GÖTEBORGS UNIVERSITET
Fysiska institutionen
S-E. Arnell, E. Karawacki/BE

Maj 1986

LABORATION T9

BOILING HEAT TRANSFER

(TVÅFASIG VÄRMETRANSPORTPROCESS)

Handledare: ....

Namn: .... Nr: ..... Labplats: .....

Laborationen utförd den ......

Laborationen inlämnad den .....

Godkänd den .... av ....

FOREWORD

Boiling Heat Transfer

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

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

Convective Boiling

When the metal surface is very little hotter than the liquid, convective currents carry the warmed liquid to the surface and evaporation is largely at the surface with little ebullition.

Nucleate Boiling

As the metal surface temperature is increased small bubbles of vapour appear and rise to the surface where they burst and release the vapour. Surface tension in the liquid offers great resistance to the birth of a bubble and initially bubbles form at nucleating points on the surface where minute local imperfections or gas pockets exist and where surface tension effects are minimised. As the metal becomes hotter, bubbles form freely and boiling is vigorous with considerable turbulence and very high heat transfer rates.

Boiling heat transfer in practical plants is normally of this tvpe.

Film Boiling

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

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

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

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

Condensing Heat Transfer

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

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

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

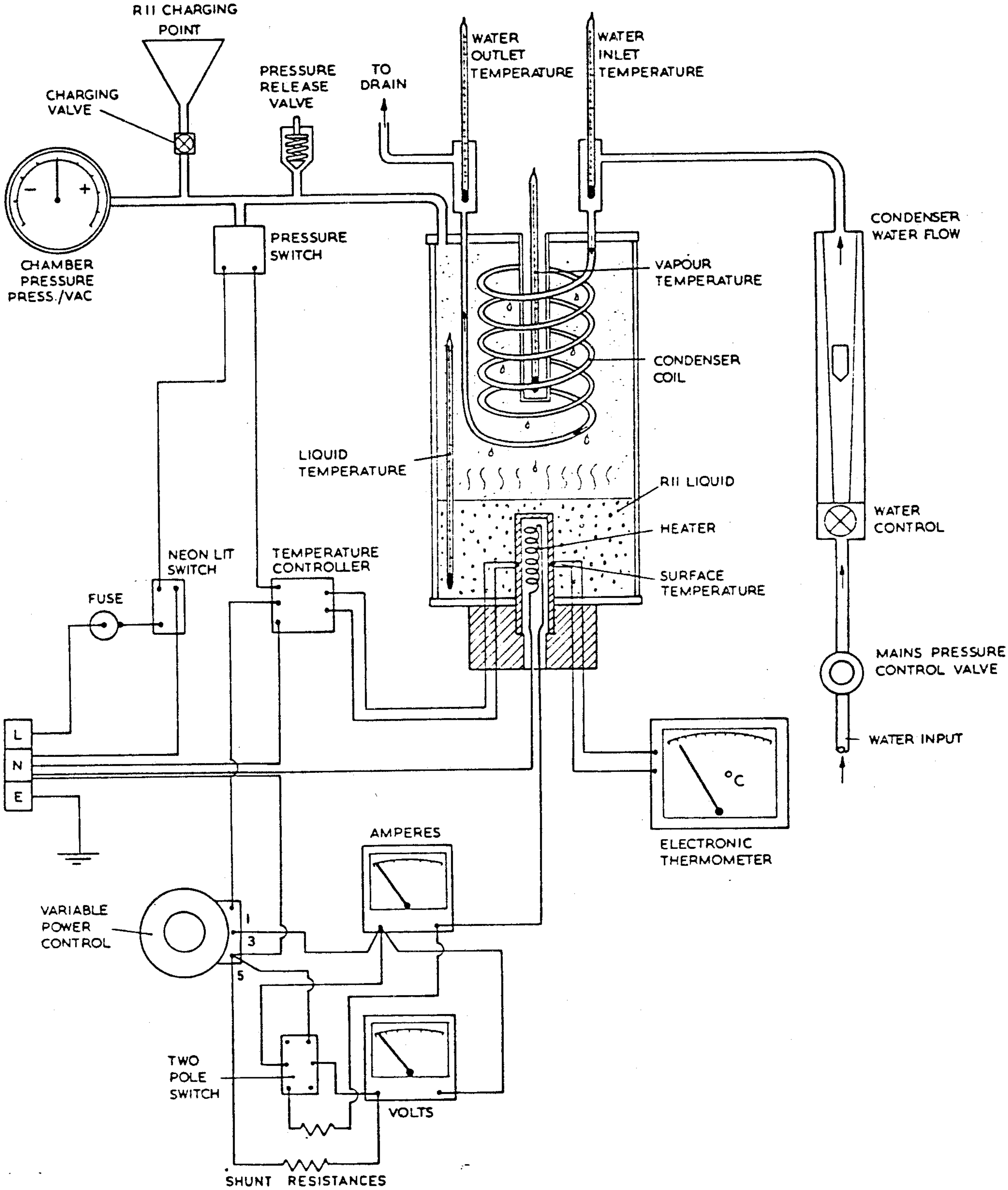
Heat transfer coefficients with dropwise condensation are higher than with filmwise owing to the absence of the liquid film.

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

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

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

SCHEMATIC DIAGRAM



HIGH TEMPERATURE CUT OUT

This unit is now fitted with a Philips LD3 controller. This has resulted in a small change in the position of some instruments

SPECIFICATION

Boiling/Condensing Cylinder

Glass Tube 305 mm long x 75 mm outer diameter x 66·6 mm inner diameter. Fitted with nickel plated brass end caps, P.T.F.E. seals and pressure relief valve set at 100 kPa (gauge).

Heater

Thick walled copper thimble containing element, fitted with thermocouple. Effective surface area 13 cm^2 approx. (See test sheet).
Normal operating condition 300 W at 140 V.

Temperature Measurement

Mercury-in-glass thermometers 0–50 °C to measure
(i) Boiling liquid temperature
(ii) Vapour temperature
(iii) Condenser cooling water temperature at inlet
(iv) Condenser cooling water temperature at outlet
Comark Electronic Thermometer with scales from −60 °C to +10°C; 0 to 60 °C; 0 to 170 °C and 0 to 400 °C, to measure thimble metal temperature.

Pressure Gauge

Range −1·0 to +1·0 Bar for vapour pressure.

High Pressure Cut Out

To interrupt power supply when vapour pressure exceeds 90 kPa (gauge) (0·9 Bar).

Variable Transformer

Berco Controls Ltd., Rotary Regavolt 0–2 Amps.

Condenser Coil

Nickel plated copper tube—surface area 0·032 m^2.

High Temperature Cut Out

Pye Ether 'Mini' controller — to limit thimble and element metal temperature to 225 °C approx.

Water Flow Measurement

Rotameter — with valve — for control and measurement of condenser cooling water flow rate.

Voltmeter 0 to 150 V }
Ammeter 0 to 2 A } To measure input to heater.

Range Extension Switch

To double the range of the voltmeter and ammeter.

Services Required

110 or 240 V Single Phase AC.
Cold water service and drain (1 litre/minute max.)

Description of Apparatus

The unit is built around a strong glass cylinder containing saturated liquid and vapour. (R11 is supplied as standard but other fluids with suitable properties and compatible with the materials of construction could be employed.)

A copper thimble containing a "high watt density element" is inserted into the cylinder at the lower end and heat is transferred from this to the boiling liquid. The heater current is supplied from an infinitely variable transformer. A water cooled coil in the upper part of the cylinder condenses the vapour produced and returns it to the boiling liquid. The temperature and pressure of the boiling process is controlled by the condenser cooling water flow rate and temperature.

A themocouple in the wall of the heater and a thermometer in the liquid enable the metal-liquid temperature difference to be continuously observed. Protection equipment has been introduced to prevent dangerously high surface temperatures occurring when the critical heat influx is exceeded and the boiling can be taken from the nucleate to film boiling mode rapidly and at will.

Safety

A standard glass cylinder and end cover assembly has been hydraulically tested to 2MPa (2MN/m^2) gauge without failure.

The following safety devices are incorporated as standard :

(a) Switch neon warning light.
(b) 10 amp panel mounted safety fuse.
(c) Pressure cut-out switch, set to interrupt the heater circuit when the vapour pressure exceeds 90 kPa (90/kN/m^2) gauge.
(d) Mechanical pressure relief valve set to discharge when the vapour pressure exceeds 100 kPa (100 kN/m^2) gauge.
(e) High temperature cut-out set to interrupt the heater power supply when the metal temperature exceeds 225 °C.
(f) Clear plastic screen to protect glass cylinder from accidental knocks.

OPERATING INSTRUCTIONS

These notes apply to the system when charged with R.11. Please refer to notes on use of R113 which exhibits slightly different results.

Charging

Open the charging valve, pull gently on the stem of the pressure release valve (so that it is open and acts as an air vent) then pour R11 liquid into the funnel until the level of liquid in the cylinder is 20–30 mm above the top of the heater. Release the pressure release valve and close the charging valve.

Purging

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

The liquid will start to boil vigorously and when the pressure reaches about 30 kPa (30 kN/m^2) gauge, or liquid exceeds 25 °C, pull on the pressure release valve stem and release any air in the cylinder. It may be necessary to repeat this before all the air is expelled.

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

The unit is now ready for use.

Before Starting any test ensure that:

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

(b) The pressure and temperature of the R11 agree with those at saturation conditions—if not, it is probable that air is present and the purging operation should be carried out.

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

(d) If a battery operated electronic thermometer is fitted, check the battery condition.

During Use

Control the saturation pressure to the desired value by:

(a) Variation of the cooling water flow rate (or temperature).

(b) Variation of the power supplied to the heater.

Ether High Temperature Cut Out

On no account should the setting on this controller be adjusted so that the temperature shown on the Comark Electronic Thermometer exceeds 225°C.
For normal operation it is advised that the controller is set to cut out at 200°C.

After Use

Always:

(a) Switch off the electrical supply and disconnect from the mains.

(b) Circulate cooling water until pressure has fallen to atmospheric.

(c) Switch off the electronic thermometer.

NOTE

Under normal conditions the Voltmeter and Ammeter will give direct readings. However, at high powers, (above about 300 W) it is necessary to switch to the (Volts and Amps ×2) position on the two pole switch. When this is done the observed meter readings must be multiplied by two.

Instrumentförteckning.

Fyra kvicksilvertermometrar mäter temperatur i vätskefas, ångfas samt vattentemperatur vid kondensorns till- och avlopp.

Kopparstavens temperatur mätes med termoelement och elektrisk termometer (OBS! Fyra olika skalor, A, B, C, D). En manometer graderad -1 bar till + 1 bar (rel. tryck) mäter trycket i ångfasen (0 till 2 bar abs tryck).

En amperemeter och en voltmeter mäter den tillförda effekten till kopparstaven.

En flödesmätare mäter vattenflödet i kondensatorn (kg/h).

Ett relä bryter den elektriska effekten till kopparstaven om dess temperatur överstiger 150^{o} C.

Uppgift 1. Convective boiling.

Utförande:

Justera vattengenomströmningen till c:a 6 kg/h. Tillför metallstaven elektrisk effekt < 10 W. Observera noga vätskan i närheten av den uppvärmda kopparstaven. Konvektionsströmmar uppstår i vätskan och droppar börjar falla ned från kondensorn vilket visar att en viss förångning äger rum. Temperaturdifferensen mellan metallstav och vätska är:

$$\Delta t = t_m - t_e = \ldots\ldots\ldots - \ldots\ldots\ldots = {}^{o}C$$

t_m = metallstavens temperatur.
t_e = vätskans temperatur.

Ange också trycket p_e svarande mot temperaturen t_e. p_e = ...

Uppgift 2. Nucleate Boiling.

Utförande:

Öka successivt den tillförda effekten och håll samtidigt trycket (p_e = ...) konstant vid något värde genom att öka kylvattenflödet.

När kraftig bubbelbildning erhållits noteras $\Delta t = t_m = t_e$ = ... - .... = .

Uppgift 3. Film boiling.

Utförande:

Fortsätt att öka effekten (200 à 300 W) tills kopparstaven omges av en ångfilm som förhindrar kontakt med vätskan.

Observera den snabba höjningen av temperaturen (använd skala D).

Uppvärmningen bryts när kopparstavens temperatur nått 150^{o} C. När detta skett ställs effekten 25 W in.

Reducera kylvattengenomströmningen så trycket p_e och temperaturen t_e bibehålles.

Observera att ångfilmen kvarstår och att värmetransporten har reducerats till c:a 1/10 (250 W - 25 W). Mät Δt = ... - .... =

Slå av effekttillförseln och ange temperaturen t_m hos metallstaven för var tionde sekund. Representera grafiskt t_m som en funktion av tiden. Återgången till värmeöverföring vid bubbelbildning svarar mot ett "hopp" i temperaturen. Förklara varför.

<u>Uppgift 4.</u> Determination of heat flux and surface heat transfer coefficient at constant pressure.

Utförande:

Ställ in värmetillförseln på c:a 15 W och justera kylvattnet så trycket 1 bar (0 bar rel.) erhålles i ångfasen.

Mät ström, spänning, vätsketemperatur t_e (bör vara c:a 23^o C) och kopparstavens temperatur t_m.

Öka successivt uppvärmningseffekten i steg om 10 V och justera kylvattnet så trycket bibehålles konstant. Avläs parametervärden enligt ovan etc.

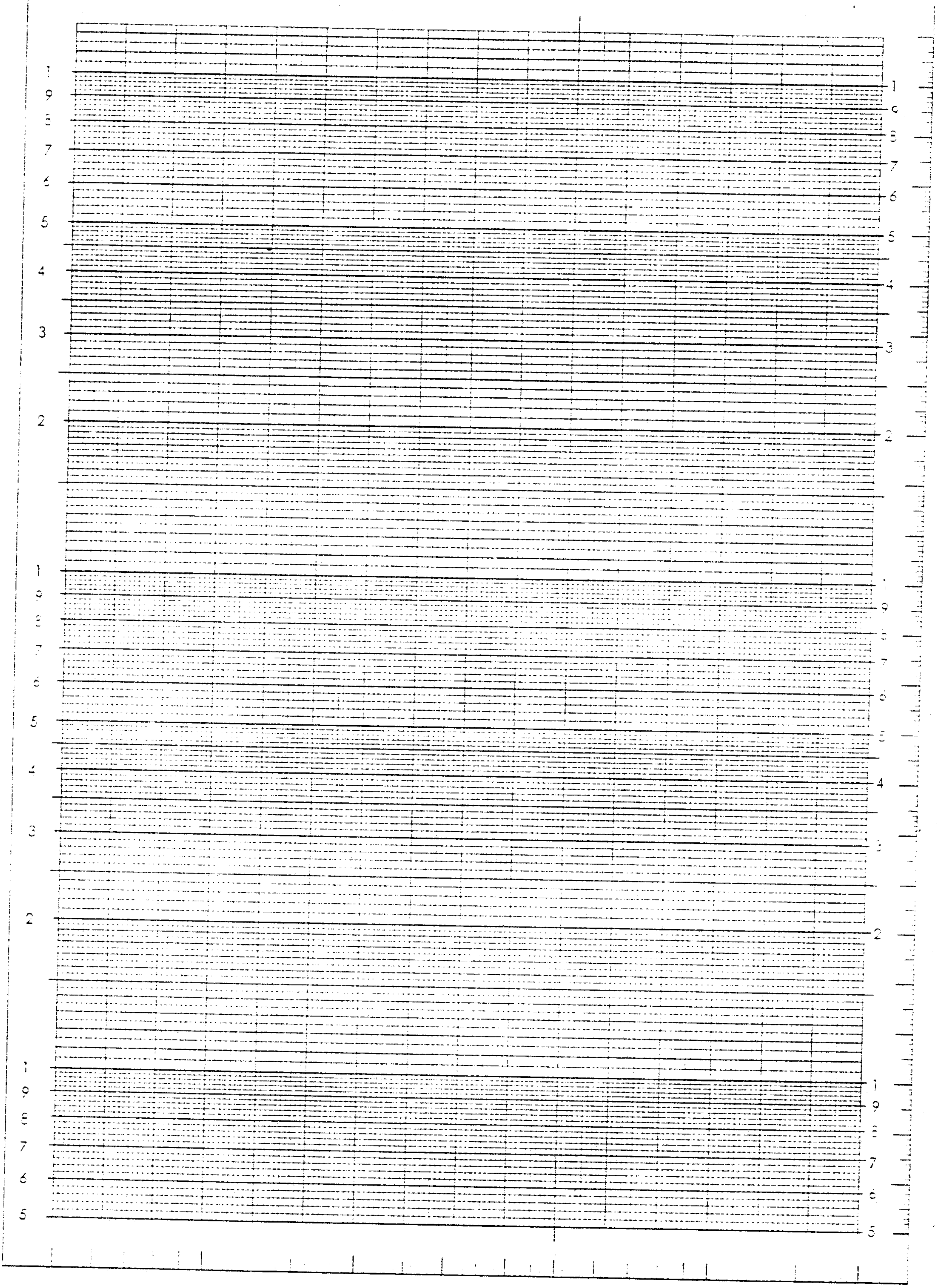
Efter erhållande av kontinuerlig ångfilm minskas uppvärmningen (V = 30) med bibehållande av trycket P = 1 bar. Avläs enligt ovan.

Fyll i följande tabell.

ϕ = termiska flödet per ytenhet från kopparstaven.
Kopparstavens yta A = 13 cm^2.

V	I	t_e	t_m	Q= U · I	$\phi = \frac{Q}{A}$	$\frac{\phi}{\Delta t}$
Volt	Amp	^oC	^oC	Watt	$\frac{kW}{m^2}$	$\frac{kW}{m^2 K}$

Upprita Q = f(Δt).



Uppgift 5. Effect of pressure on Critical heat flux.

Utförande:

Justera utan värmetillförsel med hjälp av vattnet trycket till 0,75 bar. Avläs t_e. Tillför sedan successivt effekten med bibehållande av p = 0,75 bar tills en kontinuerlig ångfilm erhållits. Notera effekten W_{max} vid transition mellan de två faserna.

Upprepa mätningen för trycken 1, 1,25, 1,50 och 1,75 bar. Bestäm för varje tryck $\phi_{max} = \frac{W_{max}}{A}$ och rita kurvan $\phi_{max} = f(p)$.

Tolka resultatet!

Uppgift 6. Filmwise condensation.

Utförande:

Välj effekten 200 W och justera trycket till 1,2 bar. Avläs vattenflöde, vattentemperatur vid tillflöde och avlopp, ångtemperatur, ström och spänning. Beräkna värmeövergången vid kondensorn och från kopparstaven. Differensen mellan dessa storheter är förlusten till omgivningarna.

Ange värmeförlusten till omgivningarna.