and can therefore be observed.

The unit is a valuable teaching aid for students in a wide range of courses from craft and technician training to first degree at a University or Polytechnic.

INSTALLATION AND COMMISSIONING

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.

Do not stand the unit in a position where it will be in strong direct sunlight for long periods. This may result in high chamber pressures with the subsequent loss of the refrigerant charge through the safety valves.

(i) The unit is fitted with two long life fluorescent lamps which for shipping are packed separately. In order to fit the lamps the rear panel of the machine must be removed.

Ensure that the machine IS NOT CONNECTED TO THE MAINS ELECTRICAL SUPPLY and remove the hexagonal bolts and one nut securing the rear panel. Note that the bolts are 8mm across flats and the correct size spanner is recommended.

The lamp sockets are located internally and are under the two vertical slots in the unit panel.

Carefully remove the lamps from their packing material and insert them in the white plastic sockets on the left hand and right hand sides of the panel. Support the sockets by hand as the lamps are inserted.

While the rear panel is removed ensure that the Residual Current Circuit Breaker switch situated on DIN rail the right side of the panel is in the ON position. The unit will have been left in the ON position when shipped but transit vibration or shock loading can cause the switched to jump to the OFF position.

(ii) Connect the mains water supply to the water inlet at the rear of the unit using the diagonal nylon reinforced hose. **When facing the rear of the machine the water inlet is on the extreme left of the panel.**

It is recommended that the water supply is fed through an isolating valve that can be turned off when the unit is not in use.

In order to increase the stability of the **condenser water flowmeter** and **evaporator water flowmeter** the control valves on these devices are fitted to the discharge side of the flowmeter. Hence if external damage results in the flowmeter tubes being broken an external isolating valve will be required to stop the flow of water from the unit.

(iii) Connect the remaining water coupling at the rear of the panel to a suitable drain using the clear plastic pipe provided.

(iv) 220/240V Units

Replace the rear panel BEFORE connecting the unit to the mains supply.

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 (for 5 Amps) 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 the green/Yellow cable should be connected to a low impedance earthing point that complies with the local regulations.

110/120V Units

The unit has an internally fitted transformer which is suitable for input voltages of between 110 and 130 Volts (110 to 130V in 5 volt steps). The integral supply lead must be connected to the nearest suitable voltage terminals and this can only be achieved by first removing the rear panel from the unit. The transformer is located on the right hand side of the unit when looking at the rear of the machine.

Before connection to the transformer, the local mean voltage between Line and Neutral should be measured, by a competent person, with a suitable meter. Until the transformer has been connected internally as described below the supply lead **SHOULD NOT BE CONNECTED TO THE LOCAL ELECTRICAL SUPPLY.**

The BROWN cable of the supply lead is connected to the 130V terminal of the transformer after testing at the factory. Once the local supply voltage has been measured the brown cable should be removed from the 130V terminal and should be connected to the nearest labelled voltage terminal on the transformer. See Figure 3 on Page 9.

The Blue cable is already connected to the 0V terminal on the transformer.

The Green/Yellow cable is connected to the Earth terminal on the transformer.

The rear panel may now be replaced.

The external free end of the supply lead may now be connected to the local electrical supply.

Connect the cable to a suitable fixed power supply via a fused outlet (for 10 Amps) 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 the Green/Yellow cable should be connected to a low impedance earthing point that complies with the local regulations.

(v) The standard instrumentation kit includes five 0°C to 50°C thermometers and two -10°C to 110°C thermometers.

One of the -10°C to 110°C thermometer should be inserted in the central thermometer pocket located in the condenser top plate and the other in the compressor discharge pocket t_7. The remaining thermometers should be inserted in the evaporator top plate pocket and the four identical evaporator and condenser cooling water pockets at the ends of the evaporator and condenser coils.

It is recommended that in order to improve the resolution of the thermometers a few drops of light machine oil is added to each thermometer pocket. This will help to improve thermal contact between the thermometers and the pockets.

(vi) If the instrumentation upgrade has been ordered at a later date the fitting of the kit is detailed in Appendix A in this manual.

(vii) A schematic diagram of the machine components is supplied on an A3 (420mm x 297mm approximately) sheet and a diagram showing the valve positions for operation is supplied on an A4 (297mm x 208mm approximately) sheet.

Two L shaped clear plastic schematic holders are supplied to contain the diagrams and these may either be suspended on a chord and hung on a wall adjacent to the unit or alternatively clipped to the top of the unit.

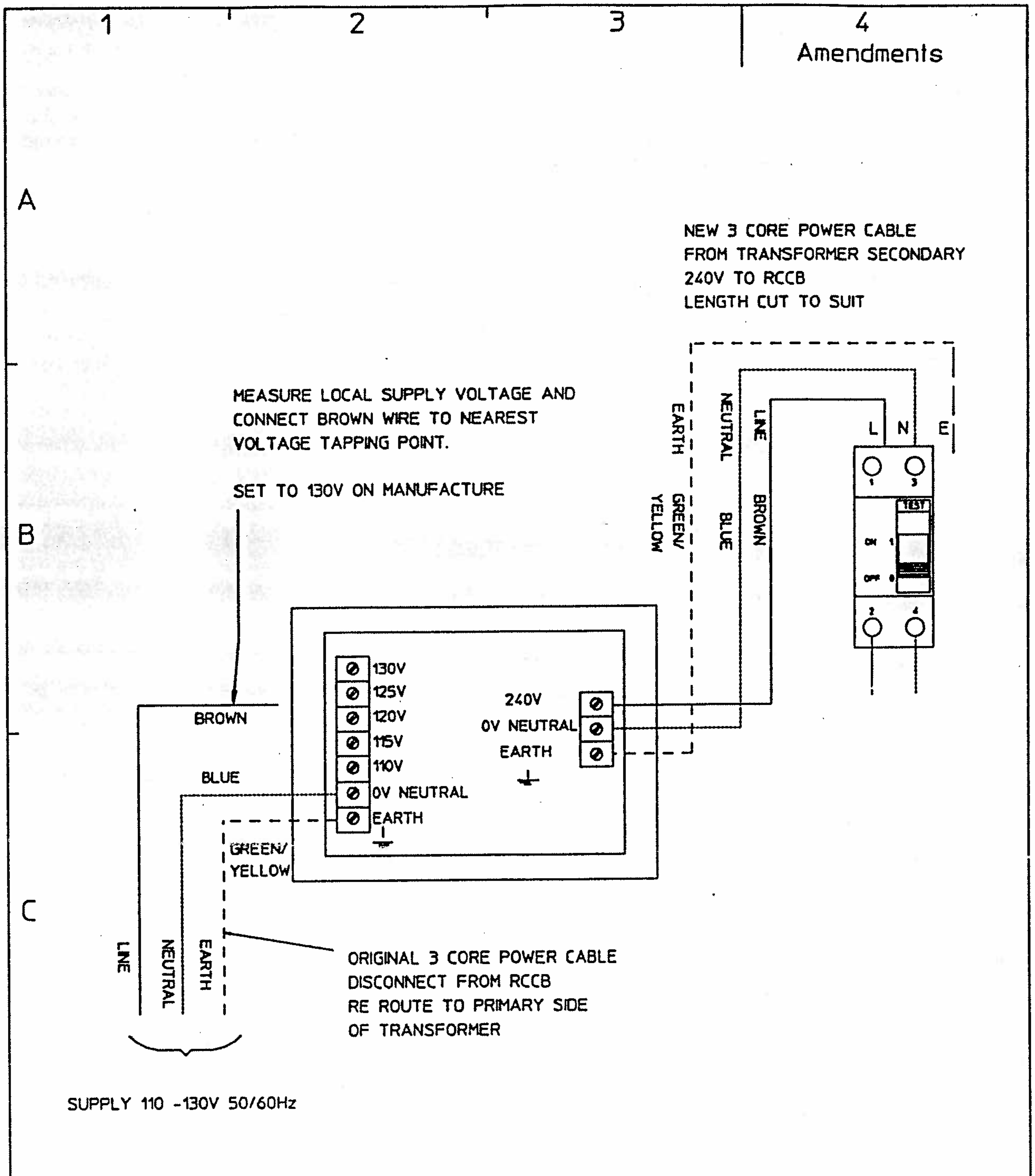
If the diagrams are to be fitted to the panel then it will be necessary to fit the four clips supplied to the top of the panel.

Brass M3 threaded inserts are already fitted to the top of the panel and these are used with M3 x 6mm pan head set screws to fix the four spring clips supplied in position.

The clips should be fitted with the OPEN end facing toward the front of the panel.

The L shaped clear plastic schematic holders are then slid under the spring clips.

In order to utilise the plastic cover for the unit the L shaped schematic holders may be removed and stored under the unit panel.



The supplier is required to deliver goods strictly according to drawing. Component inspection is the suppliers responsibility. Remove all sharp edges and burrs.	Drawn by: JB Dimensions: mm	Checked by:
Limits unless otherwise stated : Fractions ± 1/64" Decimals ± 0.25 mm	Projection: Issue: 1	
TITLE: 110 - 130V TRANSFORMER WIRING DIRGRAM	Date: 4.3.96	DRG. No 63338S
MTL. ————	Scale. —	
FINISH: ————	no/rig 1	

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Figure 3

THE HILTON REFRIGERATION CYCLE DEMONSTRATION UNIT

USEFUL DATA

Condenser: Water coil surface area: $0.032 m^2$

Evaporator: Water coil surface area: $0.032 m^2$

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

Refrigerant: R141b 1,1,-dichloro-1-fluoroethane

Quantity: approximately 800 cm^3 (approximately 1 kg)

SPECIFICATION

Compressor

Hermetic type compressor with integral 1/2 Horsepower motor drawing approximately 810 Watts. The compressor is a single cylinder reciprocating type with a displacement of 17.4 cubic centimetres.

Condenser

Vertical, thick walled high strength glass cylinder with flared ends to give tension free connection to nickel plated brass end plates with P.T.F.E. seals. Cooling surface - 9 coils of 6.3 mm dia copper tube through which water flows, fitted to upper end plate. Cooling area 0.032 m^2. Ball valve at the base of the condenser allows refrigerant charge to be contained within the condenser for demonstration purposes.

Evaporator

Flooded type - construction similar to condenser but with copper tube surface specially treated to promote nucleate boiling.

Expansion Valve

Float operated needle valve fitted in condenser base plate.

Instruments
(Standard Unit)

Pressure gauges - Two
Range -100 to +250 kN m^{-2} gauge.
To indicate evaporator and condenser pressures.

Thermometers - Seven
Five, Range 0°C to 50°C x 150mm long, glass.
Two, Range -10 to 110°C x 150mm long, glass.
Fitted in brass pockets to indicate water inlet and outlet temperatures at condenser and at evaporator, evaporation temperature, condensation temperature and compressor discharge temperature.

Flow meters - Two
Tapered glass tube type, with stainless steel indicator float, each fitted with a control valve. Range 0 to 50 gramme s^{-1}. To indicate and control water flow rate through evaporator and condenser coils.

Optional Upgrade Instrumentation
(Not supplied unless specifically ordered)

A 12 way digital temperature indicator fitted with 8 stainless steel sheathed type K thermocouples to replace the 7 standard thermometers and to measure in addition the condensed liquid temperature at station t_8 (see schematic diagram). The digital temperature indicator replaces the blanking plate in the centre of the standard panel and may easily be fitted by the customer or if purchased with the standard unit can be a factory fitted option.

Charging Valve

Fitted to base of evaporator - used to introduce or discharge refrigerant.

Sight Glass

Fitted in pipe between expansion valve and evaporator - to show generation of vapour bubbles after the expansion valve.

Oil Return Capillary

Combined with integral ball valves to allow oil to be simply returned to the compressor in a controlled manner.

SAFETY

No moving parts.
Internally mounted relief valves set to 250 kN m^{-2} gauge fitted to condenser and evaporator.
High pressure cut out fitted to stop compressor if condenser pressure exceeds 220 kN m^{-2} gauge.

Main switch is a combined double pole miniature circuit breaker and overload cut out.
30mA imbalance Residual Current Circuit Breaker fitted.

Panel — Constructed from G.R.P. - attractive moonstone wipe clean finish.

DIMENSIONS

Height	760mm
Width	760mm
Depth	430mm
Weight	60 kg 220V units (+10kg for 110V units)

CAUTION

This unit has been specifically designed to operate at low pressure on R141b and no other refrigerant should be charged into the system as damage to the compressor or other components will be the result.

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

All components are mounted on an attractive durable glass reinforced plastic panel.

The evaporator is a vertical glass cylinder with plated metal end plates. A helical coil of copper tube conveys water through a pool of refrigerant in the cylinder. The compressor draws vapour from the evaporator thereby reducing pressure in the evaporator and this causes the refrigerant to boil at a low temperature. In order to boil, or change phase from a liquid to a vapour, heat is required and this is extracted from the water passing through the copper coil and to a lesser extent from the surroundings. As heat has been extracted from the water its temperature is reduced.

The compressor is an hermetic type similar to those found in many domestic refrigerators. The compressor is inside the hermetically sealed casing and is directly coupled to an electric motor.

Vapour from the evaporator is drawn into the compressor casing and then into the compressor itself where its pressure is raised before being discharged to the condenser. Having had work done on the gas its temperature is increased as well as its pressure.

The condenser is also a vertical glass cylinder fitted with plated metal end plates, the upper one supporting a helical coil of tube through which cooling water flows. The hot high pressure vapour from the compressor cools and condenses as it transfers heat to the cooling water inside the nickel plated copper coil. As heat is transferred to the cooling water its temperature is increased.

The cooled high pressure liquid collects in the bottom of the condenser and its level controls a float operated expansion valve. This valve reaches an equilibrium position and discharges refrigerant liquid back to the evaporator at the same rate as it is formed.

As the warm high pressure liquid passes through the valve seating its pressure decreases to that in the evaporator and its temperature must fall to the saturation temperature at the lower pressure. The fall of temperature is accompanied by the formation of vapour bubbles and these may be seen through a sight glass fitted in the pipe returning the liquid/vapour mixture to the evaporator.

On entering the evaporator the low pressure liquid and vapour separate, the liquid passing into the "pool" for re-evaporation, while the vapour mixes with the vapour produced by the boiling action of the water coil. The vapour mixture then returns to the compressor to repeat the cycle.

In the standard unit instrumentation is provided to measure:

(i) The temperature and pressure of the refrigerant vapour in the evaporator and condenser.

(ii) The temperature of the water entering and leaving the coils in the evaporator and condenser.

(iii) The water flow rates through both coils.

(iv) The temperature of the hot gas leaving the compressor.

All temperatures are measured on the standard unit using red spirit thermometers.

An **optional** digital temperature upgrade kit is available that allows measurement of the temperature of the condensed liquid t_8 as well as the above list of temperatures.

With the addition of this optional upgrade the complete cycle diagram may be plotted on an R141b pressure-enthalpy diagram.

An isolating valve is fitted at the condenser outlet and this may be closed to demonstrate a technique used in refrigeration maintenance where the refrigerant charge is collected and contained in the condenser or in most cases a specialised liquid receiver adjacent to the condenser.

This technique is important in order to demonstrate how to prevent the escape of refrigerant during maintenance.

In common with all refrigeration and heat pump systems the unit contains a small amount of oil for lubrication of the compressor. During normal operation some oil, in the form of mist and oil/refrigerant solution is carried from the compressor to the condenser and ultimately to the evaporator where it collects. In order to return this oil to the compressor casing in a controlled manner a valve at the base of the evaporator connects an oil return capillary to the suction side of the compressor via a second valve.

For operator safety the refrigerant used has a very low pressure for a given temperature (vapour pressure at 20°C is 0.81 Bar absolute). In addition the unit is fitted with a pressure switch to turn off the compressor if the condenser pressure exceeds 220 kN m^{-2}.

For added safety and to allow operation by students, both the condenser and evaporator are fitted with relief valves mounted inside the instrument panel.

In order to vent any air introduced into the system during demonstration a ball valve is situated on the condenser top plate. This allows air to be vented via a pipe to the inside of the panel.

OPERATING PROCEDURE

(Please refer to Figure 1 - Schematic Diagram, and Figure 2 - R633 Valve Positions diagram)

To assist in understanding operation, item names and relevant items on the two schematic diagrams supplied are referred to in bold type in the following sections. For example, **Refrigerant Pump Down** on Figure 2 and **Condenser or Evaporator etc** on Figure 1.

The five ball valves shown on the two schematic diagrams have been installed for specific purposes. Figure 2 (Page 2) diagram shows the four standard valve combinations.

The **vent valve** on the condenser is normally only opened briefly to vent air from the system and this is referred to elsewhere.

Note that when the unit is shut down the ball valves should ALL be in the closed position. This prevents the refrigerant migrating to the lowest temperature part of the system due to vapour pressure effects and in most cases this would be the compressor casing as this will respond most rapidly to variations in ambient temperature.

Normal Operation

To start the unit first turn on the cooling water supply and the mains supply to the unit.

Open the valves indicated in Figure 2 (Page 2) for **Normal Operation.**

This allows vapour to be drawn from the **evaporator** by the **compressor** and for condensed liquid to return to the evaporator from the condenser.

Turn on the water supply to the unit and adjust the **control valves** on the **evaporator water flowmeter** and **condenser water flowmeter** to give approximately 20-30 g/s flow rate.

Turn on the main switch and the compressor will start and the two internal lamps will light.

If the **optional temperature indicator** is fitted then the display on this will also illuminate.

Evaporation Process

As the compressor runs the condenser pressure p_c will rise and the evaporator pressure p_e will fall. If the water supply temperature is high (approximately 16°C or more) then the boiling action should be readily visible from several points on the submerged evaporator coil. In order to promote evaporation from the coil surface the coil has been specially treated to provide many bubble nucleation sites.

If the water temperature is low then the evaporator pressure will need to reach a lower value and boiling may occur from single sites on the coil, from the surface of the liquid adjacent to the coil/surface interface or from the baseplate of the evaporator.

To induce further evaporation from other sites open the ball valve at the base of the evaporator. DO NOT open the **charging valve** as this will allow air to enter the system.

Opening the ball valve at the base of the evaporator will cause the oil return capillary to become part of the evaporator and the resulting large increase in heat transfer surface area relative to the small volume of liquid in the capillary will result in vapour appearing from the base of the chamber.

This technique is also used when completing **refrigerant pump down.**

During **normal operation** once nucleation has been activated from other sites within the chamber then the ball valve at the base of the chamber may be closed.

Unless the supply water temperature is high then alteration of the evaporator water flow rate will have a relatively small effect on the evaporator pressure.

However if the evaporator water flow is turned off completely then the evaporator pressure will reduce slowly until evaporation occurs from some other source surface using heat transferred from the surroundings.

Condensation Process

The vapour is drawn from the evaporator into the compressor and both its pressure and temperature are raised. The hot high pressure passes through the insulated pipe to the condenser.

The temperature of the gas leaving the compressor may be measured by the thermometer in pocket t_7. Note that if the compressor is run for long periods with the condenser pressure high then the temperature here can reach 80°C.

As the gas passes through the insulated pipe there will be some heat loss and after an initial warming up period of operation this will result in the gas being partially de-superheated before it enters the condenser. In fact just after starting, when the unit is cold, the gas entering the condenser chamber may even be partially condensed and droplets of liquid will be seen dripping from the top plate.

The gas entering the condenser under normal operation will be in a superheated condition and will initially desuperheat and then condense on the water cooled coils.

Adjustment of the **control** valve on the **condenser water flowmeter** will allow the condenser pressure to be increased or decreased.

To increase the condenser pressure reduce the cooling water flow rate.
To reduce the condenser pressure increase the cooling water flow rate.

The condenser pressure will also be effected by the inlet temperature of the cooling water. For the same water flow rate the condenser pressure will be lower if the inlet cooling water temperature is lower. The inlet water temperature will therefore limit the minimum achievable condenser pressure.

As the liquid expands through the float controlled valve at the base of the condenser some evaporation of the liquid begins to occur immediately downstream of the valve.

The valve is physically attached to the base plate of the condenser and therefore some of the heat required to bring about this phase change is extracted from the liquid at the base of the condenser. This has the effect of subcooling the liquid below the saturation temperature associated with the measured pressure shown on the **condenser pressure** gauge.

If the **optional temperature indicator** is fitted then an additional thermocouple t_8 is supplied to be fitted in the base of the condenser chamber. Hence the sub cooled liquid temperature may be measured and this together with the other measured temperatures and pressures allows a complete refrigeration cycle diagram to be plotted on the pressure-enthalpy diagram supplied.

The experimental procedures detailed elsewhere involve operation of the various ball valves and variation of the condenser pressure in order to achieve various operating conditions. These procedures are detailed in the individual experimental procedures.

Shutting Down the Unit

In order to shut down the unit it is recommended that if the refrigerant charge has been **pumped down** (transferred to the condenser chamber) then the valve at the base of the condenser is opened and the system allowed to return to a normal running condition before the machine is finally shut down.

Normal running condition is with approximately 20-25mm of liquid in the bottom of the condenser chamber and the float valve maintaining this level constant.

Once normal operating conditions have been achieved then the **main switch** should be turned off. The compressor will stop and the lights on the unit will be extinguished. If the **optional temperature indicator** has been fitted the display on this too will be extinguished.

Turn off the cooling water supply to the unit. It is recommended that the (water) **control valves** are left open so that if the user supplied external isolating valve leaks water will be allowed to run to drain and will be noticed more readily. In addition, if conditions are such that the water supply is likely to freeze then leaving the **control valves** on the flowmeters open may not prevent the glass tubes being broken but it will make breakage less likely.

Once the unit has been turned off then the ball valves on the unit should be closed to mimic the **shutdown** condition. See Figure 2 (Page 2).

This will prevent the large volume of refrigerant contained in the evaporator migrating into the compressor casing due to vapour pressure changes. The small volume of liquid in the condenser **may** migrate to the compressor under certain ambient conditions but this is no cause for concern.

Refrigerant Pump Down

This is a procedure often used in industrial and commercial refrigeration practise where the refrigerant charge is condensed and collected either in the condenser itself or more commonly in a liquid receiver. In the Refrigeration Cycle Demonstration Unit R633 the condenser and liquid receiver are combined in the same glass cylinder.

In order to carry out pumping down the unit should have been operating normally for several minutes with an evaporator and condenser cooling water flow rate of approximately 40 gs^{-1}.

By setting the valves as shown in the **Refrigerant Pump Down** diagram in Figure 2 (Page 2) the flow of condensed liquid from the base of the condenser is stopped and liquid will therefore continue to collect in the condenser chamber.

As liquid transfers from the evaporator the level will fall and less of the evaporator coil surface will be effective in evaporating the liquid. The evaporation rate will reduce and the process will become slower. This effect may be offset as the liquid level becomes very low by opening ONLY the ball valve at the base of the evaporator.

This will have the effect of utilising the capillary surface area and ambient air temperature to evaporate additional liquid.

If before pumping down the unit has been operated for a prolonged period, the liquid collected at the base of the evaporator may appear thicker and less viscous. It may also appear slightly yellow in colour. The liquid remaining in the evaporator is primarily the oil that has been carried over in the form of mist and refrigerant oil mixture from the compressor.

The oil will not evaporate at the pressures achieved by the compressor and therefore it must be physically returned to the compressor casing.

Note that the unit should not be **SHUT DOWN** when the refrigerant charge is in the **PUMP DOWN** condition as under certain ambient conditions it is possible for the charge to migrate to the compressor casing.

Oil Return (Only when in Pumped Down Condition)

Once the unit has been pumped down as described above, the oil may be returned to the compressor by setting the ball valves to the positions as shown for **Oil Return** in Figure 2 (Page 2). The condenser cooling water and evaporator water flow rates are left as for normal running and the unit remains switched on. The only path from the evaporator to the compressor is via the capillary tube.

The oil in the base of the evaporator will start to flow through the capillary back to the compressor casing.

The evaporator chamber may be at low pressure and therefore the oil return process will be slow due to the low differential pressure. This may be increased and the process speeded up if a small amount of refrigerant liquid is admitted to the evaporator by briefly opening the ball valve at the base of the **condenser. However DO NOT leave this valve open.**

Once the oil has been returned to the compressor casing then the ball valves may be returned to the position for **normal operation** as shown in Figure 2 (Page 2).

Once the operating conditions have returned to normal and the liquid level in the condenser is approximately 20-25mm then the unit may be either shut down as described above or adjusted for further experiment.

Air Venting

A **vent valve** is situated on the top of the condenser and this allows air that has been admitted to the system to be safely vented into the void inside the instrument panel.

Air that enters the system usually from the **charging valve** as part of an experiment will be swept into the compressor by the flow of vapour from the evaporator and from here to the condenser where it will collect around the condenser coils. The air will remain in this area and effectively present an insulating barrier to vapour transfer, condensation and hence heat transfer. The nett result will be a chamber pressure that is far greater than should be the case for the condensing temperature t_6 indicated.

Unless demonstrating the effects of air in a condenser it will be necessary to vent the air from the system. The oil utilised in the compressor is hygroscopic and air admitted to the system is likely to bring with it water vapour. This should therefore be vented from the system.

To vent air from the condenser it is necessary to increase the condenser pressure to approximately 50kN m^{-2} above atmospheric pressure.

With the unit running normally, close the **control valve** on the **condenser water flowmeter**. This will cause the condenser pressure to rise. The time taken to reach 50kN m^{-2} above atmospheric pressure will depend upon the local ambient temperature and the amount of time that the unit has been running.

Once 50kN m^{-2} is reached the vent valve should be **briefly** opened and gas will be heard to enter the void inside the panel. Close the valve well before the gauge pressure reaches 0 kN m^{-2}.

MAINTENANCE

High Pressure Cut Out

At regular intervals and according to the local safety regulations the high pressure cut out should be tested as follows:

Start the unit as detailed for **normal operation** in the **operating procedure** on Page 15 and operate with a moderate cooling water flow to both the condenser and evaporator as detailed.

Allow the unit to warm up and then close the **control** valve on the **condenser water flowmeter.**

This will cause the condenser pressure to rise. At approximately 220kN m^{-2} the compressor should be shut down by the internal high pressure cut out. An audible click should be heard from the cut out device.

If the compressor does not turn off automatically at a pressure of 230kN m^{-2} then **turn off the unit at the main switch. It will then be necessary to adjust the pressure switch as detailed below.**

If the compressor does turn off automatically, open the **control valve** on the **condenser water flowmeter** and the condenser pressure will immediately reduce. Once the pressure reduces to approximately 120kN m^{-2} the compressor should automatically restart.

Adjustment of High Pressure Cut out

The following procedure should only be carried out by a competent person and the compressor high pressure cut out **must never be set to operate at a pressure exceeding 220kN m^{-2} for any reason.**

Isolate the unit from the mains and remove the rear panel. The high pressure cut out is located above the compressor casing on the internal panel surface. The cut out is connected by a coiled copper capillary tube to the **condenser pressure** gauge.

The cut out has two adjusting screws on its top surface which may be covered by a plastic cap secured by a single screw. Remove the plastic top cover and to adjust the cut out pressure turn the screw with the larger range. The cut out devices are commercial devices and the pressure indicated on the scale may not match the cut out pressure indicated by the pressure gauge which is of much higher accuracy. Only turn the screw a small increment at a time and then retest in order to obtain an estimate of its effect.

By this method the cut out pressure may be set to 220kN m^{-2}.

The smaller range scale usually labelled "DIFF" indicates the difference between the cut out and restart pressures. This should usually be set at approximately 120kN m^{-2} in order to ensure that the starting load on the compressor is minimised.

After adjustment the rear cover should be replaced.

Thermometers

Due to the relatively small temperature differences between water inlet and outlet temperatures, it is advisable to calibrate the thermometers by placing them all in a container of water.

All of the thermometers should be marked in some way for identification and one selected as the reference. Alternatively, if a known standard is available this should be used.

Stir the water for about 2 minutes and record the indicated temperatures on each of the thermometers. This should give a table of small differences from the "reference" thermometer.

These differences may be added or subtracted from the readings as appropriate.

If greater accuracy is required then the water may be gently warmed and the differences noted at several temperatures. In this case a graph of indicated against difference should be plotted for each thermometer.

If the **optional temperature indicator** has been fitted then the above difference calibration will not be necessary as all thermocouples are switched in turn through to the same indicator unit.

Miniature Circuit Breaker (MCB)

The **Main 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 investigated by a competent person.

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.

Testing the RCCB

The RCCB should be tested by a competent person at intervals that comply with the local regulations.

Remove the rear panel and switch on the unit.

The RCCB will be found on the right hand side of the unit when looking into the rear of 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.

Panel

This may be cleaned with a mild detergent and then polished with a soft cloth. Abrasive cleaners must not be used.

The plastic dust cover provided should be kept in position when the unit is not in use.

Checking for Leaks

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

(A) If there is refrigerant in the system:

Place the unit in a warm place until its temperature reaches 32-35°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 an electronic leak detector.

(B) If there is no refrigerant in the system:

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 evaporator. The leak may then be located as in A.

Charging or Recharging

Under normal conditions the vapour pressure of the refrigerant does not reach atmospheric pressure until the liquid is at a temperature of approximately 32°C.

In order, therefore, to make charging the unit simpler, the one trip can supplied by P.A. Hilton Ltd contains a small amount of Nitrogen gas in order to raise the internal pressure artificially.

Before charging it is recommended that the unit is set up in the following way:

Start the unit as detailed for **normal operation** in the **operating procedure** on Page 15 and operate with a moderate cooling water flow to both the condenser and evaporator as detailed.

Allow the evaporator pressure to reduce and then position the ball valves for **shutdown** condition (see Figure 2 - Page 2) and turn off the compressor. Note that if the unit is not charged and contains air then it may be necessary to vent this from the condenser via the **vent valve** on the condenser top plate.

The unit is now ready for charging.

The charge can only be released from the can by using the brass charging valve (VC27/2) supplied in the accessories kit.

Unscrew the small brass hexagonal nut from the charging valve and screw this onto the thread on the top of the can. Screw the rest of the charging valve (VC27/2) into the **straight connector** on the refrigerant charging line (C45/2), also supplied in the accessories kit.

Remove the brass cap from the fixed **charging valve** at the base of the evaporator on the R633 unit.

Note that the **angled end** of the refrigerant charging line has a brass pin in the centre of the connector. This end should be connected to the fixed **charging valve** on the base of the evaporator. When the connector is screwed tight the pin depresses the centre of the fixed charging valve and allows access to the evaporator.

The can should be inverted and the two components of the brass charging valve should be screwed together by rotating the can. See Figure 4, Page 22. When the components of the charging valve are screwed together the refrigerant will flow into the charging line due to the nitrogen pressure in the can. Open the ball valve at the base of the evaporator and the refrigerant will flow into the evaporator.

Switch on the unit and this will again reduce the evaporator pressure and assist the flow of the refrigerant into the evaporator.

When the liquid level in the evaporator is above the level of the top coil close the ball valve at the base of the evaporator.

Allow the unit to run under normal operating conditions until the liquid level in the condenser has stabilised. Ensure the liquid level is still above the top coil of the evaporator. If this is not the case then open the ball valve at the base of the evaporator briefly until the required level is achieved.

Unscrew the charging line from the can and this will close the valve in the can. The ball valve at the base of the evaporator can be briefly opened to draw in any liquid remaining in the charging line.

The charging procedure is likely to result in some air entering the system. To remove the air follow the procedure for **Air Venting** described on Page 18.

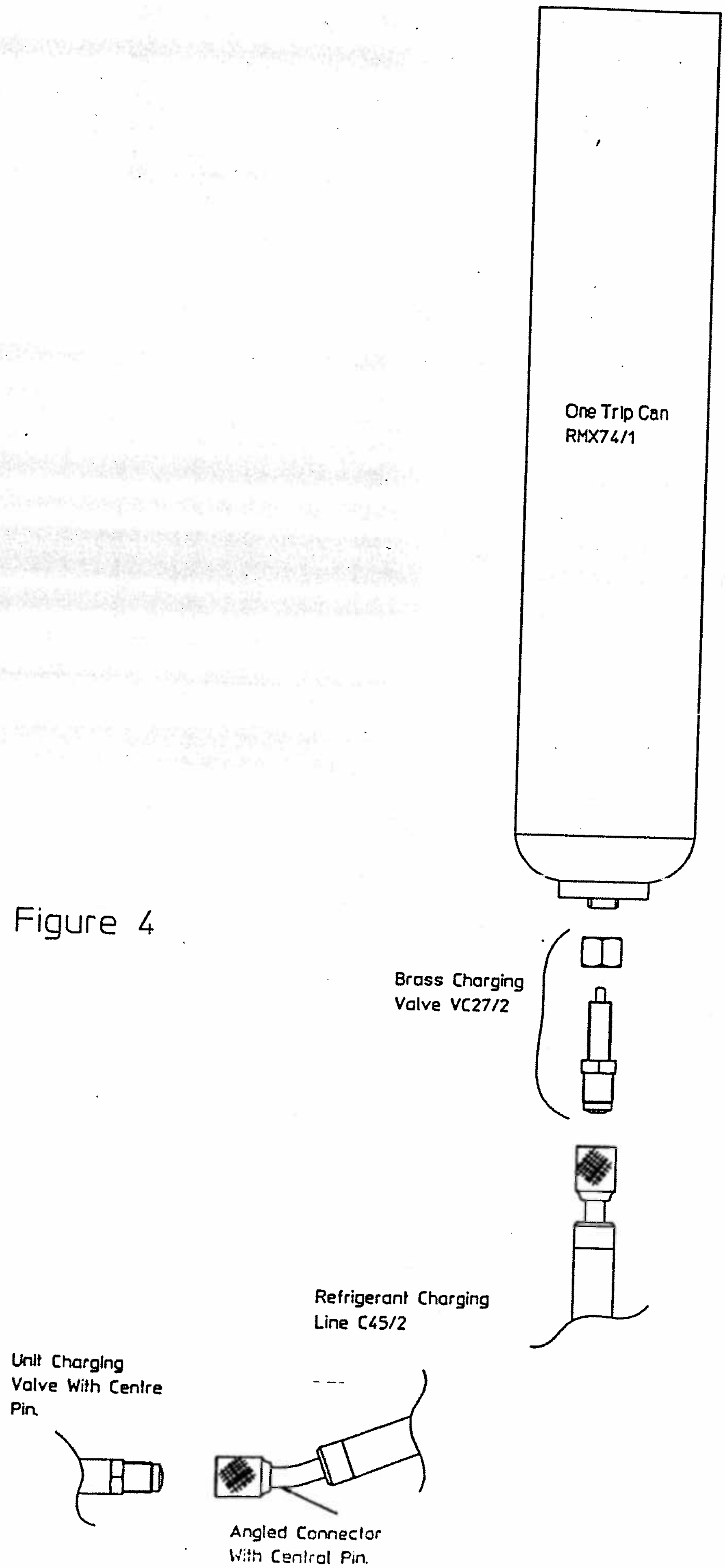

One Trip Can
RMX74/1
Brass Charging
Valve VC27/2
Refrigerant Charging
Line C45/2
Unit Charging
Valve With Centre
Pin.
Angled Connector
With Central Pin.

Figure 4

CAPABILITIES OF THE REFRIGERATION CYCLE DEMONSTRATION UNIT

1. Demonstration of vapour compression refrigeration or heat pump cycle with visual observation of the important processes.

2. Investigation/demonstration of the saturation pressure-temperature relationship during evaporation and condensation.

3. Demonstration of "pumping over" or "pumping down" into the condenser.

4. Demonstration of charging.

5. Demonstration of effect of air in a refrigeration system.

6. Determination of effect of evaporating and condensing temperatures on the refrigeration rate and condenser heat output.

7. Investigation of the effect of compressor pressure ratio on system performance.

8. Determination of overall heat transfer between R141b and water in the evaporator and condenser.

With the addition of the optional temperature indicator:-

9. Generation of a refrigeration cycle diagram on a pressure-enthalpy chart.

1. DEMONSTRATION OF VAPOUR COMPRESSION REFRIGERATION OR HEAT PUMP CYCLE

The experiment should begin with the unit at rest, having been left in the **shutdown** (See Figure 2, Page 2) condition for some time in order for all of the components to be at a similar ambient temperature.

Open the ball valves on the cylinders as for **normal operation** (See Figure 2, Page 2) but do not turn on the unit and do not turn on the water supply to the evaporator and condenser coils.

The students should note that all of the system temperatures and pressures are "approximately similar" (assuming that the unit has not been left standing in bright sunlight and that there is liquid visible in both the condenser and evaporator).

Turn on the unit and water supplies as detailed for normal operation on Page 15.

(i) Note that as the compressor draws vapour from the evaporator the pressure in the evaporator falls. Similarly as the vapour is compressed by the compressor and passed to the condenser the pressure in the condenser rises.

(ii) As the pressure in the evaporator falls the liquid will begin to boil due to the reduced pressure. The boiling action is the refrigerant changing from its liquid phase through to a vapour phase. Reference should be made to the Pressure Enthalpy diagram on Page 53 or the large encapsulated diagram (C57/10) supplied in the accessories kit.

In order to change phase at constant pressure, energy is required to increase the enthalpy of the vapour. This energy is taken from the water passing through the evaporator coil and, depending upon the water inlet temperature and the local ambient temperature, the surrounding atmosphere.

If the water supply temperature is high (approximately 16°C or more) then the boiling action should be readily visible from several points on the submerged evaporator coil. In order to promote evaporation from the coil surface the coil has been specially treated to provide many bubble nucleation sites.

If the water temperature is low then the evaporator pressure will need to reach a lower value and boiling may occur from single sites on the coil, from the surface of the liquid adjacent to the coil/surface interface or from the baseplate of the evaporator.

To induce further evaporation from other sites open the ball valve at the base of the evaporator. DO NOT open the **charging valve** as this will allow air to enter the system.

Opening the ball valve at the base of the evaporator will cause the oil return capillary to become part of the evaporator and the resulting large increase in heat transfer surface area relative to the small volume of liquid in the capillary will result in vapour appearing from the base of the chamber.

If the capillary tube is touched under these operating conditions then the surface will feel cold.

When the vapour bubbles are being produced from the evaporator coil within the evaporator chamber then heat is being extracted from the cooling water flowing through the coil. If the evaporator inlet water temperature t_1 is examined after several minutes operation and this is compared with the water discharge temperature t_2 the discharge temperature should be found to be slightly lower than the inlet temperature. In order to increase the apparent temperature difference, the evaporator water flow rate may be reduced.

If the evaporator cooling water flow rate is stopped completely then it is likely that boiling from the water coil will stop and the evaporator pressure will reduce further until another source of heat is found. This is most likely to be the base plate as heat is conducted from the outside air. In addition, depending upon the local ambient conditions, water vapour will also condense on the outside surface of the glass cylinder and base plate. The change in phase of the water vapour to a liquid will in itself provide heat to cause evaporation of the refrigerant in the chamber.

In addition, if the evaporator cooling water flow is stopped then the rate of condensation forming on the condenser coils will also reduce due to the reduced vapour generation rate in the evaporator and the reduced volumetric efficiency of the compressor and increase in specific volume of the vapour generated in the evaporator chamber at low pressure.

(iii) With the evaporator and condenser water again flowing as described in the **normal operation** conditions on Page 15 the condenser pressure should be observed.

The condenser pressure will be seen to be higher than that of the evaporator. This is obviously due to the compressor. The ratio of condenser pressure to evaporator pressure, P_c/P_e, is known as the compressor Pressure Ratio. This will vary under different operating conditions and may be investigated.

After the unit has been running for several minutes under normal conditions the condenser cooling water inlet temperature and the discharge temperature should be compared.

It will be found that the discharge temperature t_3 is greater than the inlet temperature t_4.

This is due to the heat given up by the hot high pressure gas entering the condenser from the compressor.

Depending upon operating conditions and the length of time the unit has been operating, the gas entering the condenser may be in a superheated condition. (Refer to the pressure enthalpy diagram on Page 53 or the encapsulated diagram (C57/10) supplied in the accessories kit).

If in the superheated condition, initially the gas will desuperheat and its temperature will reach the saturation temperature corresponding to the chamber pressure. At this point the vapour will condense onto the water cooled coil and this will drip down to the base of the chamber.

It is the cooling and condensing phase change that supplies the heat to raise the cooling water temperature.

If the chamber is at a temperature above that of the surrounding atmosphere then an unquantified amount of heat will be given up to the atmosphere. However this should be small relative to the heat given to the cooling water.

(iv) If the condenser cooling water flow rate is reduced then the condenser pressure will rise rapidly relative to the time taken for the evaporator pressure to reduce when the evaporator water supply was turned off.

It will also be noted that the mean temperature of the vapour in the condenser t_6 will also rise.

If the temperature pocket protruding into the chamber is condensing vapour then the temperature recorded at this point should correspond to the saturation temperature of the refrigerant at the indicated pressure. Note that the indicated pressure is **gauge pressure** and the pressures referred to on the pressure-enthalpy diagrams are **absolute pressures.**

In order to allow the thermometer pocket and thermometer to reach a representative temperature it will be necessary to hold the pressure constant for a brief period after each rise in condenser pressure.

(v) The high pressure liquid leaves the condenser through the **expansion valve** which is controlled by a simple float at the base of the condenser.

As soon as the liquid passes through the expansion valve its pressure drops to approximately the pressure inside the evaporator. This causes the liquid to immediately start to change phase from liquid to vapour. As in the evaporator energy is required to bring about the phase change and some of this is taken from the base plate of the condenser as the expansion valve is attached to the base plate.

Extracting heat from the base plate reduces its temperature and this in turn reduces the temperature of the condenser liquid at the base of the condenser. This results in the liquid being "sub cooled" below its saturation temperature.

If the **optional temperature indicator** is fitted then an additional thermocouple t_8 is supplied to be fitted in the base of the condenser chamber. Hence the sub cooled liquid temperature may be measured and this together with the other measured temperatures and pressures allows a complete refrigeration cycle diagram to be plotted on the pressure-enthalpy diagram supplied.

In the condenser therefore the refrigerant changes from superheated vapour on entry, through to saturated vapour then to saturated liquid and ultimately to sub cooled liquid before it leaves the condenser chamber.

As the refrigerant passes along the pipe leading from the expansion valve to the evaporator heat will be extracted from the surroundings and the liquid will be further converted to a vapour. The **sight glass** just before entry to the evaporator allows the liquid/vapour mixture to be observed.

2. PRESSURE TEMPERATURE RELATIONSHIP

The relationship between saturation pressure and temperature may be observed in both the evaporator and condenser. However as variation in the evaporating temperature is small for all but extreme changes in cooling water flow the condenser provides a more graphic illustration.

As the condenser contains refrigerant in all stages from superheated vapour through to sub cooled liquid the thermometer pocket t_6 only records temperatures close to saturation when the pocket is showing signs of condensed liquid. Therefore it is recommended that the pressure temperature relationship in the condenser is investigated as the condenser pressure **increases**.

If the pressure temperature relationship is investigated by reducing the condenser pressure then the t_6 thermometer pocket will be at a temperature that is higher than the surrounding vapour due to its thermal inertia. Therefore no vapour will condense on the pocket and an incorrect temperature will be measured.

Note that the pressures referred to on the pressure-enthalpy chart and on the pressure-temperature chart on Page 29 are "absolute" values.

Absolute pressure = Pressure gauge value + Local atmospheric pressure

Procedure:

(i) Start the unit for **normal operation** as shown on Page 15 but increase the condenser cooling water flow to the flowmeter maximum (50 g s^{-1}). The pressure at which the condenser stabilises will depend upon the water inlet temperature.

(ii) Allow the unit to run for approximately 15 minutes in order to reach a uniform operating temperature. Then record the condenser pressure P_c, evaporator pressure P_e, the condensing temperature t_6 and the evaporating temperature t_5.

(iii) Reduce the cooling water flow by a small increment so that the condenser pressure increase by approximately 10-20kN m^{-2}. This amount will vary depending upon the cooling water inlet temperature.

Allow the unit to stabilise for a few minutes and again record the above parameters.

(iv) Repeat the procedure up to the maximum condenser pressure required or to the high pressure cut out value of 220kN m^{-2}

Typical results are shown in the table below.

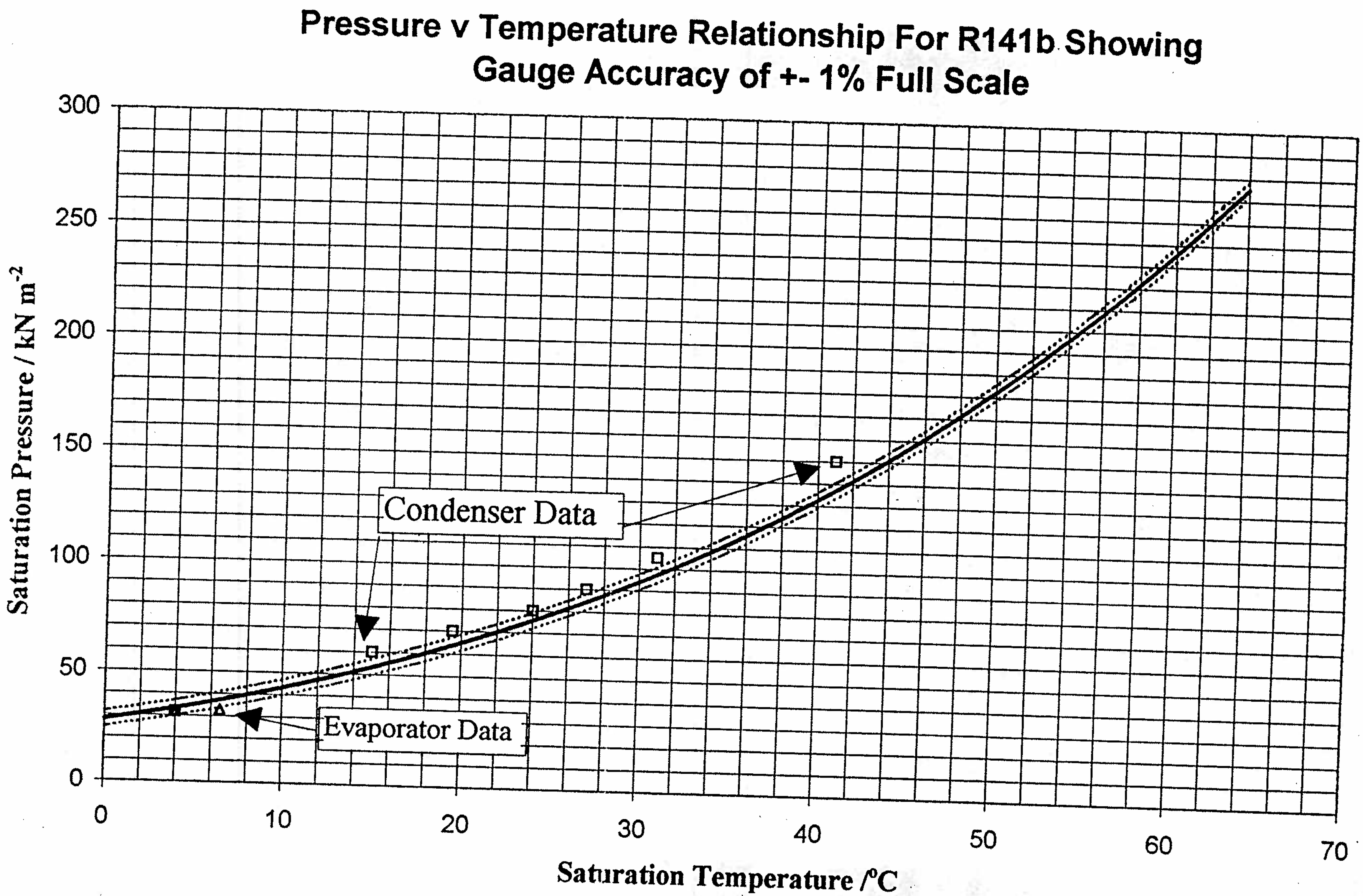
Local Atmospheric Pressure: 101kN m^{-2}

Condenser Pressure	P_c / kN m^{-2} gauge	-41	-31	-21	-11	+4	+49
Condenser Pressure	P_c / kN m^{-2} absolute	60	70	80	90	105	150
Condensing temperature	t_6 / °C	15.0	19.5	24.0	27.0	31.0	41.0
Evaporator Pressure	P_e / kN m^{-2} gauge	-68	-69	-69	-69	-69	-69
Evaporator Pressure	P_c / kN m^{-2} absolute	33	32	32	32	32	32
Evaporating temperature	t_5 / °C	6.5	4.0	4.0	4.0	4.0	4.0

Note that temperatures have been estimated to the nearest 0.5°C using the standard thermometers supplied. Where the **optional temperature indicator** is fitted temperatures may be recorded to the nearest 0.1°C.

The results are plotted in graphical form on Page 29.

Note that the standard pressure gauge accuracy of ±1% of gauge full scale has been shown as dotted lines about a mean. The absolute accuracy of the thermometers (or optional temperature indicator and thermocouples) plus reading errors will also add to any discrepancies.


Pressure v Temperature Relationship For R141b Showing Gauge Accuracy of +- 1% Full Scale
Saturation Pressure / kN m-2
Saturation Temperature /°C
Condenser Data
Evaporator Data
0
50
100
150
200
250
300
0
10
20
30
40
50
60
70

3. DEMONSTRATION OF "PUMPING OVER" OR "PUMPING DOWN" INTO THE CONDENSER

During maintenance of refrigeration plants, particularly when replacement of components is involved, it is convenient to transfer the refrigerant to the condenser. This has the advantage of saving the refrigerant for further use and also may avoid the need of evacuation prior to recharging.

In addition, for ecological reasons following the guidelines of the Montreal Protocol, the venting of refrigerant is in many countries now a criminal offence.

This is a procedure often used in industrial and commercial refrigeration practise where the entire refrigerant charge is condensed and collected either in the condenser itself or more commonly in a liquid receiver connected to the condenser. Once the charge has been pumped into the condenser or liquid receiver then work may be carried out on the system without losing large quantities of refrigerant to atmosphere. For ecological reasons following the guidelines of the Montreal Protocol, the venting of refrigerant is in many countries now a criminal offence.

In the Refrigeration Cycle Demonstration Unit R633 the condenser and liquid receiver are combined in the same glass cylinder.

In order to carry out pumping down, the unit should have been operating normally for several minutes with an evaporator and condenser cooling water flow rate of approximately 40 gs^{-1}.

By setting the ball valves as shown in the **Refrigerant Pump Down** mode (see Figure 2 - Page 2), the flow of condensed liquid from the **expansion valve** at the base of the condenser is stopped and liquid will therefore continue to collect in the condenser chamber.

As liquid transfers from the evaporator, the level will fall and less of the evaporator coil surface will be effective in evaporating the liquid. The evaporation rate will reduce and the process will become slower. This effect may be offset as the liquid level becomes very low by opening (ONLY) the ball valve at the base of the evaporator.

This will have the effect of utilising the capillary surface area and ambient air temperature to evaporate additional liquid.

If, before pumping down, the unit has been operated for a prolonged period, the liquid collected at the base of the evaporator may appear thicker and less viscous. It may also appear slightly yellow in colour. The liquid remaining in the evaporator is primarily the oil that has been carried over in the form of mist and refrigerant oil mixture from the compressor.

The oil will not evaporate at the pressures achieved by the compressor and therefore it must be physically returned to the compressor casing.

Note that the unit should not be **SHUT DOWN** when the refrigerant charge is in the **PUMP DOWN** condition as under certain ambient conditions it is possible for the charge to migrate to the compressor casing.

Note: In an industrial plant, isolating valves are usually fitted between all major components. As soon as the refrigerant has been transferred to the condenser (or liquid receiver) the valves may be closed, trapping the liquid. The defective component can then be serviced or replaced without losing the refrigerant charge.

At the end of the demonstration the opportunity may be taken to return the oil collected in the base of the evaporator to the condenser. The procedure for this is given under **Oil Return** on Page 17.

However, if oil is not to be returned to the compressor at this stage, the ball valves should be set for normal operation (See Figure 2, Page 2) and the refrigerant allowed to return to the evaporator.

4. DEMONSTRATION OF CHARGING

Due to the restrictions of the Montreal Protocol it is not recommended that the refrigerant charge is removed from the machine for any reason other than essential repair.

If charge removal is necessary then recharging may be "demonstrated" if convenient to do so.

Charging from a Hilton supplied one trip can should follow the Charging or Recharging procedure on Page 21.

Note that any refrigerant removed from the machine should be stored in a screw topped metal can to prevent evaporation and to stop moisture being absorbed by the oil in solution.

Any refrigerant stored in such a can may be drawn back into the evaporator by connecting the charging line to the **charging valve** in a similar way to the standard charging procedure but then immersing the open end in the liquid inside the container. If the unit is turned on for **normal operation** then the pressure drop in the evaporator will cause the refrigerant to flow into the evaporator. Note that air is likely to need venting from the condenser.

5. DEMONSTRATION OF THE EFFECT OF AIR IN A REFRIGERATION SYSTEM

When air is present in a refrigeration plant, it will normally be swept from the evaporator by the flow of refrigerant vapour and will become trapped in the condenser.

For a combination of reasons, the air will cause the compressor delivery pressure to rise, reducing the coefficient of performance, and increasing the power input for a given duty.

The increase of pressure is due to

(i) The total pressure in the condenser is approximately equal to the sum of the refrigerant saturation pressure and the pressure of the air present (Dalton's Law of partial pressures).

and

(ii) The air tends to be swept towards the heat transfer surfaces, forming an insulating layer which reduces the heat transfer coefficient. This in turn drives up the temperature difference required for a given heat transfer rate and this results in a higher refrigerant saturation temperature and pressure.

The effect of air in the system may be demonstrated as follows:

Procedure:

(i) Start the unit for **normal operation** and adjust the evaporator cooling water flow rate so that the evaporator pressure is below atmospheric pressure. Unless the cooling water temperature is very high this is likely to be the case in all conditions.

Ensure that the unit is free of air and if necessary follow the air venting procedure shown on Page 18.

(ii) Run the unit for several minutes in order to reach normal operating temperatures then record all system temperatures, pressures and flow rates. Also visually note the condensation rate on the condenser cooling coils.

(iii) Connect the angled end of the charging line (C45/2) supplied in the accessories kit to the charging valve at the base of the evaporator.

(iv) Observe the evaporator pressure gauge and **briefly** open the ball valve at the base of the evaporator. The evaporator pressure gauge will indicate an increase in pressure followed by a return to its original value.

The condenser pressure gauge, however, will increase and remain at the new value.

(v) Repeat opening of the ball valve until the condenser pressure has approximately doubled from its original value. Note that if the condenser pressure reaches 220kN m^{-2} then the high pressure cut out will operate and the experiment will have to be repeated from an air free condition.

When air is admitted to the evaporator it initially adds to the pressure within the evaporator according to Dalton's Law. However it is almost immediately swept through into the compressor by the flow of refrigerant vapour. The mixture then passes through to the compressor and ultimately to the condenser where it can go no further due to the liquid at the base of the condenser.

In addition, the continuous flow of refrigerant vapour towards the condenser cooling coil causes the air to remain around the coil region. The reduced rate of condensation should be observed as well as the increase in condenser pressure.

Record all system temperatures, pressures and flow rates.

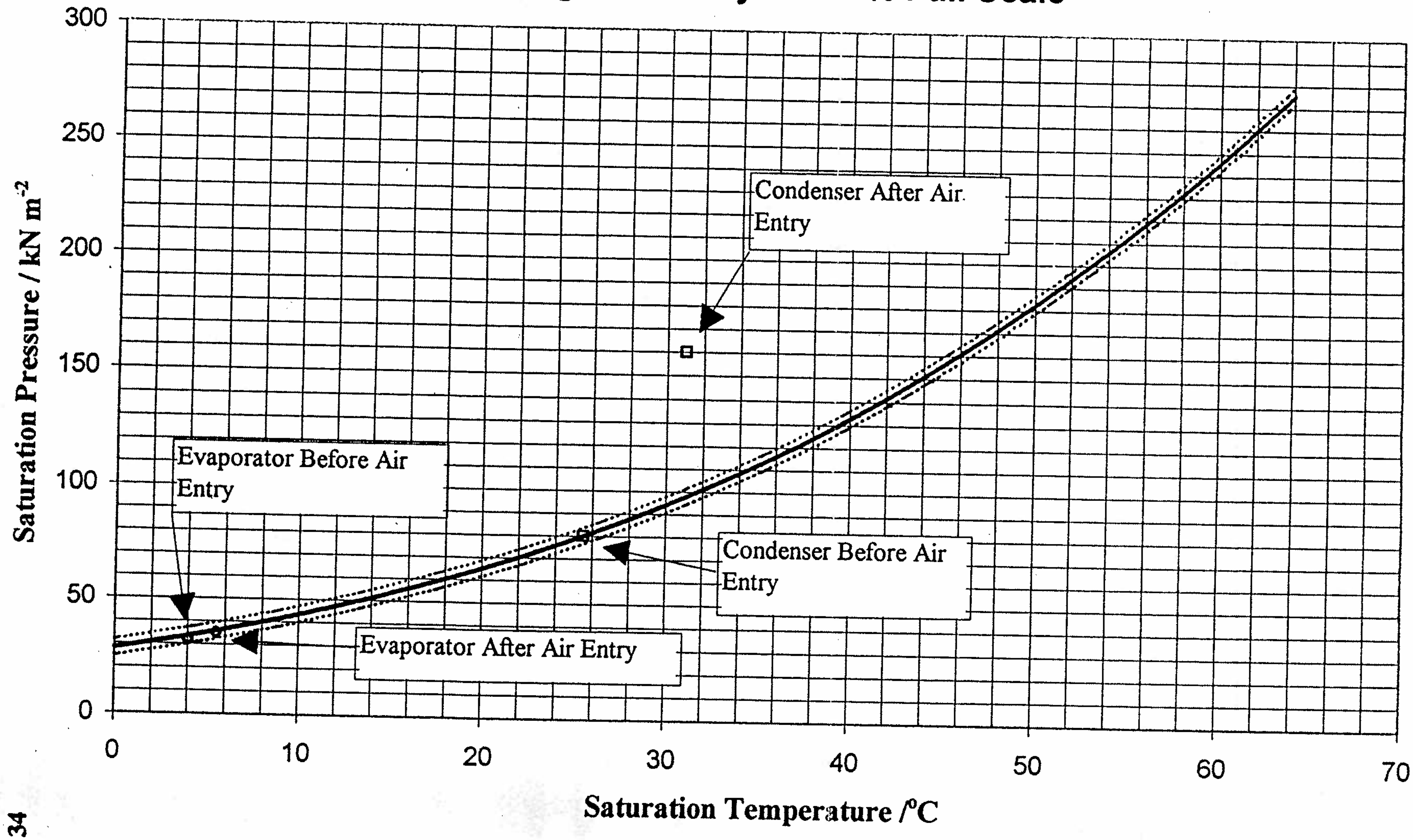
Typical results are shown in the following table.

Local Atmospheric Pressure: $101 kN\ m^{-2}$

Test No.		1 Air Free	2 With Air
Evaporator Gauge Pressure	P_e / $kN\ m^{-2}$	-69	-66
Absolute Evaporator Pressure	P_e / $kN\ m^{-2}$	32	35
Evaporating temperature	t_5 / °C	4.0	5.5
Evaporator water flow	m_e / $g\ s^{-1}$	20.0	20.0
Evaporator water inlet	t_1 / °C	11.0	11.0
Evaporator water outlet	t_2 / °C	9.5	10.0
Condenser Gauge Pressure	P_c / $kN\ m^{-2}$	-21	59
Absolute Condenser Pressure	P_c / $kN\ m^{-2}$	80	160
Condensing Temperature	t_6 / °C	25.5	30.5
Condenser water flow	m_c / $g\ s^{-1}$	4.0	4.0
Condenser water inlet	t_4 / °C	12.0	12.0
Condenser water outlet	t_3 / °C	22.0	20.3

The results are plotted on a temperature-pressure graph on Page 34.

Pressure v Temperature Relationship For R141b Showing Gauge Accuracy of +- 1% Full Scale



6. EFFECT OF EVAPORATING AND CONDENSING TEMPERATURES ON THE REFRIGERATION RATE AND CONDENSER HEAT OUTPUT

The effect of evaporating temperature on the refrigeration rate can be investigated, but due to the limited effect on evaporating temperature of all but very large changes in cooling water flow it is more graphic to investigate condensing temperature first.

If time permits, the corresponding effects of evaporating temperature may then be investigated.

The effect of increasing the condensing temperature on many refrigeration systems and heat pumps is a reduction in the heat discharged from the condenser and in many cases a smaller reduction in the refrigerating effect at the evaporator.

Similar reductions will be observed if the evaporating temperature is lowered.

The effects are due primarily to the reduction in volumetric efficiency of the compressor at high pressure ratios (P_c/P_e) and the reduction in specific volume of the refrigerant gas as the evaporating temperature reduces.

An investigation of the effects of pressure ratio are given in the following experiment.

A simple explanation for this is that for each suction stroke of the compressor a lower mass of gas (for the same volume) is drawn in to the cylinder to be compressed.

The effect of increasing condenser pressure may be investigated in the following manner.

Procedure:

(i) Start the unit for **normal operation** as shown on Page 15 and ensure that the unit is air free by venting air from the condenser as described under air venting on Page 18.

Once air free increase the condenser cooling water flow to the flowmeter maximum (50 g s^{-1}). The pressure at which the condenser stabilises will depend upon the water inlet temperature.

(ii) Set the evaporator water flow to approximately 20-30 g s^{-1} and allow the unit to run for approximately 15-20 minutes. The time taken to stabilise will depend upon the local ambient conditions and the cooling water inlet temperature.

(iii) Record all the system parameters as illustrated in the table on Page 36.

(iv) Reduce the condenser cooling water flow rate until the condenser pressure increases by approximately 5-10 kN m^{-2}. Allow the unit to stabilise and again record the parameters on Page 36.

(v) Repeat for increasing condenser pressures to the minimum readable value on the condenser water flowmeter is reached, or the condenser pressure reaches 200 kN m^{-2} gauge pressure.

OBSERVATIONS

Local Atmospheric Pressure: 101kN m^{-2}

Test No.		1	2	3	4	5
Evaporator Gauge Pressure	p_e / kN m^{-2}	-68	-69	-69	-69	-69
Absolute Evaporator Pressure	p_e / kN m^{-2}	33	32	32	32	32
Evaporator Temperature	t_5 / °C	6.5	4.0	4.0	4.0	4.0
Evaporator Water Flow Rate	$\dot{m}_e$ / gm s^{-1}	20	20	20	20	20
Evaporator Water Inlet Temp.	t_1 / °C	11.0	11.0	11.0	11.0	11.0
Evaporator Water Outlet Temp.	t_2 / °C	10	10	10	10	10
Condenser Gauge Pressure	p_c / kN m^{-2}	-41	-31	-21	-11	4
Absolute Condenser Pressure	p_c / kN m^{-2}	60	70	80	90	105
Condenser Temperature	t_6 / °C	15.0	19.5	24.0	27.0	31.0
Condenser Water Flow Rate	$\dot{m}_c$ / gm s^{-1}	50.0	10.0	4.0	2.0	1.0
Condenser Water Inlet Temp.	t_4 / °C	11.0	11.0	11.0	11.0	11.0
Condenser Water Outlet Temp.	t_3 / °C	12.0	16.5	22.0	26.5	31.5

Note that the temperatures recorded have been estimated to the nearest 0.5°C using the standard thermometers supplied. If the **optional temperature indicator** is fitted with the thermocouple sensors then the temperatures may be recorded to the nearest 0.1°C.

SPECIMEN CALCULATIONS FOR TEST NO. 2

EVAPORATOR

Rate of Heat Transfer to Water in Evaporator:

$$\dot{Q}_e = \dot{m}_e \, C_p \, (t_1 - t_2)$$
$$\dot{Q}_e = 20.0 \times 10^{-3} \times 4.18 \times 10^3 \times (11.0 - 10.0) \; W$$
$$\dot{Q}_e = \underline{83.6} \; W$$

CONDENSER

Rate of Heat Transfer to Water in Condenser:

$$\dot{Q}_c = \dot{m}_c \, C_p \, (t_3 - t_4)$$
$$\dot{Q}_c = 10.0 \times 10^{-3} \times 4.18 \times 10^3 \times (12.0 - 11.0) \; W$$
$$\dot{Q}_c = \underline{229.9} \; W$$

DERIVED RESULTS

Evaporating Temperature	t_5 / °C	6.5	4.0	4.0	4.0	4.0
Condensing Temperature	t_6 / °C	15.0	19.5	24.0	27.0	31.0
Heat Transfer in Evaporator	$\dot{Q}_e$ / W	83.6	83.6	83.6	83.6	83.6
Heat Transfer in Condenser	$\dot{Q}_c$ / W	209	229.9	183.9	129.6	85.7

The graph on Page 38 has been drawn from these results.

It will be seen that the heat transfer at the condenser decreases as the condensing temperature increases.

The above test may be repeated at other evaporating temperatures.

Note: In order to expand the range of experiment and to investigate wider variations in evaporator and condenser temperatures it is possible to supply warmed water to the unit. However unless the internal pipe connections of the unit are modified this will have the effect of supplying warmed water to both the condenser and evaporator coils. This will tend to increase both condensing and evaporating temperatures.

Heat Transfer Rates In Condenser and Evaporator V Condensing Temperature