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Report

THE HARWELL HIGH PRESSURE HEAT TRANSFER LOOP

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THE HARWELL HIGH PRESSURE HEAT TRANSFER LOOP

by

A. W. Bennett and R. K. F. Keeys

ABSTRACT

A detailed description is presented of the Harwell (Chemical Engineering & Process Technology Division) high pressure, steam-water heat transfer loop; this description is aimed at supplementing the information given in reports on individual experiments. The operating instructions for the loop are given in an Appendix.

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HARWELL.

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Plates 1 - 6 show sections of the loop, operating panels, data collecting system and the motor generator house.

1. Introduction

The Harwell (Chemical Engineering & Process Technology Division) two-phase heat transfer loop has been operating since 1960, and a wide variety of experiments have been performed on it. A list of the unclassified reports of work on the loop is given in Appendix I and it will be seen from this list that the experiments cover fluid flow and heat transfer problems over the range from subcooled water through the two phase water/steam region to superheated steam. In reports on individual experiments, it is not possible to give a detailed description of the rig components and operating instructions, or indeed any complicated circuit diagrams. Also, from experiment to experiment, the flow diagram varies considerably and the way in which this diagram is related to the loop circuit is not usually specified. The aim of the present report is to provide a basic, detailed description of the loop to which reference can be made in future experimental reports.

The loop was first proposed in about 1957 and the basic circuit was designed and built in the period 1958/1960. The overall design was done by Messrs. J. G. Collier and G. Fowler of AERE and detailed design and construction was done by Foster Wheeler Ltd. It was soon realised that to accommodate an increasing range of experiments, it would be necessary to modify the loop considerably; higher steam flows, separate pressurisation, higher electrical power input etc. would be needed. A design study for the modifications was carried out in 1962 by Messrs. G. Fowler and C. K. S. Wilmot of AERE in collaboration with Mr. R. Guy of Foster Wheeler Ltd. The modifications were finally completed in 1965. The present report describes the loop in its modified form and supersedes an unpublished document written in 1961.

The loop can be considered simply as a means of providing a supply of superheated steam, a supply of water with a temperature range up to within 5 - 10 deg F of the saturation temperature and a supply of power. It can be operated at pressures up to 1500 p.s.i.a. to supply up to 1000 lb/h of steam and 9000 lb/h of water. It is also fitted with a main condenser which can remove 10^6 Btu/h and a dump condenser which can condense 500 lb/h of steam. For the provision of power to the various test sections there are two supplies available, an A.C. supply of 0 - 100 kVA and a D.C. supply of 0 - 700 kW.

2. General Description of Loop

The general arrangement is shown in Figure 1. Various views of the loop are shown in plate 1 - 6. The following main items are included in the circuit:

(a) A "once-through" type steam generator which is fired with diesel fuel oil.

(b) An air-cooled desuperheater which is used to adjust the temperature of the steam after it leaves the generator.

(c) A pipe heater for final removal of water droplets and adjustment of steam temperature immediately before the steam enters the test section.

(d) A water cooled condenser with variable surface area.

(e) A main circulating pump.

(f) A dump condenser designed to condense part of the steam generator output when test requirements of steam are lower than the minimum output of the generator.

(g) A water treatment plant to maintain the purity and pH value of the loop water at the required level.

(h) Two main heating vessels for heating the water flowing to the test sections.

(i) A boiler preheater to control the boiler feed water temperature.

(j) A pressuriser for automatic control of the loop pressure.

The loop components were manufactured in stainless steel except for the cooling coils in the two condensers which were made of nickel.

The flow from the main circulator can be divided into two streams. If steam is required in the experiment, water is passed via the preheater to the steam generator, and the issuing steam goes via the desuperheater and orifice plate to the test section. If water is required, it is passed through the two main water-heating vessels and then to the test section, again via an orifice plate. The outflow from the test section is returned to the loop via the main condenser which acts as the inlet reservoir for the main circulator. In addition, a small part of the loop flow passes continuously through the water treatment plant.

Each item of the loop will now be detailed separately.

2.1 The main circulating pump

The pump is a canned rotor type with internal and external cooling. It was bought originally for other work and has not yet been used to full output capacity.

The following are the relevant details:

Manufacturer:	K.S.B. Manufacturing Co. Ltd.
Type:	LUVS 65/2
Installation:	Suspended vertically in piping; motor below pump
Suction and Discharge Connections:	2½ in
Maximum Fluid Temperature:	270°C (518°F)
Maximum capacity:	185 g.p.m.
Maximum Differential Pressure:	400 ft head
Maximum Pressure at Suction Branch:	1450 p.s.i.
Maximum Discharge Pressure:	1550 p.s.i.
Speed:	2850 r.p.m.
Motor Rating:	30 H.P.
Supply:	440 V/50 cycles/ 3 phase
Type of Starting:	Direct on line
Material:	Chrome-nickel steel containing at least 18% chromium and 11% nickel

The pump characteristics are shown in Figure 2. The water coolant stream for internal cooling of the pump (~1.7 g.p.m.) is itself cooled from ~120°F to 85°F by heat transfer to cooling water in two external coiled tube, jacketed water coolers with the following relevant design parameters:

Shell Design Pressure	100 p.s.i.g.
Shell Test Pressure	150 p.s.i.g.
Coil Design Pressure	1700 p.s.i.g.
Coil Design Temperature	150°F
Coil Test Pressure	2550 p.s.i.g.

The inlet and outlet temperatures are monitored and if they rise above 85°F and 120°F respectively, an alarm is initiated. An air-vent (V 89, Figure 1) is fitted to the high pressure coolant circuit to permit venting of the pump casing.

2.2 The steam generator or boiler

The heating surfaces are formed in radiant and convection sections. The radiant section consists of two banks of tube in parallel along the sides of the furnace. Each bank consists of continuous multi-loop, stainless steel elements terminating in welded-on flanges which connect to the inlet and outlet headers. The convection heating surfaces consist of four multi-loop stainless steel elements in parallel, mounted vertically in the boiler stack. The elements and sections are similar to those in the radiant bank.

The steam rating of the boiler has been increased by increasing the heating rate and the water feed rate. This was achieved by making the following modifications:

(a) The original feed water valve (V54) limited the feed rate. A bypass valve (V54a) was fitted which can be set at any required value leaving the final control on the original valve (V54).

(b) Boiler fan: The original forced draught fan (which delivered 800 c.f.m. of air at 25 in WG of which approximately 300 c.f.m. was used for cooling the floor of the combustion chamber) was replaced by a larger fan delivering 1500 c.f.m. of air at 32 in WG. In addition an induced draught fan was fitted which was designed to handle 5720 c.f.m. of air at 550°F, with 2.25 in WG suction at the inlet. This fan is installed in a stack bypass. A damper is provided to divert flow either direct to the main stack or to the induced draught fan. The outlet pipe from the forced draught fan is fitted with a bypass vent to atmosphere. These arrangements allow the boiler to be operated over a range of heating rates from $\sim 5 \times 10^5$ Btu/h to 2.5×10^6 Btu/h.

The following measurements can be made: water inlet temperature (T4, Figure 1), steam outlet temperature (T18), water inlet pressure (P4), steam outlet pressure (P1) and steam outlet flowrate (FCR1). In addition, in order to control the boiler, thermocouples have been clamped to the outside of each bank of boiler tubes.

The boiler was designed for a pressure of 1700 p.s.i.a. with a maximum tube temperature of 875°F and header temperature of 700°F. The 1 inch main steam exit valve was manufactured by Newman Hender Ltd. (Type VEE-REG) and was suitable for operation at 1500 p.s.i. at 600°F. The maximum steam outlet temperature from the boiler is 750°F.

This table compares estimated through outputs of the boiler before and after modifications.

	Original Design with $10^{o}F$ Superheat	Modified Design 2000 lb/h with $50^{o}F$ Superheat	$100^{o}F$ Superheat
Boiler Pressure p.s.i.	1,000	1,000	1,000
Maximum Steam Quantity (lb/h)	1,500	2,000	2,000
Inlet Water Temperature (^{o}F)	536	540	540
Outlet Steam Temperature (^{o}F)	551.4	596.4	646.4
Heat Output (Btu/h x 10^{6})	1.0	1.412	1.494
Total Pressure Drop (p.s.i.)	29.0	62.5	66.5
Pressure Drop over Radiant Section	18.0	27.5	29.5
C.V. of Fuel (Btu/lb)	19,000	19,000	19,000
Fuel Quantity (lb/h)	95	164	197
Efficiency (%)	56.6	45.4	39.9
Excess Air (%)	100	100	100
Gas Temperature Exit (^{o}F)	820	1,130	1,260
Gas Flow (lb/h)	2,940	4,540	5,560
Furnace Pressure with 20ft stack (in W.G.)	0.36	0.81	1.4
Furnace Liberation Btu/cu.ft./h.)	14,700	25,200	30.200

2.3 Boiler feed water pre-heater*

The boiler feed water pre-heater consists of a cylindrical pressure vessel (design pressure 1700 p.s.i.g. at $620^{o}F$, test pressure 2550 p.s.i.g.) with hemispherical ends and with four sheathed tube heater elements welded to each end cover. Transverse baffle plates are tack-welded to the heater element tubes. Each element has rating of 6 kW, making a maximum power for the pre-heater of 48 kW. The heaters were manufactured by Heatrae Ltd. and were suitable for connection to 400 volt, 3 phase supply.

The heat input to the vessel is controlled from a Smiths Series 5 indicator/controller. Each element is independently switched, one being on Variac control. Two thermocouples and a pressure tapping (connected to a Bourdon type pressure gauge) are mounted in the exit pipe.

Under conditions of low flow it is possible to generate steam in the vessel leading possibly to burnout. A number of thermocouples have been inserted into the heater sheaths to monitor for excessive temperature.

2.4 Steam desuperheater

The desuperheater is designed for 1700 p.s.i.g. at $620^{o}F$ and consists of a stainless steel coil which is contained in a galvanised steel casing. A stream of air from

* In the original loop this heater was used as the main water feed heater.

a constant speed centrifugal fan is passed over the coil and the rate of cooling is controlled by an air discharge damper. The damper is controllable both manually and automatically from a controller on the main console. When on automatic control, the position of the air damper is adjusted pneumatically using a Fisher Governor (type 657) air motor actuated by the output of a chromel/alumel thermocouple (TRC1).

2.5 Pipe Heater

When operating the loop at low steam flowrates the thermal losses from the pipework between the generator and the inlet to the test section can give an unacceptable drop in steam temperature. As the maximum outlet steam temperature for the generator is fixed by the design at 750^{o}F it is thus not always possible to provide dry steam at the correct temperature at the test section inlet. To dry the steam and/or to raise its temperature a section of the steam line is electrically heated by passing an A.C. current through its walls from a transformer and Variac. Alternatively, the same transformer and Variac unit can be used to adjust the water inlet temperature by heating the water feed pipe. This is often necessary when a close approach to saturation temperature is required.

2.6 Main condenser

The condenser also acts as a reservoir for the water supplied to the main circulator. Thus it is necessary to keep the temperature of the water leaving the condenser at a value sufficiently below the saturation temperature to avoid cavitation at the pump inlet. (Account must also be taken in this respect of any water returned from the dump condenser). The level in the condenser must not be allowed to fall below about half-full to avoid vortex formation leading to the entrainment of steam from the condenser to the pump inlet.

The condenser consists of a stainless steel all-welded cylindrical shell with hemispherical ends containing four nickel, helical cooling coils; the design pressure is 1700 p.s.i.g. at 620^{o}F and the test pressure 2550 p.s.i.g. The coils are of varying diameters and overall lengths to give 51%, 28%, 10% and 7% respectively of the total cooling surface area.

Low pressure cooling water is fed separately to the respective coils, each line having a rotameter of the appropriate size. Each coil can be isolated and drained when not in use and is also provided with a pressure relief valve set at 100 p.s.i.g. In each inlet pipe connection to the condenser there is fitted an impingement baffle to improve the water distribution in the coils. A visual indication of the steam/water interface in the condenser is provided by a Klinger colour-change sight glass (Type SVA-36).

The coils are so positioned in the containing vessel that a large part of the coil is always submerged in the condensate. Thus, the upper part of the coils can be used to condense vapour, and the lower part to provide the necessary subcooling. The amount of subcooling taking place can be controlled by adjusting the level in the condenser, by adjusting the flow of cooling water through the coils and by selecting the best combination of condenser coils from the four available.

Under any particular conditions of flowrate and heater loading the loop pressure is sensitive to the condensate level in the condenser. It has been found in practice that adjustment of this level by pumping water into the system or draining water from it is the best way of controlling loop pressure.

2.7 Dump condenser

The boiler cannot be operated below a certain minimum flowrate (~500 lb/h) and this would seriously limit the range of steam rates available for experimental work. To allow lower steam flows to the test section, a dump condenser is provided to which up to 500 lb/h of steam can be diverted. A sufficiently high total flow through the boiler can thus be maintained.

The condenser is of the U-tube in shell type with cooling water through the tubes. The shell and tube design pressure is 1700 p.s.i.g. at 620^{o}F (test pressure 2550 p.s.i.g.). The header cover design pressure is 100 p.s.i.g. with a test pressure of 180 p.s.i.g. and a relief valve set at 100 p.s.i.g. The U-tubes were of nickel and were expanded into a stainless steel tube plate; those in line with the steam inlet are protected by a stainless steel impingement plate and a baffle plate is fitted between the tubes to give the correct flow distribution.

2.8 Main water heater

The main water heater consists of two identical cylindrical vessels, "A" and "B", mounted vertically alongside one another. Water flows from the main circulating pump into the bottom of vessel "A", out from the top and into the bottom of vessel "B". From the top of this latter vessel it flows via an orifice plate to the inlet of the test section. The design pressure for the vessels is 1700 p.s.i.g. at 620^{o}F and the test pressure is 2550.

Each vessel is fitted with thirty heater elements each rated at 5 kW, fifteen being fitted through the base plate and fifteen through the top plate. The heaters are Stabilag Type WR 85V - 185/20S operating from a 240 v, A.C. supply. For control purposes the heaters are grouped in banks of 30 kW and 45 kW. The control of the various banks is as follows:

Vessel	Power	Switching Arrangement
"A" - top	30 kW	Single Switch
	45 kW	" "
"A" - bottom	30 kW	" "
	45 kW	" "
"B" - top	30 kW	" "
	45 kW	" "
"B" - bottom	30 kW	" "
	45 kW	Individual switch for each 5kW heater, one heater on Variac control.

Thus, by a suitable selection of heaters, any power input between 0 and 300 kW can be obtained.

The 45 kW bank of heaters at the bottom of vessel "B" can be controlled from a Kent Multilec Mark II potentiometric temperature recorder/controller having two set levels (TCR2). The 45 kW bank is split into a subsidiary 0 - 30 kW base load and a 0 - 15 kW trim load. When the first set temperature on the instrument is reached, the trim load is switched off; if the overshoot is too great, thus exceeding the second set level, the base load is also switched off. As the temperature falls the base load is switched on, followed by the trim load. The values of the base and trim loads are selected to give the best control with minimum hunting.

As a safety measure, all power to the main water heater is controlled from a second recorder/controller instrument which is set at 5°F below the saturation temperature for the loop operating pressure. When a temperature 5°F below the set point (i.e. 10°F below saturation) is reached both an audible and a visual alarm is given. The audible alarm can be cancelled but the visual alarm stays on. If the set point is then reached further audible and visual alarms are given and the heaters are tripped. These alarms cannot be cancelled nor can the heaters be switched on again until the temperature has fallen to below the set point.

The heaters are interlocked with the main circulating pump power supply and cannot be switched on unless the pump has been switched on.

To guard against inadvertently switching on the heaters at zero flow, one of the water control valves in the line to the test section is fitted with microswitches which are set to give audible and visual alarms when the valve is ⅓rd open and fully closed. The alarms at the ⅓rd open position can be cancelled but those at the fully closed position cannot. Also in this latter position of the valve, the heaters are isolated and cannot be switched on until the valve has been partially opened.

Summarising, the controls are as follows:

(1) Water control valve closed - heater cannot be switched on.

(2) Main circulator off - heater cannot be switched on.

(3) Control point reached - 45 kW base and trim loads operative.

(4) Saturation temperature reached - all heaters switched off.

(5) No-flow condition due to zero pressure drop across the pump, although the pump is switched on - no direct action.

There are two water control valves in parallel; these are ½ inch Newman Hender VEE-REG suitable for 1500 p.s.i.g. at 600°F.

2.9 Steam pressuriser

To improve the pressure control of the loop it was decided to incorporate a pressuriser vessel. Steam pressurisation was chosen in preference to gas pressurisation for economy and to maintain a low gas content in the circuit.

In practice, it has been found impossible to obtain an adequate pressure control using the particular design of pressuriser installed. The main difficulty is that the response time is large and it is not possible to obtain the rapid fine adjustments of pressure which are necessary in high accuracy experiments. In all experiments done so far, therefore, the pressuriser has been run flooded and unheated and pressure control achieved by controlling the amount of liquid in the loop. In effect, this gives a fine adjustment to the level in the condenser and, thus, to the rate of heat extraction. Very accurate control is possible by this means. However, for reference purposes, it is worth giving details of the pressuriser and these are as follows.

The vessel is a cylindrical shell 12 in I.D. of $1^{3}/16$ in wall thickness and 5 ft long over the cylindrical section. The end pieces are hemispherical and are welded to the cylinder. Into the top end piece is fitted a flanged spray nozzle. Heating pads are fitted to the lower 2 ft 6 in of the vessel and are, for safety reasons, arranged to avoid the bottom weld. The vessel is mounted vertically in the loop and is connected into the main circulator inlet line. The spray nozzle supply line is connected into the main circulator outlet but immediately in front of the main heater vessel connection.

The spray can be operated manually or automatically by means of a Blakeborough diaphragm control valve rated for 1500 p.s.i.g. and 1125^{o}F. The valve air control is connected to a Foxboro Model 40 pressure recorder/controller. The loop pressure is used to initiate an air signal which operates the valve and varies the volume of water being sprayed into the pressuriser thus varying the loop pressure as required to maintain the desired pressure. The six 4 kW heaters are controlled on independent switches.

Since the volume of water in the vessel must not be allowed to fall below the top of the heated section of the vessel, a 9-port Klinger sight glass was fitted between the two branch lines welded on to the vessel to permit visual observation of the level. The sight glass was of the Red/Green porthole type made from EN58J stainless steel to Richard Klinger Drawing No. SVA 36.

2.10 <u>Water treatment plant</u>

The plant is shown diagrammatically in Figure 1. It consists of

(a) a regenerative heater

(b) a cooler

(c) three treatment columns.

The regenerative heater is a stainless steel pressure vessel (design pressure 1700 p.s.i.g., design temperature 620^{o}F, test pressure 2550 p.s.i.g.) fitted internally with a stainless steel coil. The water cooler is made of mild steel and is fitted with a stainless steel coil. The outer vessel of the cooler is designed for a pressure of 100 p.s.i.g. and maximum temperature of 150^{o}F. It is fitted with a pressure relief valve and with vent and drain cocks. The cooler coil is designed for 1700 p.s.i.g., 400^{o}F (test pressure 2550 p.s.i.g.). The water treatment columns (design pressure 1700 p.s.i.g., design temperature 620^{o}F, test pressure 2550 p.s.i.g.) are cylinders made of stainless steel, each containing a different ion exchange resin and fitted with isolation valves. The ion exchange resins are held in position by a perforated plate at the bottom of each column.

Water is admitted to the water treatment section of the loop from the main loop recycle circuit via valve V6. The inlet stream passes through the coil in the regenerative heater, where it is cooled by the flow of water returning to the main loop after treatment. From the regenerative heater, the cooled water flows through the water cooler where its temperature is reduced to below 140^{o}F before it enters the ion exchange column. A thermostatic alarm (AP3) operates if the temperature at entry to the column exceeds 140^{o}F, and gives audible and visual warnings. The audible warning can be cancelled but the visual alarm stays on until the temperature falls to below 140^{o}F.

Approximately 1% of the loop flow is treated in the water treatment plant and any excess water admitted through valve V6 is bypassed through valve V66 and returned through the regenerative heater to the main circulator inlet. The temperature of the return stream is below the saturation temperature of the system and helps to reduce the temperature of the pump inlet water to below the saturation temperature and so prevent cavitation in the pump.

The flow through the column in use is calibrated at room temperature and pressure by direct measurement through the appropriate bleed-off valve (V34, 35 or 38) into a measuring cylinder. The flowrate is controlled by either V41, 61 or 65 depending on which column is being used.

The amount of water admitted through valve V6 is dependent on the amount of cooling required at the pump inlet and consequently the valves V6, V66 and the ion exchange column inlet valve need to be set by trial and error to give the desired flow through the column and the desired cooling at the pump inlet. It is essential that there is a flow of water through the plant to the pump and if the columns are isolated, then the flow must be maintained via the bypass valve V66.

The three columns contain different types or forms of resin and are as follows:

Column 1 - a 1:2 mixture of Zeo-Karb 225 in the hydrogen form and De-acidite "FF" giving a pH value of about 7.0.

Column 2 - a 1:2 mixture of Zeo-Karb 225 in the potassium form and De-acidite "FF" giving a pH value up to 10.0.

Column 3 - Zeo-Karb 225 in the hydrogen form giving pH values less than 7.0.

2.11 Test section power supplies

Two alternative power supplies are available for connection to the test sections. One is a Brentford Regulator, type giving a continuously variable A.C. supply of 0 to 50V with a maximum current rating of 2000 amps and a maximum power output of 100 kW. It is situated adjacent to the main console. The power supplied to the test section is measured by a Cambridge sub-standard wattmeter. Control is good and it is possible to add power in increments of 0.2 kW.

The second power supply is obtained from a G.E.C. rotary motor generator set giving D.C. up to 250V and 3000 amps, housed in a building away from the main loop. The system is limited to a maximum power output of 700 kW due to the rating of the input circuit breaker. It can be controlled from both the generator house and the loop area. The voltage output can be continuously varied by adjusting the current to the field windings of the generator. Control at low voltage and current can be improved by the use of a water cooled series resistor in the supply line. The power supplied is obtained from readings of current and voltage.

Both power supplies can be tripped very fast. The A.C. supply has a Salford type quick acting circuit breaker on its input side. The D.C. generator has a contact breaker capable of breaking 3000 amps. Either contact breaker can be operated by means of burnout detectors as required.

2.12 Instrumentation

Pressure gauges, temperature recorder/controllers, water and steam flow measurement devices, thermocouples, etc. are provided for the necessary plant control and measurement.

Steam circuit

The water entering the steam generator, via the valve V54 and the water preheater, is maintained at a constant temperature by controlling the power input to the preheater vessel. The power is controlled from a Smiths Series 5 indicator/controller instrument.

The flow of the steam leaving the boiler is measured with an orifice plate fitted into the line between the desuperheater and the test section inlet. The orifice carrier (Kent. ref. No. 59/30053) had corner tappings and used a "D" type orifice. The orifice plate is used with a Kent recorder/controller which in conjunction with a two-term pneumatic control unit, operates a Fisher air/diaphragm motor valve (V54) which controls the flow of water to the steam generator. The mercury-less recorder has a range of 50 in water gauge. In practice, for most experiments, it has been found best to use manual control for valve. (V54). In view of the high flowrates required for some of the tests, it has been found necessary to fit a further, manually controlled, valve (V54A) in parallel with valve V54.

The temperature of the steam to the test section is measured on a single point Kent Multilec Mark II recorder/controller (TCR1). It has a range of 0 - 750^{o}F, is calibrated for use with chromel/alumel thermocouples, and is fitted with one set of back setting, high alarm contacts. If a thermocouple fails the instrument is driven upscale. The instrument can also be used to operate the damper of the desuperheater and for this purpose works in conjunction with a three-term pneumatic control unit.

Main water circuit

The flow of water to the test section from the main water heaters is measured with a "D" orifice plate (FR1) with corner tappings, in conjunction with a Kent flow recorder instrument (Kent. ref. No. 92/59/30053). The range of the recorder is 100 in WG.

The temperature of the water is recorded on a Kent Multilec recorder/controller (TR2) with a range of 0 - 750^{o}F. This instrument also controls the 30 kW base load and 15 kW trim load heaters fitted into the base of vessel "B" of the main water heater.

Test section data

Originally readings of pressure, temperature and flow were recorded manually but later work demanded that a large number of results should be logged. The maintaining of absolutely steady conditions of pressure and temperature over a long period is difficult and it became necessary to introduce an automatic data recording system which is described in report AERE - R 5128 by D. Benn, and is capable of recording visually and of printing out 50 pieces of data in one minute. The data system can be used to register any measurement which can be converted into millivolt signals and in the present work has been used to record temperatures and differential pressures measured using thermocouples and transducers respectively.

3. Alarm and Safety Circuits

To safeguard the loop against possible damage from mishandling, electrical failure and loss or cooling water supply, several safety devices and alarm systems have been incorporated in the system. Some have been mentioned above, but are included here for completeness.

(a) Main circulator

The starter contactor is interlocked with the cooling water electrical circuit. This ensures that the circulator cannot be started until the cooling water is flowing through the loop cooling systems.

(b) Cooling water system

To safeguard against loss of cooling water two pumps are incorporated into the system. Only one is in use at any given time but if it should fail and thus cause a loss of water pressure then the stand-by automatically comes into operation. If this should occur, then a warning buzzer is sounded and a fault alarm lights up on the pump control panel. The audible signal can be cancelled but the visual alarm stays alight until the fault is remedied.

A second protection, which has to be used manually, is for use in case of a complete loss of cooling water due, say, to an electrical breakdown. A supply of water from the building main is piped to a point close to the loop and can be connected to the loop cooling system with a section of fire-hose using a quick coupling device. If it should be necessary to use this supply, then normal plant running would not be possible and the experiment would have to be shutdown.

(c) Bursting discs

To safeguard against over-pressurisation and possible damage, the loop is fitted with two bursting discs. Each is backed by a pressure alarm and a pressure relief valve. The discs are designed to fail at about 1500 p.s.i.g. and the relief valves are set to lift at 1510 p.s.i.g. The alarms are both visual and audible, the audible warning can be cancelled but the visual alarm remains alight until the fault is corrected.

In some experiments, an annulus test section is used, where the test rod is supported by a stainless steel bellows designed to withstand a differential pressure of about 200 p.s.i.g. The bellows is connected to a nitrogen supply which is used to balance the pressure in the bellows against the loop pressure. To safeguard the bellows against fracture a bursting disc is fitted in the nitrogen circuit and is designed to fail at 200 p.s.i.g.

(d) Main water circuit

The heaters are interlocked with the main circulator supply and cannot be switched on unless the main circulator pump has been switched on. To prevent power being applied to the main heater vessels until there is a flow of water through the test circuit, the flow control valve (V5) to the test section is fitted with two microswitches. The upper switch is operative when the valve is two-thirds closed when a warning light and an alarm bell are triggered off. These signals can be over-ridden by pressing a button near the alarm, and a "fault" signal lights up which remains alight until the water flow is increased. The lower switch is operative when the valve is closed completely. Once again audible and visual alarms are triggered off, but in addition the main water heaters are isolated and cannot be reset until the flow of water has been restored. The heaters have then to be reset manually.

As a further safeguard the entire load of 300 kW is controlled from a recorder/controller connected to a thermocouple sited in the exit line from the second heater vessel. The set-point of the controller is adjusted to 5 deg F below the saturation temperature for the loop operating pressure; if the water temperature rises to 5 deg F below the control temperature both audible and visual alarms are triggered off. These alarms can be cancelled. If the water temperature continues to rise and reaches the control temperature, further alarms are triggered off and also the heaters are switched off. This alarm cannot be cancelled and the heaters cannot be reset manually until the temperature falls back to below the control temperature when the alarm is cancelled automatically.

(e) Emergency controls for power to main heater systems

Two controls have been fitted for use in cases of emergency.

(1) Motor generator set - the console is fitted with an emergency trip button which can trip the circuit breaker to stop the generator and also switch off the heaters on the main water vessels, the boiler feed-water pre-heater and the pressuriser vessel.

(2) Wander lead - this is fitted with two buttons, one switches off the power only, the other switches off all heaters and also trips the circuit breaker and stops the generator. The control box is attached to a long lead so that an operator can carry it around during an experiment.

(f) Temperature/pressure alarms

All alarms are both visual and audible. The audible signals can be cancelled but the visual alarms remain on until the fault is corrected.

(1) Excessive steam temperature (TCR1) - a warning that the steam temperature is in excess of 650^{o}F.

(2) Excessive loop pressure - a pressure gauge/controller (P1A) makes on rising pressure. It is set at 5 - 10 p.s.i. above loop pressure.

(3) Failure of bursting discs (AP4 and AP5) - an alarm is set off if either disc fails.

(4) Main circulator pump cooling circuit (AP1 and AP2) - an alarm is given if,

(a) the inlet water temperature exceeds 105^{o}F

(b) the outlet water temperature exceeds 120^{o}F

(5) Water feed to water treatment plant - an alarm is given if the inlet water temperature to the ion exchange columns exceeds 140^{o}F.

4. Operating Experience

In its period of operation the loop has been used for a variety of work (see list of reports in Appendix I). This has included heater transfer in annulus flow and tubular flow, and burnout detection in short and long annuli and in long and short tubes. A visual study of flow patterns in steam/water mixtures at 500 and 1000 p.s.i.g. has been made and photographed and a preliminary attempt at an X-ray study of the same has been made. Studies of the "SPUTTERING" phenomena, the effect of geometrical parameters on flow and burnout have been carried out successfully. Several runs of 60 hours duration have been carried out to investigate the deposition of solids on a heated rod under varying water conditions.

The effect of non-uniform heat flux on burnout has been studied and the post burnout conditions in flow in a tube investigated.

The loop has been operated over the pressure range 50 - 1500 p.s.i. with water flowrates between 400 and 7000 lb/h and steam flowrates between 250 and 900 lb/h. Water temperatures from ambient to 5^{o}F below the saturation temperature have been used. Steam temperatures can range from saturation temperature to 750^{o}F at the boiler header pipes.

APPENDIX I

List of Reports

1. Collier, J.G., Bennett, A.W. and Lacey, P.M.C. "Heat transfer to mixtures of high pressure steam and water in an annulus. Part I. Single phase experiments, superheated steam". AERE - R 3653 (1961).

2. Collier, J.G., Bennett, A.W. and Lacey, P.M.C. "Heat transfer to mixtures of high pressure steam and water in an annulus. Part II. The effect of steam quality and mass velocity on the 'burnout' heat flux for an internally heated unit at 1000 p.s.i.a.". AERE - R 3804 (1961).

3. Collier, J.G., Bennett, A.W. and Lacey, P.M.C. "Heat transfer to mixtures of high pressure steam and water in an annulus. Part III. The effect of system pressure on the burnout heat flux for an internally heated unit". AERE - R 3934 (1963).

4. Collier, J.G., Bennett, A.W. and Lacey, P.M.C. "Heat transfer to mixtures of high pressure steam and water in an annulus. Part IV. The effect of test section geometry". AERE - R 3961 (1964).

5. Bennett, A.W., Kearsey, H.A. and Keeys, R.K.F. "Heat transfer to mixtures of high pressure steam and water in an annulus. Part VI. A preliminary study of heat transfer coefficients and heater surface temperatures of high steam qualities". AERE - R 4532 (1964).

6. Bennett, A.W., Hewitt, G.F., Kearsey, H.A., Keeys, R.K.F. and Lacey, P.M.C. "Flow and visualisation studies of boiling at high pressure". AERE - R 4874 (1965). Published in Proceedings of the Symposium of Boiling Heat Transfer in Steam Generating Units and Heat Exchangers, Manchester, 15/16th September 1965. Inst. of Mech. Engrs, 180, Part 3C, Paper 5.

7. Kearsey, H.A. "Steam-water heat transfer - post burnout conditions". Chem. & Proc. Eng., August 1965.

8. Bennett, A.W., Hewitt, G.F., Kearsey, H.A. and Keeys, R.K.F. "Measurement of burnout heat flux in uniformly heated round tubes at 1000 p.s.i.a.". AERE - R 5055 (1965).

9. Benn, D. "An outline of the characteristics and construction of the data acquisition system used on the Harwell High Pressure Steam/Water Loop". AERE - R 5128 (1966).

10. Bennett, A.W., Hewitt, G.F., Kearsey, H.A., Keeys, R.K.F. and Pulling, D.J. "Studies of burnout in boiling heat transfer to water in round tubes with non-uniform heating". AERE - R 5076 (1966).

11. Bennett, A.W., Hewitt, G.F., Kearsey, H.A. and Keeys, R.K.F. "The wetting of hot surfaces by water in a steam environment at high pressure". AERE - R 5146 (1966).

12. Bennett, A.W., Hewitt, G.F., Kearsey, H.A. and Keeys, R.K.F. "Heat transfer to steam-water mixtures flowing in uniformly heated tubes in which the critical heat flux has been exceeded". AERE - R 5373 (1967).

APPENDIX II

Operating Instructions

Complete instructions for operating the loop are given here but the operator should select the appropriate ones depending on the requirements of the experiment. It is assumed that the loop is completely drained.

1. Start up

A. Electrical contacts

Make the following electrical contacts:

(1) Main heater vessel contactors (2)

(2) Boiler water feed pre-heater and pressurised vessel contactor

(3) Control circuits contactor

(4) Main circulator contactor

(5) Gauge glass lights contactor

(6) Panel lights contactor

(7) Control circuit contactor

(1), (2) and (3) are sited on the bridge platform and (4),(5),(6) and (7) on the North Wall near the loop.

(8) Switch on electrical supply to burnout trips if these are to be used.

(The switch is sited on the rear panel of the circuit breaker housing)

B. Main condenser rotameters

Select the rotameters required for the experiment and isolate and drain the cooling coils that are not to be used.

C. Alarm circuits

Switching in the electrical circuits operates the alarm circuits for the power and heater supplies and these must be cancelled. Switch on the 250V D.C. supply to the burnout trips.

Press, in the following order, the two O/C "B" reset buttons, the D.C. earth leakage reset button, emergency stop reset, and the remote power cut-off reset. Press alarm cancel buttons on the main heater control panel.

D. Cooling water circuit

(i) Select one of the two circulating pumps for use.

(ii) Switch on both pump contactors and that for the cooler fan. The selected pump will come into operation and the other will be on standby ready to come into operation if the selected pump should fail for any reason.

These pumps are interlocked electrically with the main circulator and it cannot be started until the pumps are switched on.

The switch gear for the pumps and cooler is sited on the West wall of the building.

(iii) Ensure the emergency mains water cooling supply valve is turned on.

2. Evacuation and filling of the loop with water

To fill the loop with water it is first necessary to evacuate the loop for about five minutes and then to start running water into the loop whilst continuing the evacuation.

While the loop is filling and before the water reaches the top of the main condenser sight glass, start and stop the main circulator several times. This allows any trapped air to rise through main heater vessel vents (V73 and V74) and through the sight glass to the vacuum system. If necessary the flow of water into the loop must be halted until all the air has been vented by repetition of the above procedure. When all the air has been removed close loop vent valves and shut down the vacuum system. Continue filling the loop with water until a loop pressure of 100 p.s.i.g. is reached. The loop is then ready for start-up.

To evacuate and fill the loop

(1) Open V3 (steam to test section), V4 (steam to dump condenser), V5 (water to test section), V6 (water to water treatment plant), V66 (bypass to water treatment plant), V2 and V8 (sight glass on the main condenser), V45, V46, V47, V48, V59, V60, V61, V62, V63, V64, V65 (water treatment plant).

(2) Close V43, V44, V143 and V144 (water treatment sampler valves), V108 (vent valve on line from main condenser), V114 (loop drain valve).

(3) Connect the vacuum line to V67 (on top of main condenser).

(4) Connect the demineralised water supply line to valve V81.

(5) Close V76 and V72 (vacuum receiver bleed valves), V116 (vacuum vent valve), V108 (loop vent valve).

(6) Start the vacuum pump and after one minute open the balancing valve on the vacuum pump.

(7) After 5 minutes open the valve in the demineralised water line and allow water to run into the loop until a loop pressure of 100 p.s.i.g. is registered. Stop the water supply and close valve V81.

To shut down the vacuum system

(1) Close V67 and disconnect the vacuum line.

(2) Open V116 and close V70.

(3) Close the balancing valve on the pump and after two minutes switch off the pump

(4) Open V71 and V72.

(5) Close V109 and V110 (vent valves on loop).

3. Start-up of steam and water loops

The loop can be used to provide (1) a supply of steam, (2) a supply of hot water or

(3) supplies of both. The following instructions will cover (3), supplies of both steam and hot water. If steam only or water only is required, the relevant parts of the instructions should be omitted.

A. (1) Start the main circulator and note that the indicator light on the console panel signalling that the trip circuits are in order has come on.

(2) Open the D.P. cells on FCR1 (steam flowrate) and FR1 (water flowrate).

(3) Adjust the water flowrate to near the required value by means of V5. The bypass V5A should only be used for high water flowrates.

(4) Set V54 at ~30% open by manual adjustment at FCR1. V54A should only be used when high steam rates are required.

(5) Check that V3 is fully open, and that the solenoid valve in the steam bypass to the test section is closed.

(6) Check that the flow of cooling water through the dump condenser is ~15 g.p.m.

(7) Close V73 and V74 (gas bleed lines from the main heaters). At this stage all gas should have been removed from the system. However, some gas may be released as the system warms up and V73 and V74 should be cracked open occasionally to free any gas from the top of the main heaters.

B. Steam circuit

Start up the boiler by:

(1) Manually opening V122 - solenoid valve on the oil fuel gravity feed tank. This is connected to a fusible link which in the event of a fire, melts and trips V122 and cuts off the oil supply. This valve is also connected to a remote push-button situated near the exit from the building, on the wall between the two laboratories.

(2) Open V120, V2 and V123 (further oil shut off valves). The oil is now shut off only by V121 which is linked to a photo-electric cell, capable of observing the flame in the furnace.

(3) Set the air supply to the burner in the open position.

(4) Start the forced draught fan and purge the furnace for 5 - 10 minutes.

(5) Open V121 and light the burner.

(6) Close the air control to the "Run" position and adjust the oil rate and draught to get a clean, stable flame. The oil rate at this stage will be about 5 g.p.m. as shown on the rotameter F7.

(7) After 5 - 10 minutes to warm up the quarl, increase the oil flowrate to 7 g.p.m. and start the induced draught fan.

N.B. Check that the damper in the stack has moved to direct the furnace gases into the bypass. Check the water flow through the fan bearings.

(8) Position the photo-electric cell before the furnace and V121 should drop into the "Control" position.

(9) (a) As the water heats up and expands, control the loop pressure by draining water from the loop via V85. V84 is a hot valve for shut off if V85 fails and is normally fully open. Do not allow the level of water in the main condenser to fall below the halfway mark ($\sim$10 reds showing in the portholes of the sight glass).

(b) Steam temperatures up to 750°F at the boiler header can be used. The outlet steam temperature is recorded from T18 on a recorder sited on top of the control console. The boiler tube temperatures are also recorded and these temperatures are used when controlling the boiler to close limits.

(c) An over-temperature alarm which is fitted in the steam line gives an audible and visual signal at a temperature of 650°F.

C. Hot water circuit

(1) After the boiler has been running for 10 - 15 minutes switch on the main water heaters required. Adjust the heaters until the water temperature is steady at the required value.

(2) The temperature should never exceed a value of 5°F below the saturation temperature for the loop operating pressure.

A summary of the heater arrangements and control is repeated here.

There are two cylindrical vessels mounted vertically, connected in series and each fitted with thirty x 5 kW immersion heaters and are designated vessels "A" and "B".

Heater switch controls

Vessel	Power	Switching Arrangement
"A" - top	30 kW	Single switch
	45 kW	" "
"A" - bottom	30 kW	" "
	45 kW	" "
"B" - top	30 kW	" "
	45 kW	" "
"B" - bottom	30 kW	" "
	45 kW	Individual switch for each 5 kW heater, one heater on Variac control.

Thus any power from 0 - 300 kW can be selected.

Control of heaters

The 45 kW bank in the bottom of vessel "B" can be controlled from a Kent Multilec Mark II temperature recorder/controller. Thebank is split into a base load of 30 kW and a trim load of 15 kW.

The whole 300 kW is controlled from a second recorder/controller, the set point of which is adjusted to 5 deg F below the saturation temperature for the loop operating pressure.

A warning is given at 10 deg F below saturation temperature and if the temperature rises another 5 deg F, a second alarm is sounded and all heat to the vessels is switched off automatically.

The supply is also interlocked with the water control valve and cannot be switched on until there is a flow of water through the test section.

Thus summarising:

(a) water valve closed - heaters cannot be switched on

(b) main circulator off - " " " " "

(c) control point reached - 45 kW base and trim loads operating

(d) saturation temperature −5 deg F− all heaters switched off

D. Pressuriser

If the pressuriser is to be used it is necessary to raise its temperature above saturation by use of the heaters on the body of the vessel. The level in the sight glass is lowered until a steam bubble can form in the vessel. The flow through V86, the pressuriser spray control valve, is adjusted to a value which leaves sufficient margin on either side of the set point for alterations to be made to the flow through the nozzle sufficient to control the pressure changes in the loop.

If the pressuriser is not in use then V86 is left closed to prevent circulation through the vessel and the heaters are not switched on.

4. Plant operation and control

When operating conditions are achieved the two main variables are pressure and temperature. These are interlocked to some extent but are controllable independently. The flows of steam and water usually stay very close to the set values and do not need constant attention.

A. Steam circuit

(1) Flowrate: If a change in flow is desired then this can be done in one or both of two ways. The flow of water via V54 to the boiler can be varied or part of the produced steam can be bypassed through a dump condenser. The dump condenser is used when small adjustments to the steam flowrate are required and it is not desirable to alter the feed water to the boiler or to adjust the firing rate. This is valuable because the response is immediate, whereas adjustments to the boiler have a time-lag before any response is obvious. The minimum flowrate for the boiler is 500 lb/h. Thus if lower steam flows are required (as low as 100 lb/h) this is feasible by bypassing the greater part of the generated steam through the dump condenser. If low steam flows are required then it is essential that a pipe heater is attached to the pipework between the loop and the test section to make good all heat losses.

(2) Temperature: The steam temperature can be controlled in several ways, the firing rate can be adjusted, the water feed rate can be adjusted (only if the

flowrate is not correct), and by using the desuperheater. A further slight increase in temperature can be achieved by use of a pipe heater.

B. Water circuit

(1) Flowrate is adjusted as necessary by adjusting the setting of valve V5.

(2) The temperature is controlled by adjustment of the heater load on vessel "B".

C. Dump condenser

When using the dump condenser first check that the cooling water is flowing, the control valve is V50. To pass steam through the condenser gradually open V4. When a low flowrate of X lb/h is required bring the loop to operating conditions with a steam flowrate (indicated on FCR1) of (500 + X) lb/h, then

(1) bring the dump condenser into operation,

(2) throttle back V3 (steam to test section control valve) until the required flowrate (X lb/h of steam) is observed on FCR1.

D. Action on alarms

When a fault occurs warning is given by an audible alarm and warning light; the audible alarm can be cancelled but the light remains on until the fault is corrected.

(1) Excessive steam temperature (backsetting alarm contacts on TCR1): If the steam leaving the desuperheater exceeds the set figure warning is given by a light and a bell.

ACTION: Reduce the burner output and increase the water supply to the boiler by opening V54.

(2) Failure of bursting discs (AP4 and AP5): Warning is given by a light and bell in the event of failure.

ACTION: If the loop is operating at low pressures and the pressure relief valves hold, it may be possible to continue operating. If the valves do not hold, then the loop must be shut down as detailed in the next section.

(3) Excessive loop pressure: An alarm (P1A) is fitted and is set at 5 - 10 p.s.i. above the loop operating pressure.

ACTION: Lower the pressure by draining water from the loop and adjusting loop temperatures as necessary.

(4) Main pump cooling water circuit (AP1 and AP2): Alarms are given (a) if the inlet temperature exceeds 105^{o}F or (b) the outlet temperature exceeds 120^{o}F.

ACTION: Reduce the temperature of the water feeding the main circulator by adjustment of rotameter flows to the main condenser.

(5) Water feed to water treatment plant: An alarm is given if the inlet water temperature to the ion exchange columns exceeds 140^{o}F.

ACTION: Adjust flow to the columns or cooling water flow to the coolers until the temperature falls below 140^{o}F.

E. Water treatment plant

Three ion exchange columns are built in to the loop. Each column is filled with ion exchange resins to give varying pH values and only one column is normally in use during loop operation.

About 1% of the loop flow is fed to the plant, the flow being through V6 to the columns and through a bypass via V66 back to the main pump inlet. More than 1% of the loop flow passes V6 and adjustment of the column inlet valves causes the excess flow to pass via V66.

Provision is made for sampling the loop contents. One sample point is in the inlet to the water treatment plant (V43 and V143) and the other in the outlet (V44 and V144). The samples are collected in polythene bottles after passing through lengths of capillary tube between valves V43 and V143 and V44 and V144.

F. Electrical power to the test section

There are two sources of power available for application to the test section in use (a) a 100 kW A.C. supply and (b) a 700 kW D.C. supply.

Details of the supplies and their controls:

(1) A.C. power:

To supply A.C. power to the test section

(a) Connect the wattmeter to the lower plug on the wattmeter panel. (Meter reads $^{1}/400$th of actual current).

(b) Wind the transformer voltage regulator back to zero.

(c) Switch on "Mains" and "Bridge Balance" on A.C. trip panel and "Mains" on panel next to it.

(d) Put "Test Section" mains isolator and "Test Section" isolator to "ON" (North wall).

(e) For "Test Section Heating Trip", press "ON" button and subsidiary button at same time (North wall).

(f) Red light will show above voltmeter and ammeter on second control panel.

(g) Supply power to the test section as required by turning the handle of the voltage regulator.

To shut off the A.C. power

(a) Wind the voltage regulator back to zero.

(b) Switch off the panel switches (item (c)) and isolators on the North wall (item (d)).

(2) D.C. power:

A D.C. generator providing 3000 amps at 250 volts is available. It can be controlled from both the generator house and the loop area. It is normally started up by the electrician on duty but details of the start-up procedure are included here for completeness.

Ensure all main and auxiliary supplies are available and switched on at

(a) Control panel (Loop Area)

(b) D.C. breaker-trip supply

(c) Generator control panel.

Close isolator (S2) and main switch (S3) on control panel and press the "O/C alarm reset", "O/C trip reset", "emergency stop reset" and "power cut off reset" push buttons. Two lamps should then be lit - the "emergency stop healthy" and "power cut off healthy" lamps. Close isolator (S1) on the generator control panel. Press the "O/C A trip reset" and "D.C. earth leakage reset" push buttons.

Three lamps should then be lit on the generator control panel - the "motor off", the "zero field" and "reverse field" lamps.

<u>NOTE</u>: The zero field lamp and reverse field lamp may not be lit if the Variac is not in its zero position. If this is so, then when the interlocks are completed the field Variac will run down to zero and the lamps will then light.

Wind the liquid resistor to the start position when the "closing interlocks completed" lamp on the starter should light.

Failure to light may be due to:

(1) The "O/C trip" has not been reset on the control panel.

(2) The "emergency stop reset" push button on the control panel has not been reset.

(3) The "remote power cut off healthy reset" push button has not been reset.

(4) The "D.C. earth leakage reset" push button on the generator control panel has not been reset.

(5) The "O/C A trip reset" push button on the generator control panel has not been reset.

(6) The field Variac has not run down to zero. (This can take a few minutes).

(7) A main supply failure.

(8) The temperature burnout trip has not been reset- if connected as per drawings.

When the "closing interlocks completed" lamp has lit then close the starter. (NOTE: it is impossible to close the starter until this lamp is lit).

The machine will start to rotate. Now take out the liquid resistance slowly until near the end. The last bit of resistance should be removed quickly to prevent undue arcing of the liquid resistance contacts. After the M/C has synchronised adjust the motor excitation to give a slightly leading power factor. Check the bearings to ensure the oil rings are rotating freely.

Switch the excitation control to "Remote" position - and the generator is ready to supply load. During running a periodic check should be made of the generator bearings.

Shut down

To shutdown the machine press "Shut down" push button on the generator control panel.

Isolate the generator control panel and the control panel in the loop area.

Operation of the various push buttons

Pressing the field push button on the generator control panel will:

(1) Cut off the field supply, or

(2) Drive the field Variac to zero.

Pressing the Shut Down push button will:

(1) Trip the starter.

(2) Trip the D.C. Breaker.

(3) De-energise the field circuit.

(4) Drive the Variac down to zero when the push button is released.

Pressing the "Emergency Stop" on control panel or on the wander lead will:

(1) Trip the starter.

(2) Cut off the field supply.

(3) Trip the D.C. breaker.

(4) Trip the mag. oil valve.

(5) Trip the main heater contactor.

(6) Trip the pre-heater contactor.

(7) Trip the pressuriser relays.

(8) Trip the test section.

Pressing the power cutoff on the control panel or on the wander lead will:

(1) Trip the D.C. breaker.

(2) Trip the test section.

(3) Cut off the field supply.

(4) Run the field Variac down to zero.

5. Normal Shut Down procedure

When the experimental programme is completed it is necessary that the loop is cooled down to a safe temperature before any engineering work, such as test section changes, can be carried out. During this cooling period it is essential that sufficient pressure is maintained in the loop to prevent boiling; thus water has to be pumped into the loop throughout this period.

The following sequence of events is recommended:

(1) Reduce the electrical power to the test section in steps until the power is down to zero. Then switch off at source.

(2) Pump water into the loop using the K.S.B. pump.

(3) Switch off the main water heaters (if used).

(4) Switch off power to any trace-heating or pipe heaters that may be in use.

(5) Switch off boiler feed water pre-heater heaters (if used).

(6) Switch off pressuriser heaters (if used).

(7) Reduce the oil firing rate to the boiler (if used).

(8) Increase the cooling water supply to the main condenser.

(9) Open the desuperheater damper fully and operate the cooling fan (if the boiler has been used).

(10) Open the pressuriser spray nozzle valve.

(11) When the main condenser level gauge indicates over ¾ full (say 3 reds showing at the top of the glass), shut off the oil supply to the boiler (if used).

(12) When the loop has cooled to ca. 270^{o}F, any main condenser cooling coils which have not been in use during the experiment can be brought into circuit.

(13) Continue cooling until the loop water temperature reaches $<140^{o}$F at TRC1 and TCR2.

(14) Continue pumping water into the loop until it is full (i.e. the pressure begins to rise again as indicated on the pressure gauges).

(15) Shut off the main circulator, boiler fans (if used) and the make-up water pump.

(16) Vent the main condenser through valves V108, V109, V110.

(17) Isolate all electrical switch boxes.

(18) Shut down the make-up water treatment plant.

NOTE: If experimental work is being done using the annulus test section, it must be remembered that there is a stainless steel bellows in the system which is pressurised with nitrogen to balance the loop pressure. Thus, when cooling down, the nitrogen pressure must be reduced in step with the loop pressure. At the end of the cooling down period, the nitrogen circuit should be vented via valve V111; valves V124 and V125 in the nitrogen balancing circuit must be closed and the nitrogen cylinder isolated and the lines vented to atmosphere.

6. Emergency Shut Down Procedure

A. General

In certain circumstances, such as a serious steam leakage from the loop it becomes necessary to quicken the normal shut down procedures. In such an event the following sequence should be adopted.

(1) Press the emergency button on the motor generator control panel or on the wander lead. This switches off all the main water heaters, the D.C. power to the test section, if used, the boiler water pre-heater and the heaters on the pressuriser vessel.

(2) If A.C. power is being used on the test section, then isolate the power at the contact breaker.

(3) If the leak is on the test section (Section 6D), divert flow through the test section bypass by operating the solenoid valves from the main console. (For normal running conditions, all three switches are in the "UP" position; in emergency conditions all three switches should be in the "DOWN" position).

(4) Pump in make-up water to the loop using the K.S.B. pump.

(5) Increase the flowrate through the main condenser cooling coils.

(6) If the boiler is in use: (a) reduce the oil firing rate,
(b) open the dump condenser fully.

(7) Continue reducing the oil firing rate as the water level rises in the main condenser.

(8) Shut off all trace heating and pipe heaters.

(9) Complete normal shut down procedure.

B. In case of fire

(1) Press the emergency switch to cut off the oil supply to the burner.

(2) Pull the solenoid trip wire to isolate the oil fuel gravity feed tank.

(3) Ring the Fire Brigade - Ext. 2222.

(4) Carry out the emergency or normal shut down procedure as the circumstances permit.

(5) Fight the fire.

C. In case of electrical failure

If the electrical supply fails then automatically -

(1) The emergency lighting will come on, and

(2) If the boiler is in use, the oil supply to the burner will be cut off and

the boiler fans will stop.

(3) The main circulator and the cooling water pumps will stop.

(4) All power to the test section, the main water heaters, boiler water preheater and pressuriser vessel will be cut off.

If such an incident should occur then -

(1) Isolate the oil supply at V2 and open the burner. Open the burner control fully to permit the maximum natural circulation of air through the gas generator passages. Ensure that the damper in the boiler stack has opened.

(2) Connect the mains water to the rig via the fire hose connections and turn on the supply.

(3) Open the boiler feed water inlet (V54) fully.

(4) Open the main heater outlet valve (V5) fully.

(5) Open the main heater vent valves (V73 and V74).

(6) Open the dump condenser valve (V4).

(7) When the electrical supply is restored complete the cooling of the loop as under normal conditions, except

(b) NOTE: Do not restart the main circulator.

D. In case of a steam leak in a test section

(1) Direct flow through the test section bypass.

When STEAM and WATER circuits are in use

(1) Open V75 - in bypass line.

(2) Close V76 and V77 - in steam inlet and test section outlet lines.

(3) Close V5 - in water inlet line.

(4) Switch off heaters to main heater vessels and power to test section.

(5) Continue as for normal shut down.

In case of a failure when WATER circuit only is in use

(1) Open V75.

(2) Close V76 and V77.

(3) Switch off power to test section and power to all heaters in use.

(4) Continue as for normal shut down.

To ease the process of cooling down, the test section is fitted with a bypass line through which flow of liquid or steam can be maintained. Three solenoid air-operated valves are involved in the isolation of the test section and are operated from the console. These are:

V76 - in the test section outlet line
V77 - in the test section inlet line
V75 - in the bypass line

If the steam circuit is in use then the bypass must always be connected to the steam inlet line. Thus in the event of a test section failure the steam flow can be diverted to the bypass line and the boiler cooled down in the normal manner. If two-phase flow is involved, then the water circuit must be shut off, at V5. The main water heaters must be switched off and the vessels allowed to cool down without forced circulation.

If the steam circuit is not in use then the bypass is fitted to the water circuit inlet line.

(2) If the leak is sudden and violent, carry out the emergency shut down procedure.

(3) If the leak rate is not serious, carry out a normal shut down.

E. In case of a nitrogen leak

If the short annular test sections are in use, it is possible for a leak to develop in the nitrogen balancing system.

Try if possible to stop the leak. If this proves to be impracticable then carry out a normal shut down.

F. In case of a steam leak in the boiler (between V3 and V54)

(1) If the leak is small then follow the normal shut down procedure. If necessary, the boiler flow can be reduced by closing valve V54.

(2) If, however, there is a major leak it will be necessary to shut down the boiler, although if possible a small flow of water should be maintained via valve V54 to assist in the cooling down of the boiler. In such an event the procedure to be adopted is:

(2.1) Switch off the power to the test section.

(2.2) Switch off the power to the main water heaters, boiler water preheater and the pressurised vessel.

(2.3) Switch off any trace heaters or pipe heaters.

(2.4) Close valve V3, the feed to the test section and open V4, to dump condenser.

(2.5) If both steam and water are being used, open V5 fully.

(2.6) Open the burner fully and shut off both boiler fans.

(2.7) Ensure that the damper in the boiler stack is open.

(2.8) Pump make-up water into the loop.

(2.9) If the level of water in the main condenser shows it to be more than half-full, then valve V54 can be kept cracked open so long as the level does not fall. If it does, then V54 must be closed or damage may be done to the main circulator.

(2.10) Complete the shut down.

G. <u>In case of a steam leak in the water treatment plant</u>

(1) <u>A leak between V6 and the top of the columns</u>:

(1.1) Shut V6, V45, V61, V65 and V66.

<u>NOTE</u>: This will cause the temperature of the water entering the main pump suction line to rise.

(1.2) Carry out a normal shut down.

(2) <u>A leak at the columns</u>:

(2.1) Isolate the column or columns using the appropriate valves.

((2.2) Carry out normal shut down.

(3) <u>A leak between the base of the columns and the pump inlet</u>:

Proceed as in (1) above.

H. <u>A leak at the flanges of the main water heater vessels</u>

Depending on the severity of the leak, carry out an emergency or a normal shut down.

I. <u>In case of failure of the main circulator</u>

(1) Press the emergency button on the motor generator control console or the wander lead.

(2) Close V2 (oil to burner).

(3) Stop the boiler fans and open the burner fully to ensure the maximum natural circulation.

(4) Ensure that the damper in the boiler stack is open.

(5) Switch off all trace heating and pipe heaters.

(6) Increase the cooling water supply to the main condenser to its maximum.

(7) Open the dump condenser (V4) flow.

(8) Increase the cooling water supply to the dump condenser (V50).

(9) Open V5 (main water heater outlet valve).

(10) Open V54 and V54A (boiler water inlet valves).

(11) Open the desuperheater damper fully and start the cooling fan.

(12) Pump make-up water into the loop.

(13) Complete a normal shut down procedure when the loop is cool.

J. <u>In case of the failure of bursting discs in the main loop circuit</u>

There are two bursting discs fitted in the loop;

BD1 in the steam circuit, and
BD2 in the condenser inlet line.

Each disc is backed up by an alarm and a pressure relief valve (V68 and V69).

In the event of a disc failure the appropriate light alarm will show on the console and the alarm bell will start ringing.

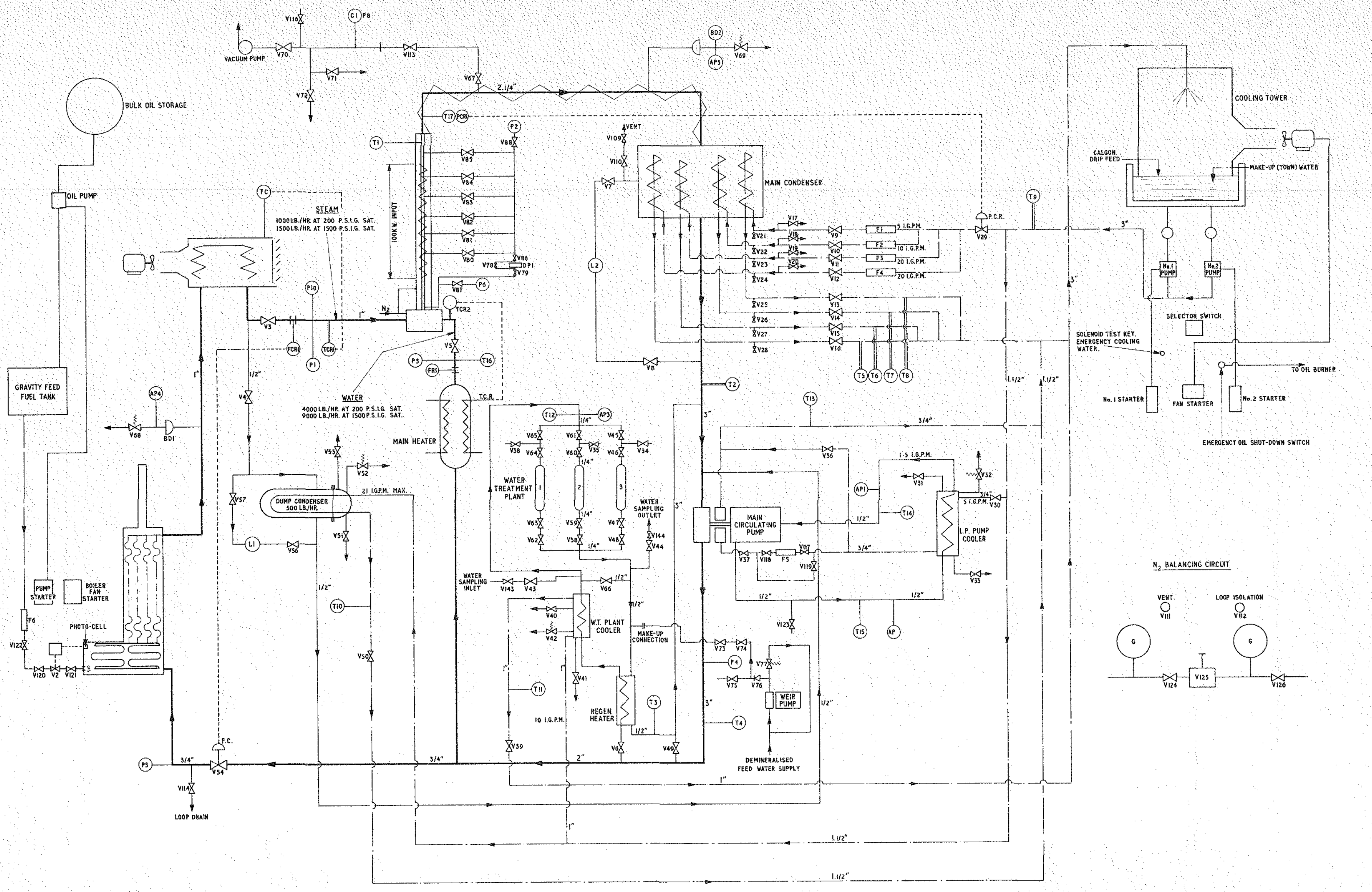
The pressure relief valves are set to operate at 1510 p.s.i.g. allowing the pressure to fall to 1500 p.s.i.g. when the valves should close again.

(1) If a disc fails at low pressure and the pressure relief valve holds, it may be possible to carry on operating the loop.

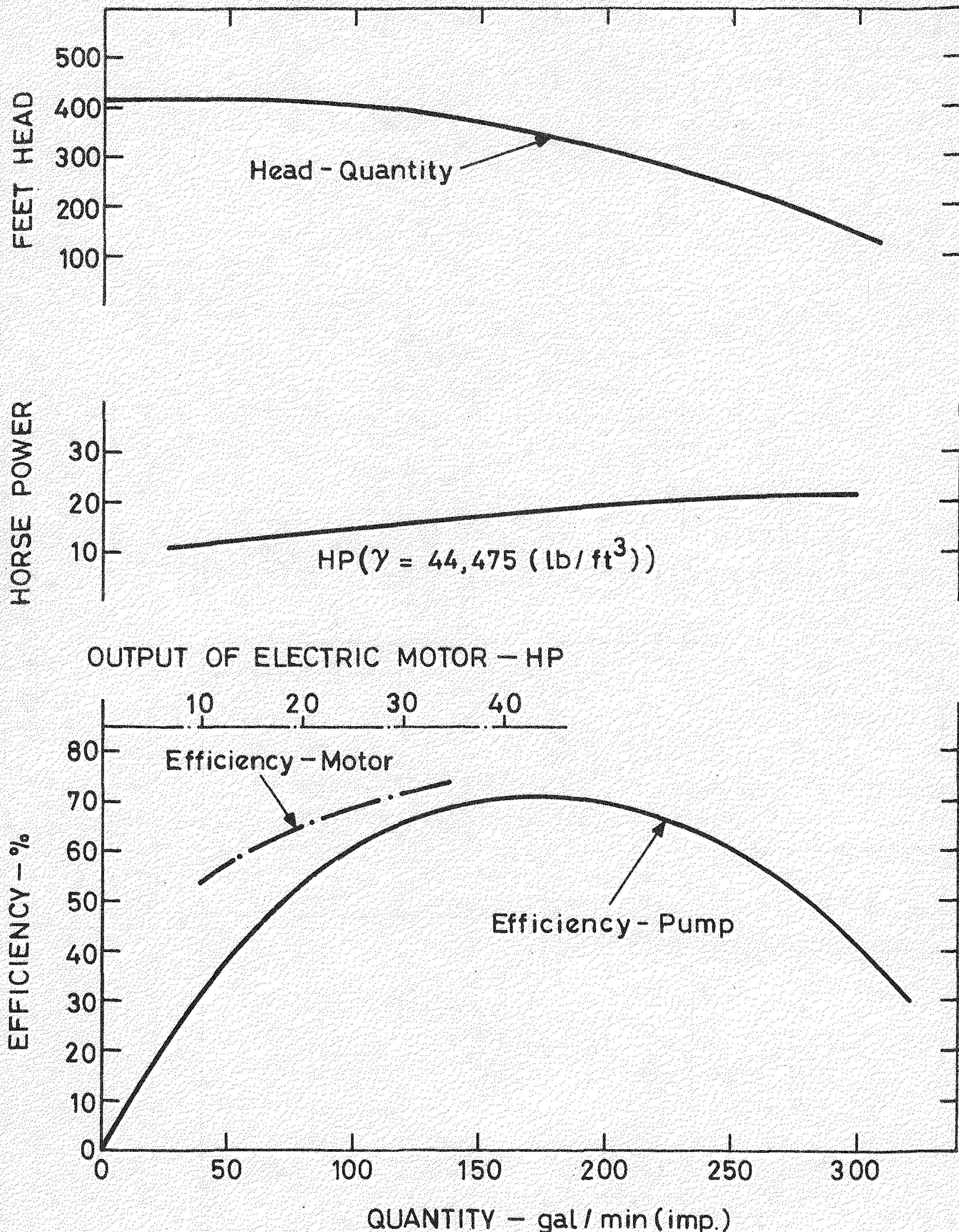
(2) If, however, BD1 fails and the pressure relief valve fails to hold or does not re-seat, then the water input to the boiler will be less than the quantity of steam generated.

If this should happen, the boiler flame should be extinguished and the inlet water flow to the boiler adjusted manually using valve V54 in order to keep the steam temperature below 750°F.

The emergency cooling procedure should then be started.

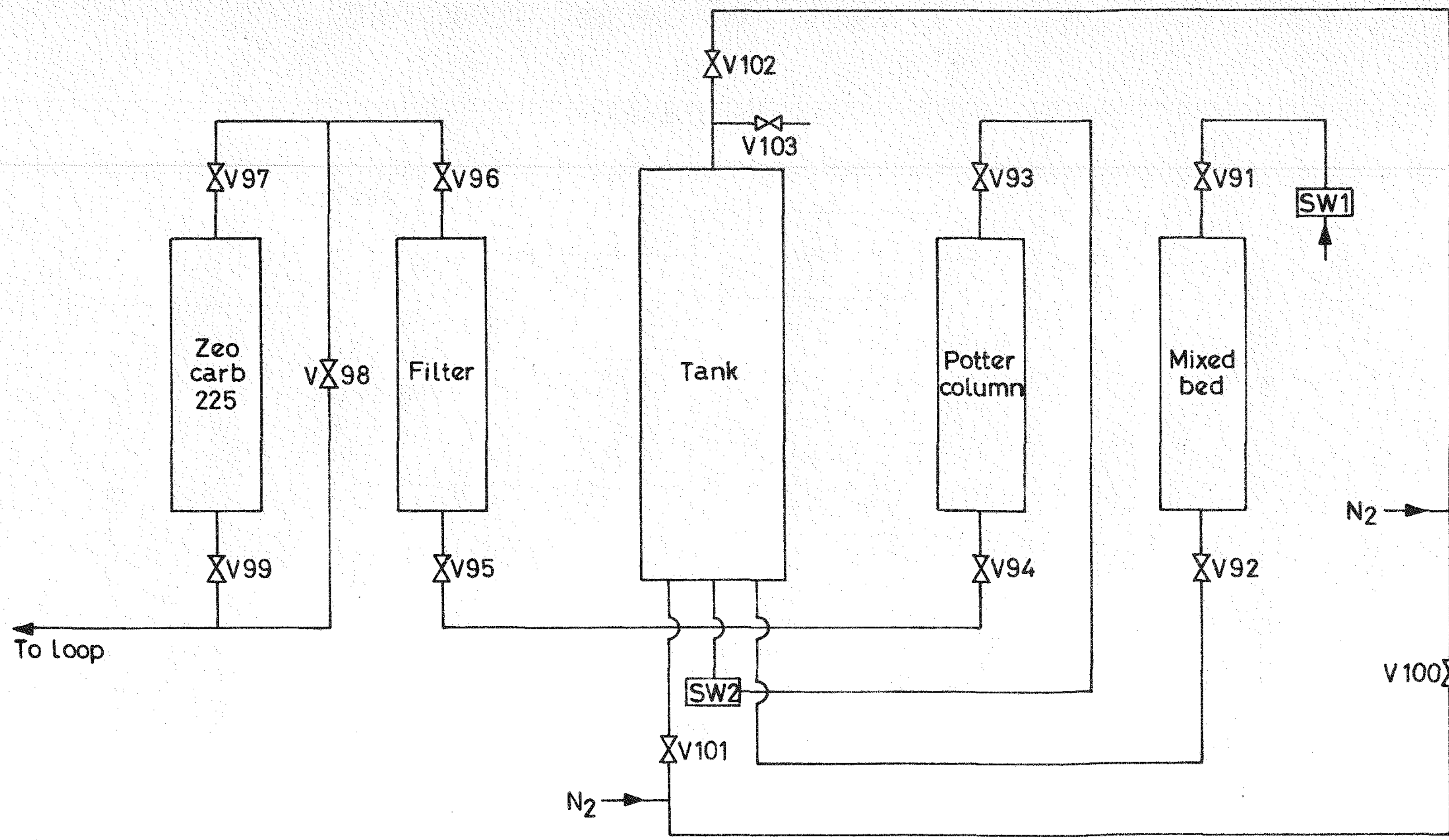


AERE - R 5145 Fig. 1
Flow diagram of Loop and a Test Section



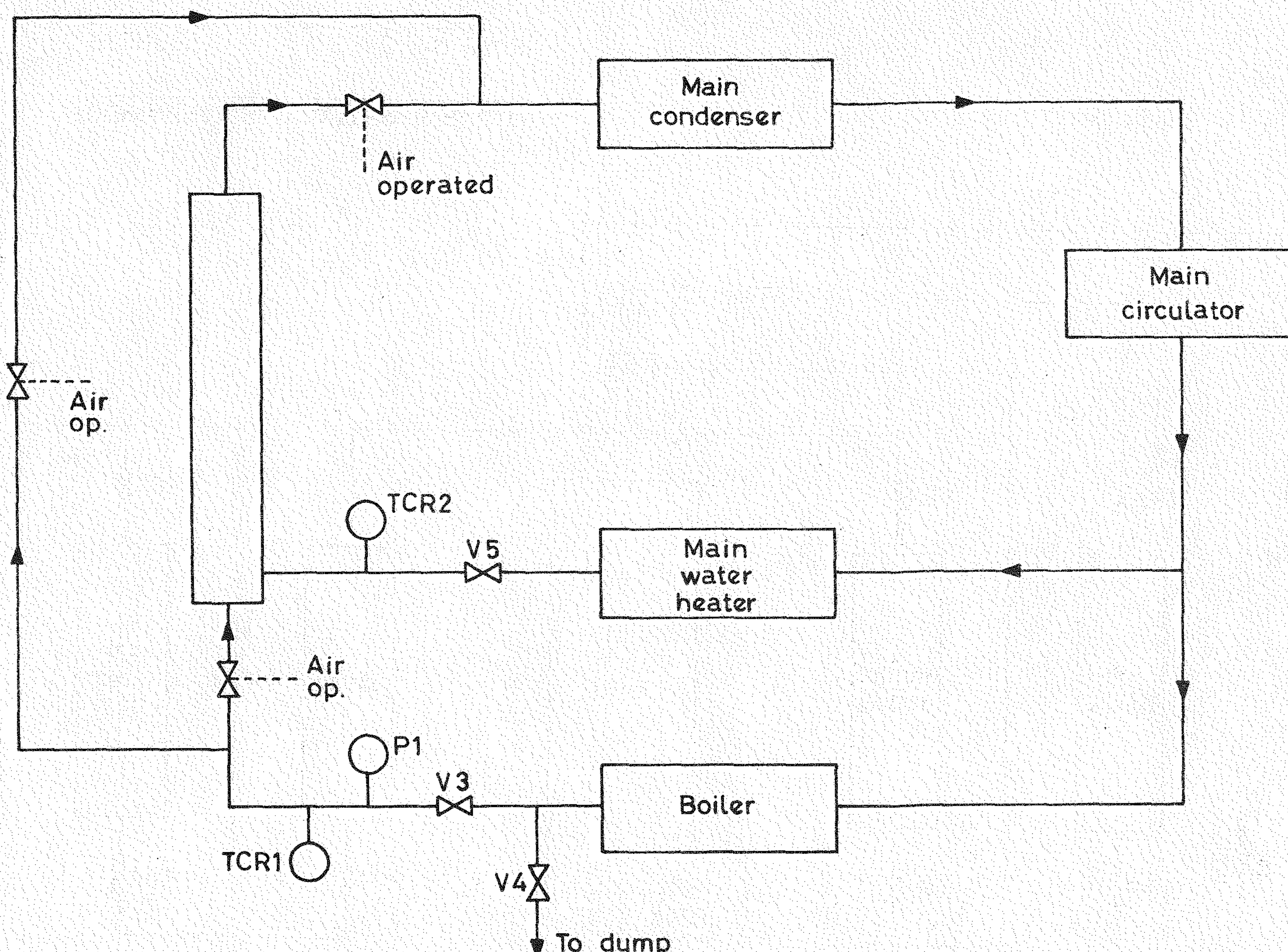
CHARACTERISTIC CURVES OF MAIN CIRCULATOR.

FIGURE 2. A.E.R.E.-R.5145.



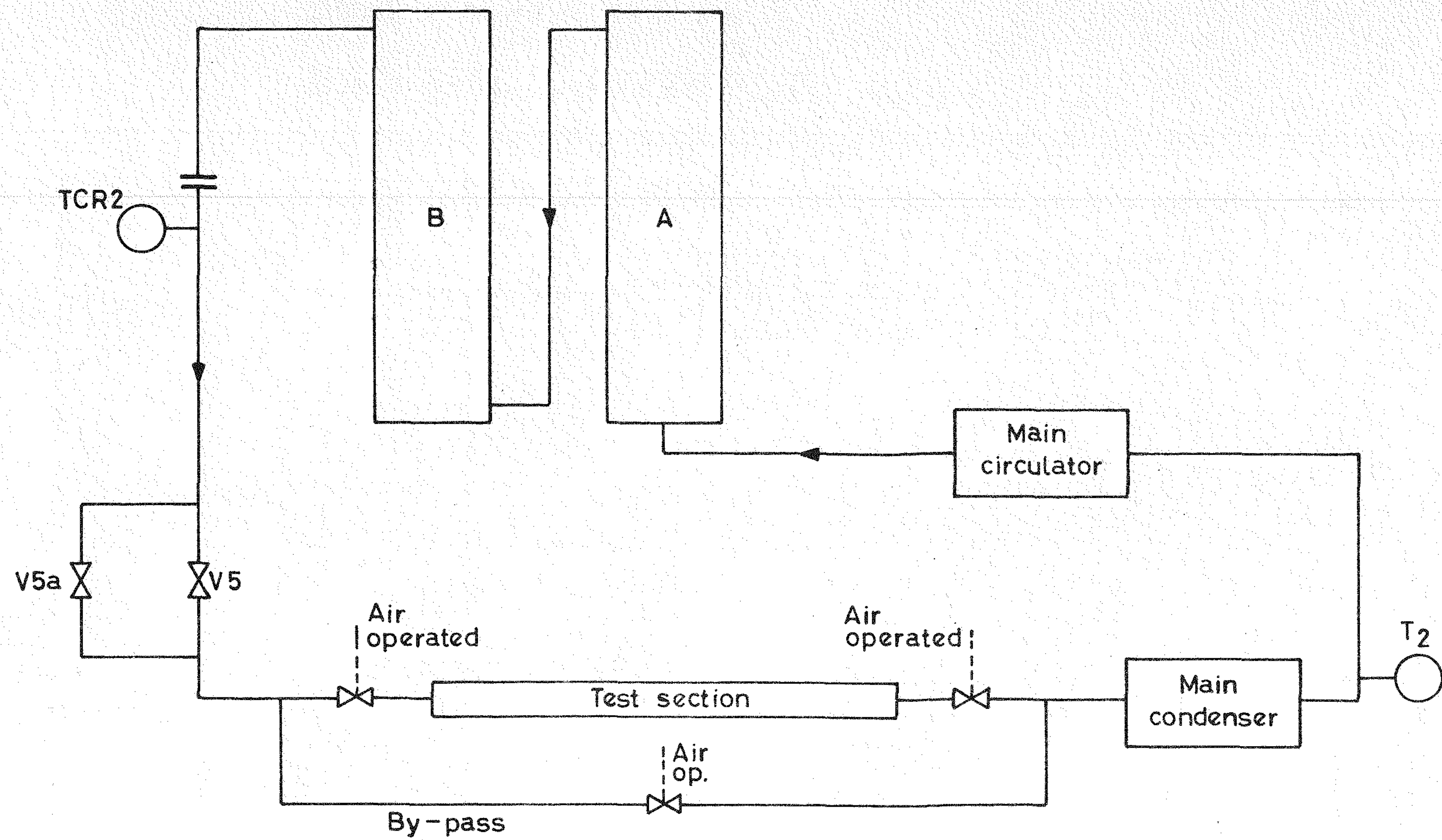
DEMINERALISED WATER CIRCUIT.

FIGURE 3. A.E.R.E. – R. 5145.



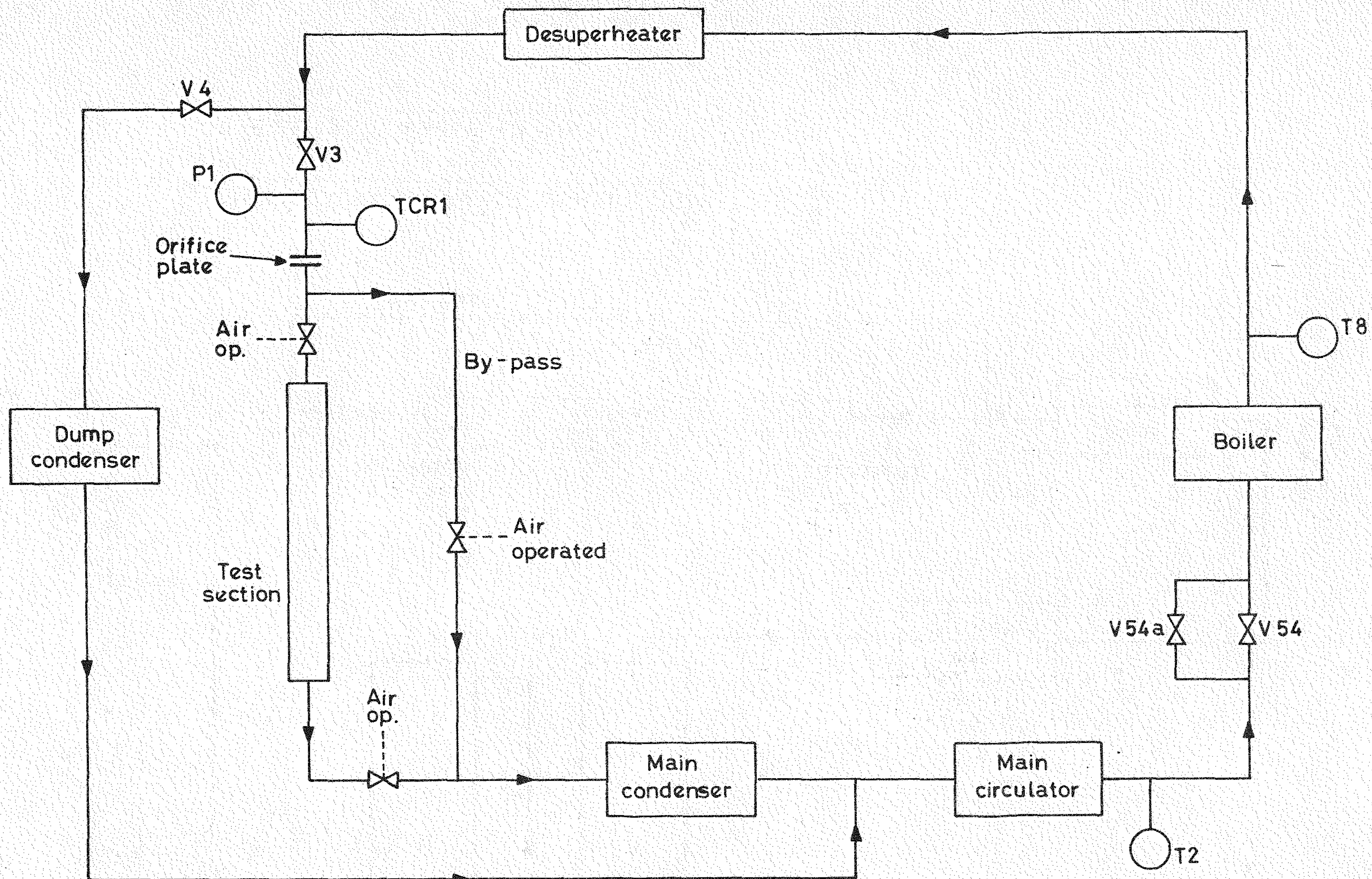
FLOW DIAGRAM FOR TWO PHASE FLOW.

FIGURE 4. A.E.R.E. – R. 5145.



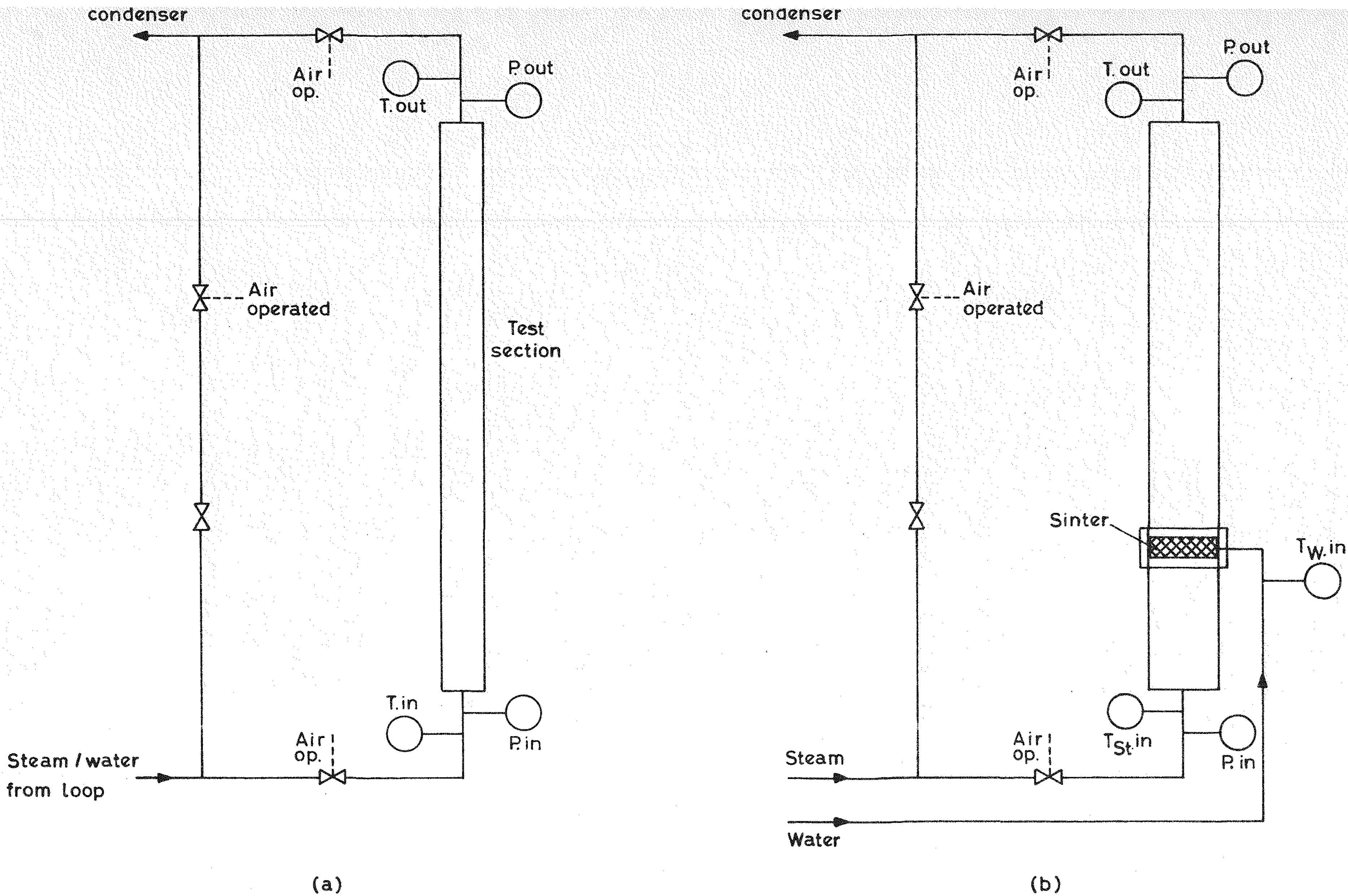
FLOW DIAGRAM — WATER CIRCUIT ONLY.

FIGURE 5. A.E.R.E.-R. 5145.



FLOW DIAGRAM — STEAM CIRCUIT ONLY.

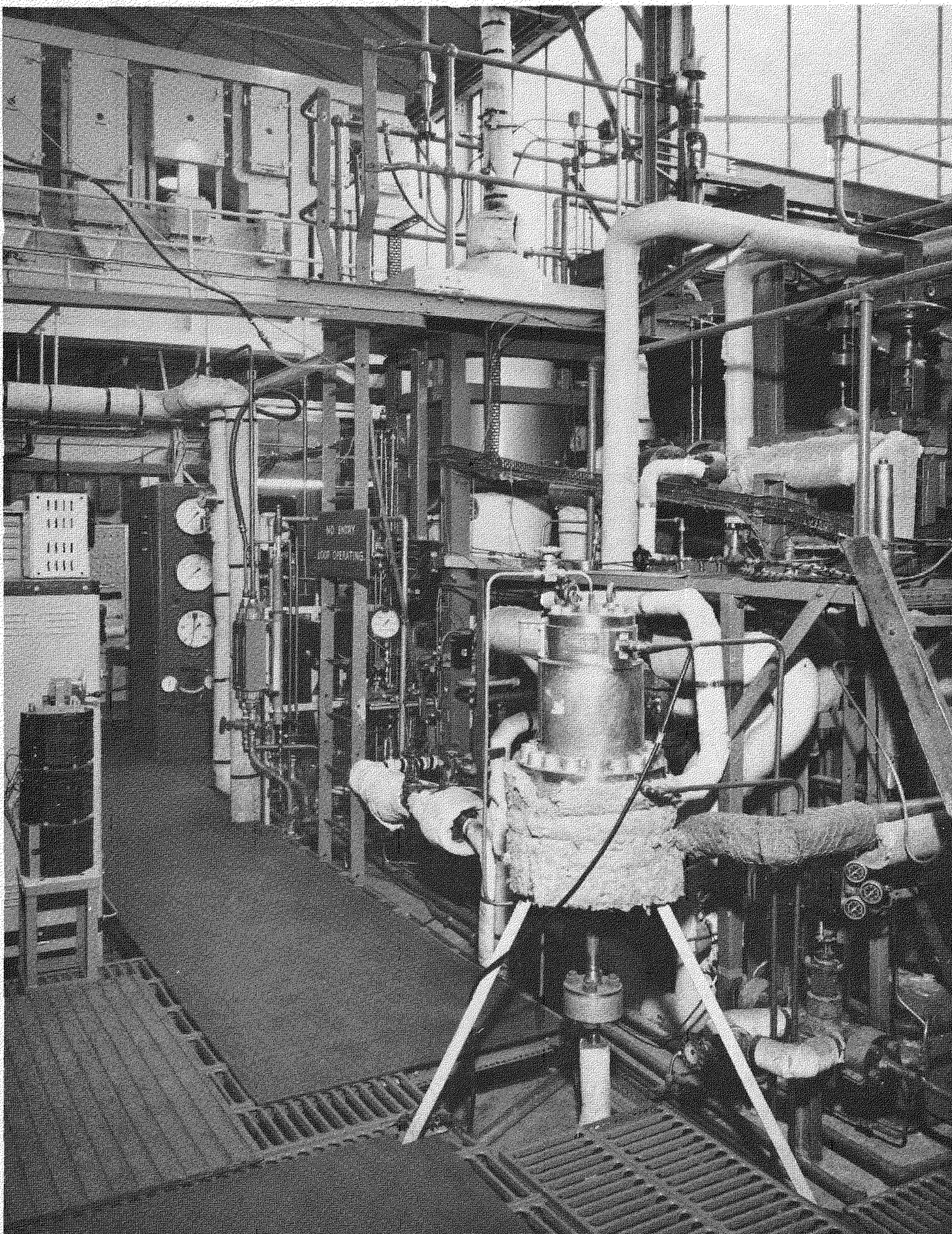
FIGURE 6. A.E.R.E.—R. 5145.



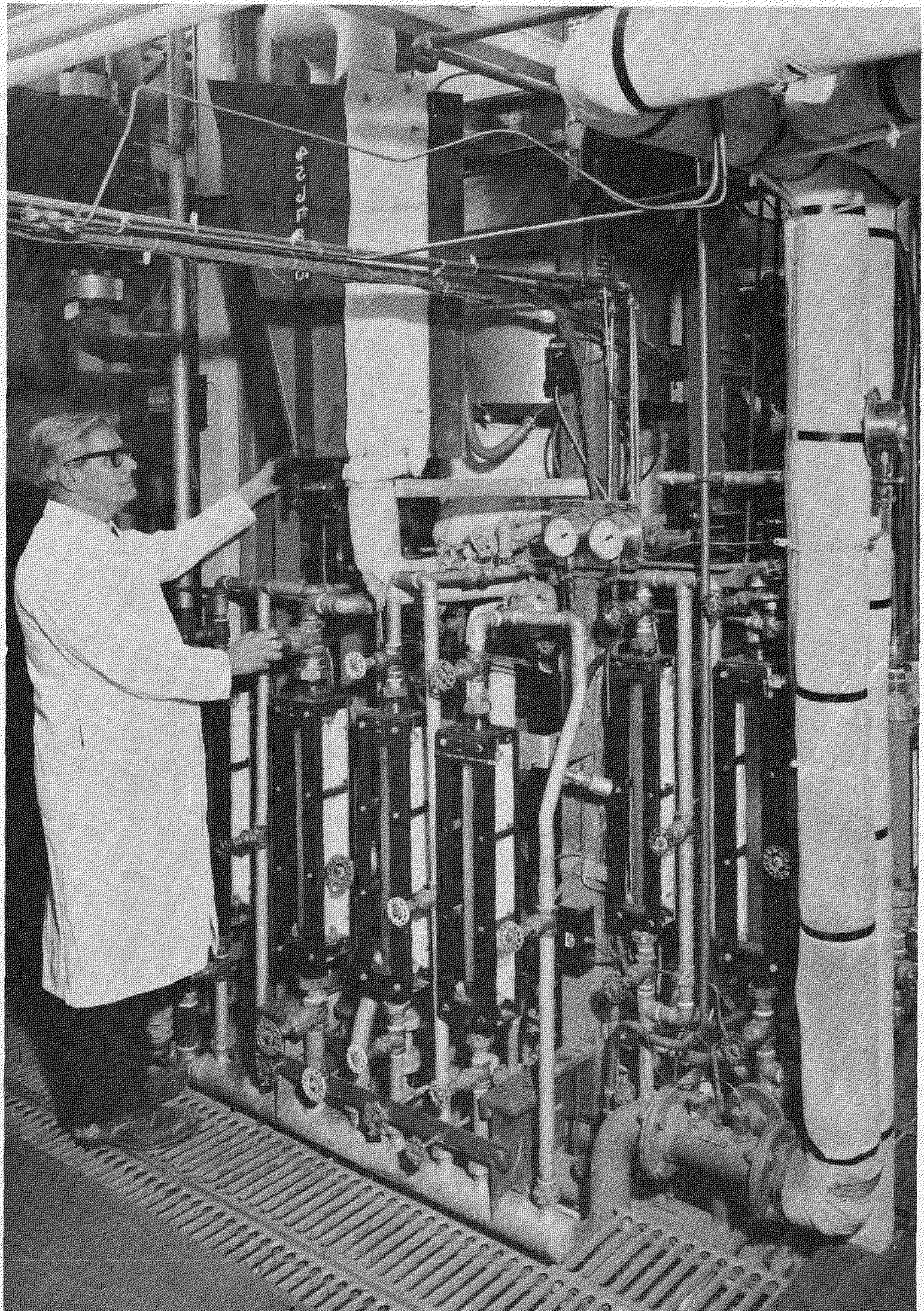
(a) SINGLE PHASE STEAM WATER.

(b) TWO PHASE STEAM AND WATER.

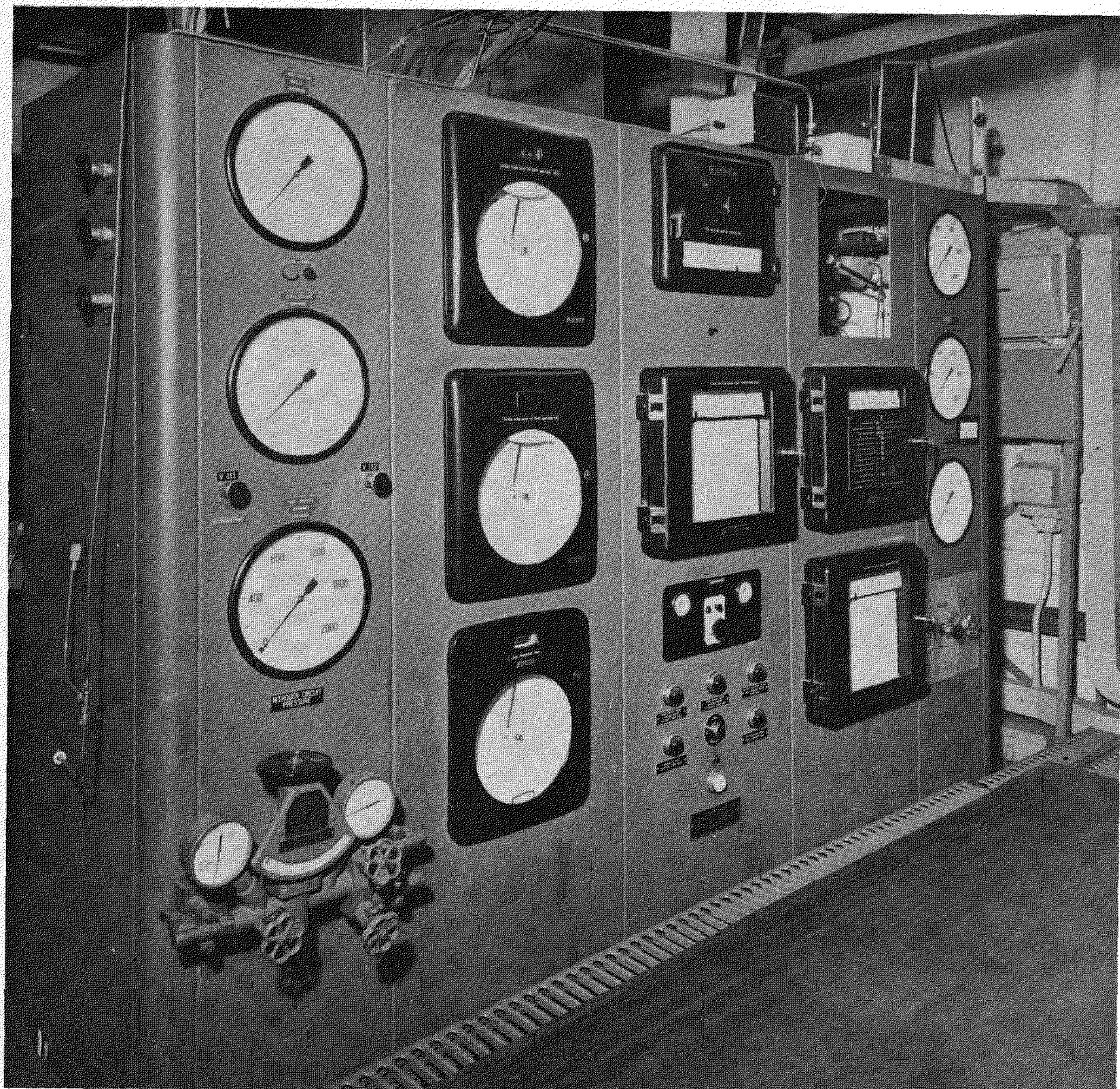
FIGURE 7. A.E.R.E.-R. 5145.



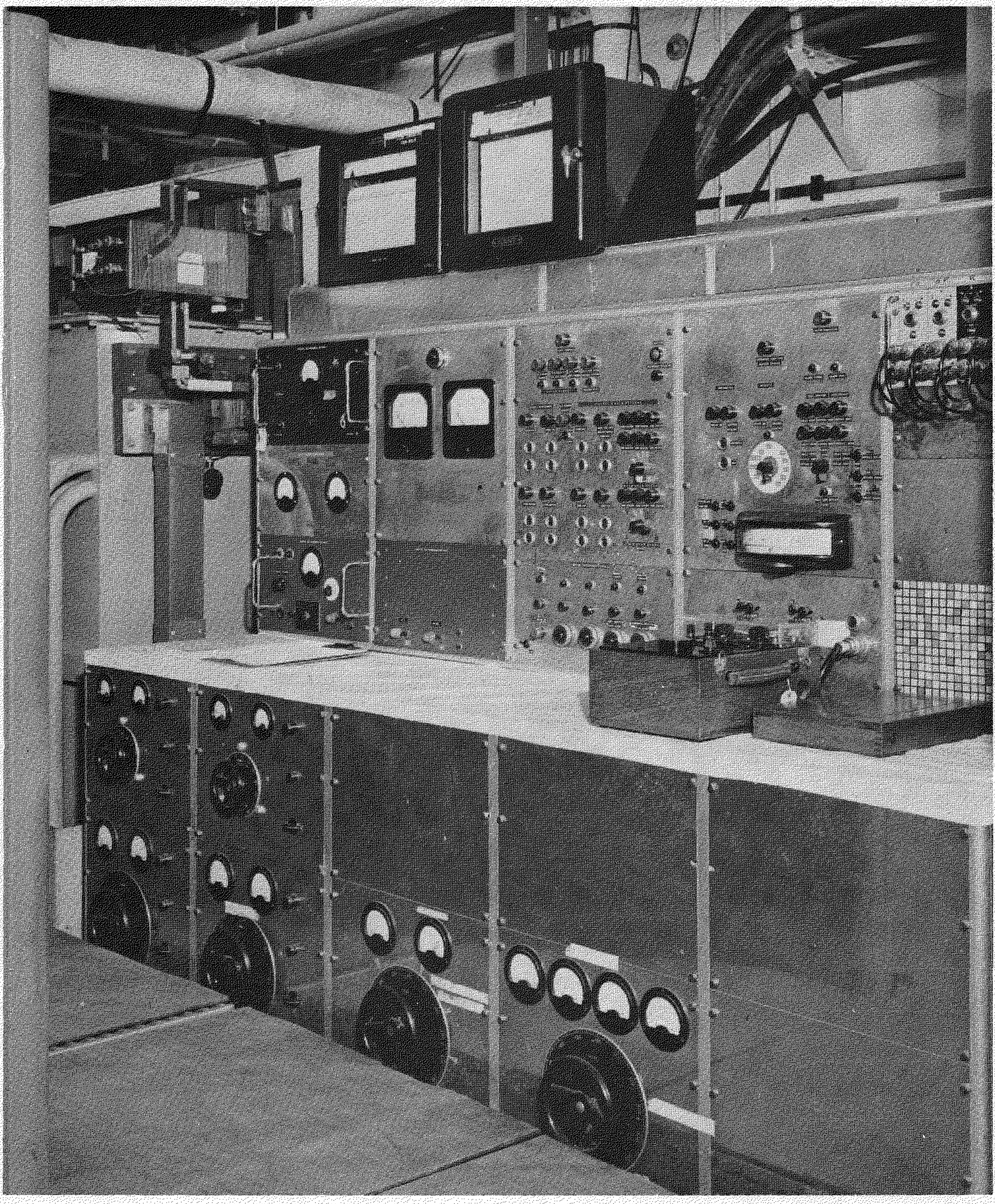
AERE - R 5145 Plate 1
General view of high pressure heat transfer loop



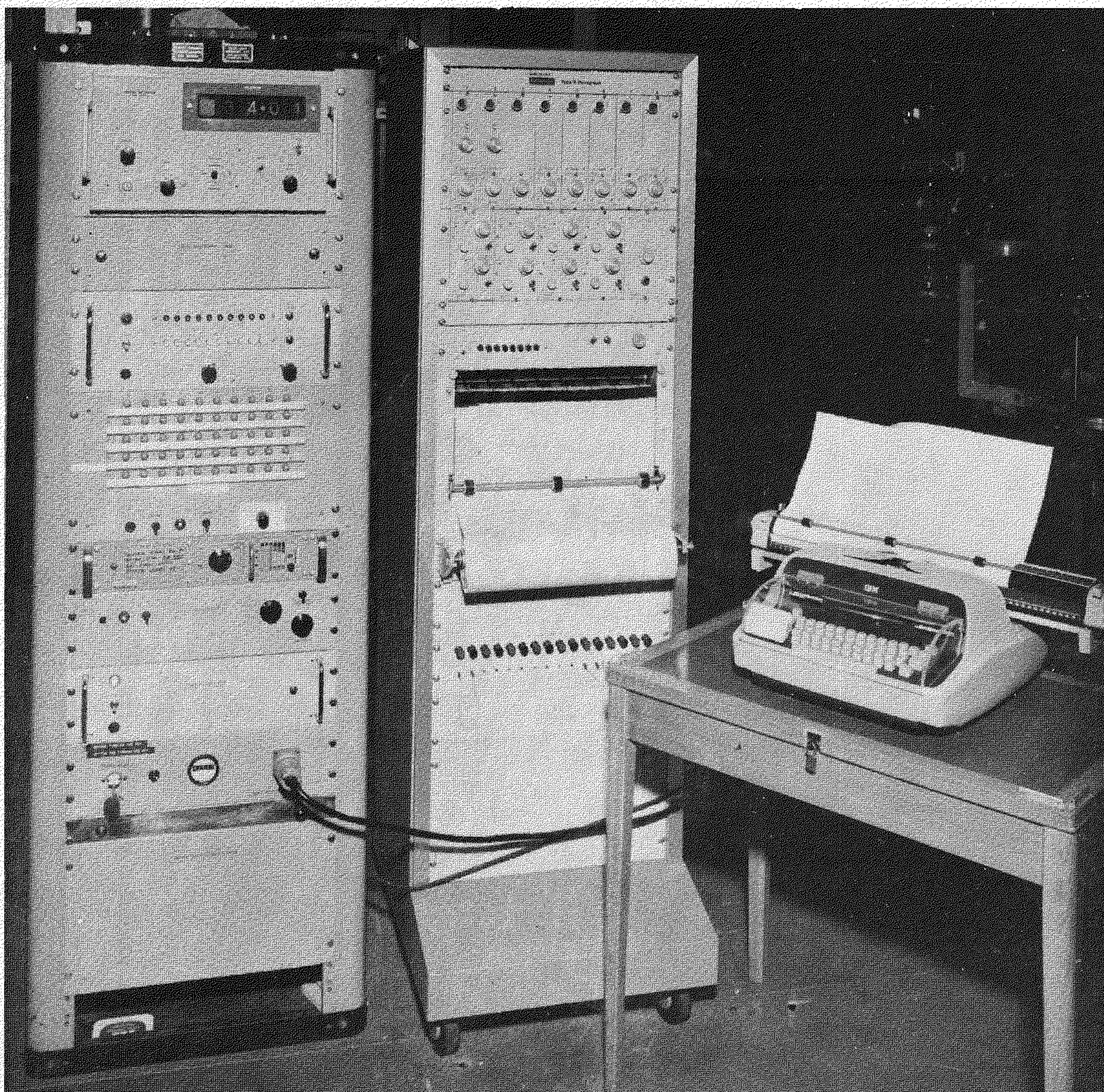
AERE - R 5145 Plate 2
Condenser cooler control system



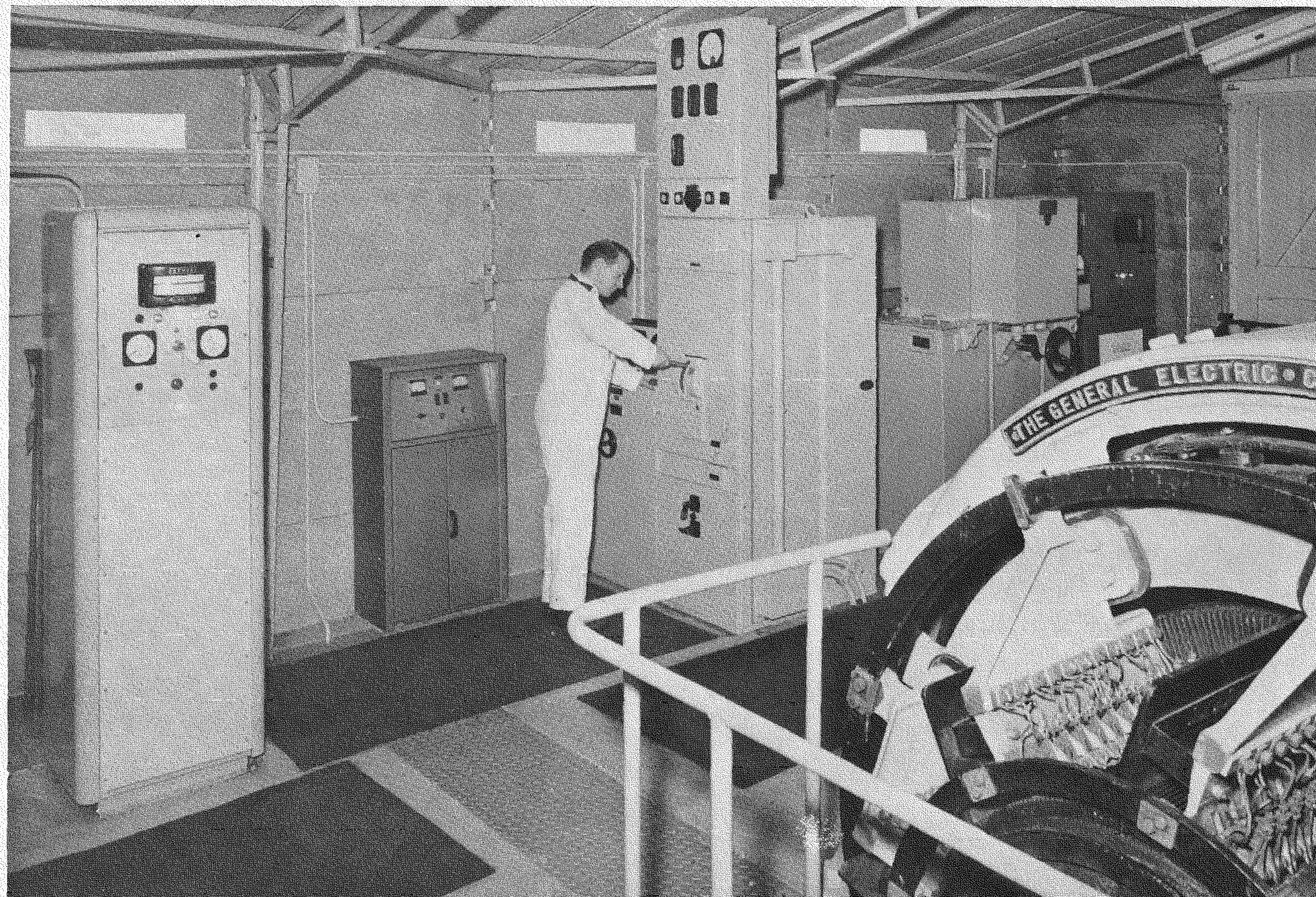
AERE - R 5145 Plate 3
Main instrument panel



AERE - R 5145 Plate 4
Main heater control panel



AERE - R 5145 Plate 5
Data collecting unit



AERE - R 5145 Plate 6
Motor generator house