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THE VAPOUR-BLANKET TRANSITION ZONE IN SIMPLE BOILING-METAL SYSTEMS

by

H. E. J. SCHINS and M. C. OOMS

1973

Joint Nuclear Research Centre
Ispra Establishment - Italy

Technology Division

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If it is defined that a stable vapor-blanket transition zone is characteristic for stable boiling then the open heat-pipe, the thin film evaporator and the transpiration evaporator are inherently stable.

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ABSTRACT

It was demonstrated that nucleate boiling of Sodium in stagnant conditions cannot be termed stable boiling. The reason is that as a result of the big volume of the vapor bubbles a considerable amount of bulk liquid is continuously explused from the pool. This liquid will gather in the condensation region and will flow down in subcooled condition. The subcooled liquid sodium tracks cause important thermal stresses in the vessels walls and also preferential condensation of sodium vapor. Bulk expulsion and preferential condensation evidently cause major instabilities in the vapor column and disturbance of the vapor-blanket transition zone.

If it is defined that a stable vapor-blanket transition zone is characteristic for stable boiling then the open heat-pipe, the thin film evaporator and the transpiration evaporator are inherently stable.

KEYWORDS

HEAT PIPES
SODIUM
LIQUID METALS
VAPORS
TRANSITION BOILING
NUCLEATE BOILING
POOL BOILING
BUBBLES
INSTABILITY

Introduction

Since the course of hypothetical LMFBR accidents is influenced greatly by the coolant behaviour, sodium boiling dynamics continues to be studied both experimentally and analytically. In this context the present study is concerned with stable and unstable boiling systems.

Several boiling systems are known and described in literature which behave very stably. The heat input can be varied in great intervals without causing any remarkable irregularities to occur.

A first example of such systems is the open heat-pipe [1-2] as shown in fig. 1. Here there is no pool in the heating zone and the liquid metal boils from a wick structure. Characteristic for this system is firstly that the phenomenon of superheat is scarcely noted, and secondly that there establishes immediately a sharp transition zone between vapour and cover gas. The vapour zone can be noted by visual inspection as it is isothermal and corresponds to a saturation temperature given by a pressure equal to the Ar-pressure.

A second example of a stable boiling system is the thin film evaporator [3]. Liquid sodium boils out of a wick structure in a vessel which contains moreover a, slightly subcooled, pool (fig. 2). From a film showing the start-up of the test loop connected to this boiling system, it was evident that the transition zone behaves exactly as the one of the open heat-pipe in [1].

Finally a third system has been described [4] which proved to be stable and apt for application to problems with a varying heat-input. It is a transpirating system where sodium (actually it has been experimented on potassium) is forced through a gap between heating surface and a finely porous sheet or tube (fig. 3). By the effect of capillary forces and system pressure the liquid metal will be sucked into this sheet and boil off (or evaporate) on the cooling side.

Contrarily to the stable behaviour of the systems described above, boiling in small-batch pool boiling devices shows irregularities and instabilities, the most typical of which is that there does not establish a sharp transition zone. The following experiments were deviced in order to study the causes of the instability of pool-boiling.

1. Tubular Boiling Vessel with a Wick Structure in Expulsion Test

In the expulsion test [5] the heated zone of the pool is sandwiched between subcooled liquid metal regions. At boiling incipiency a big, expulsion provoking, bubble originates at high pressure, because this pressure corresponds to the high incipient superheat. This bubble collapses then immediately and system pressure will reestablish itself. The temperature of the heating surface will drop now to a value which suffices to maintain a certain vapour volume cf. fig. 2 of [5]. Thus, by heating bulk liquid in this manner one is immediately confronted:

1) with high incipient boiling temperatures (and consequently by pressure peaks)
2) with bumping when the boiling initiates and temperature drops to reasonable nucleate boiling superheat values
3) with the impossibility to define a transition zone: in this case the transition between vapour and liquid metal above it.

Originally it was thought that a surface containing an immense number of artificial cavities should cause stable boiling with a minimum of superheat, incipient or nucleate even in this most extreme of boiling tests. The test section was a Nickel tube which had three layers of 250μ Ni spheres sintered on its inside. This test section was inserred in an expulsion test loop but evidently these particular artificial cavities, which operate perfectly in boiling from a wick, did not activate easily in the expulsion boiling test and no stable boiling resulted. Better results in the expulsion test were obtained by a different surface treatment as reported in [6], where at least the bumping was eliminated.

2. Simple Sodium Pool Boiling System without Additional Cooling Circuit

This conceivably most simple system is sketched in fig. 4, where the condensor is to be left out. Heating of the pool is effectuated by application of a R.F.-coil. The system pressure ranges from 100 torr to 760 torr, so the boiling temperature T_{sat} from 700°C to 880°C. When the condensor is left out, the only cooling is by radiation of the hot container surface. After heating up of this system following two operation modes could be distinguished:

A. Surface evaporation mode

This is **a** non boiling operation mode. The pool can be superheated considerably to an initial wall temperature T_{wi} which can be very different from the vapor column temperature, which is at the saturation temperature T_{sat}. This vapor column remained more and more stable at more considerable vapor column heights. In order to arrive at incipience of boiling the set-up had to be changed. More heat-input had to be allowed for, and thus also an extra cooling device had to be installed, see chapter 4.

B. Boiling mode

When the surface evaporation mode breaks down by the incipiency of nucleate boiling the initial superheated wall temperature T_{wi} will drop to some nucleate boiling superheat temperature T_w. If T_{sat} is 700°C, T_w can be 740°C and T_{wi} 900 °C. The nucleate boiling mode was noted here, but will be studied more in detail in chapters 3 and 4.

3. Simple Water Pool Boiling System Provided with a Cooled Refluxing Condenser

This experiment was performed primarily in order to acquire more information for the interpretation of the observations on the analogous system of the Na-apparatus, figs. 4 and 6. There is no reason why the water boiler as sketched in fig. 5, when operated in a vertical position at ambient pressure should not behave as the open heat-pipe system, indicated above [1] and fig. 1. Up to a large extent this is the case indeed. First of all there is a distinguishable transition region and no water vapour will escape out of the boiling-condensation region, that is out of the container tube. The transition region can be raised or lowered when varying the heat input or the cooling-water flow. However, it was noted that:

1) there is some, hardly perceivable, phenomenon which could be interpreted as boiling incipiency and bumping;
2) water expulsion out of the bulk by the vapour bubbles, which are in the order of some millimeters, is not a striking effect;
3) the transition region is not very sharp;
4) the refluxing water is not a homogeneous film: it can cause local subcooling in the vapour column region when it makes drop-tracks in running down the wall.

4. Simple Sodium Pool-Boiling System Provided with a Cooled Refluxing Condenser

The system of chapter 2 was provided with water-cooling, which was separated from the hot wall by an air-gap [7], see fig. 4. As in chapter 2 two operating modes are found:

A. One starts always with a considerable superheating, surface temperature T_{wi}, the surface evaporation mode. The collapase of this mode is accompanied by the bumping phenomenon which characterises the incipiency of boiling, and the wall temperature drops then instantaneously to some boiling superheat T_w. Thus one arrives at the second mode:

B. The sharp transition zone characteristic for the evaporation mode disappears. When boiling has been initiated it is found that no sharp transition zone can be maintained no more. The reason for this cannot be the fact that most of the pool should have been expulsed after the bump which accompanies the initiation of boiling. This cannot be the case because it was made sure repeatedly that a pool remained. Also, because of the fact that a sodium blocking, argon displacing object was put above the cooling zone, it was impossible that much of the sodium could escape of the system. Moreover, the absence of sodium in the heating zone would cause dry-out or burnout, which would be noticed immediately. Most typical phenomena were the dark pencils, leaking like tongues over the isothermal container surface in the vapour column region. Especially the analogy with the water pool-boiling test of chapter 3 made it evident that these were undercooled condensate tracks. Now and then the refluxing condensate represented a mass comparable to the pool-mass. Then the temperature of the pool would drop below T_{sat} and the hole cycle of phenomena repeated: first the surface evaporation mode with its large incipient superheat established, then the bumping and immediately thereupon after collapse of the incipient boiling expulsion bubble, the instable nucleate boiling mode.

There is a reason why pool-boiling is accompanied by more bulk expulsion and hence by more condensate reflux then boiling from a wick. The reason is that pool-boiling is characterised by the formation of far bigger bubbles: even assuming that in wick-structures evaporation is by bubble-boiling, the bubbles cannot be large because they originate within too thin a liquid layer. But, as it is generally accepted [8,9] that vapour bubbles in bulk boiling alkali metals are even larger than water vapour bubbles, that is in the range of a few cm, it must be accpeted that small batch boilers provoke necessarily an expulsion effect. If these suppositions are right, one ought to find a method for preventing the gross of the expulsed bulk to be removed too far and for retaining it in the neighbourhood of the boiler. Only thus one could obtain more stable transition zones in pool-boiling. A proposition for the realisation of such a boiler will be done in the next of these series of experiments, cf chapter 5.

5. Pot-Boiler Experiment

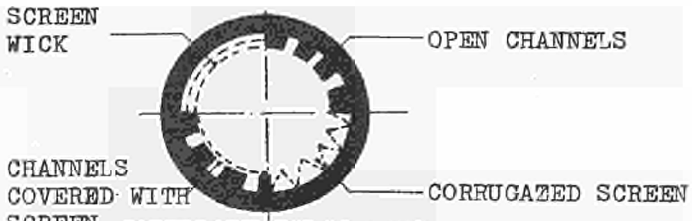
This boiling apparatus is sketched in fig. 6. Experiments with this boiling system are planned in the near future.

Acknowledgement

The test section of chapter 1, a nickel tube provided with a triple layer of nickel spheres of 250μ on the inside was a grant of Mr. G. Gammel of the Brown Boveri Zentrales Forschungslabor in Heidelberg, Germany. The water pool-boiling system of chapter 3 was in glass and entirely made by Mr. H. Kind of the Technology Division. Their collaboration, and also that of Messrs. Spiller and Droste is gratefully acknowledged.

Literature

1. BOHDANSKY J. and H.E.J. SCHINS, New Method for Vapor-Pressure Measurements at High Temperature and High Pressure. J. Appl. Phys. **36** (1965) 3683
2. SCHLITT R., Temperaturstabilisierung durch Wärmerohre. Forschg.Ing.Wesen **37** (1971) 91
3. SPIGT C.L. and H. UHLEMANN, Experiences with a natural circulation 65 kW Sodium evaporation and condensation loop operating at 750 °C. Liq. Met. Boiling Meeting, Karlsruhe, Nov. 6–7, 1972.
4. VAN ANDEL E. and H.E.J. SCHINS, Potassium transpiration cooling for a fast reactor. ATKE **20** (1972) 295.
5. SPILLER K.-H., D. PERSCHKE and G. GRASS, Sichtbarmachen von Natrium-Sieden am Modell eines Reaktor-Kühlkanales. Chemie-Ing-Technik **42** (1970) 381
6. SPILLER K.-H., The influence of the surface structure on sodium incipient superheat, Liq. Met. Boiling Meeting, Karlsruhe, Nov. 6-7, 1972
7. MARQUER R., Conductivité thermique d'une lame de gaz, CEN-Saclay, 1972, CEA-R-4345
8. WICHNER R.P. and H.W. HOFFMAN, Vapor bubble growth rates in superheated liquid metals, 1966 ORNL-TM-1413, Oak Ridge, USA
9. DEANE C.W. IV and W.M. ROHSENOW, Mechanism of nucleate boiling heat transfer to alkali liquid metals, 1970 ASME Winter Annual Meeting: Liquid Metal Heat Transfer and Fluid Dynamics, N.Y. USA



CAPILLARY STRUCTURES
FOR HEAT PIPES

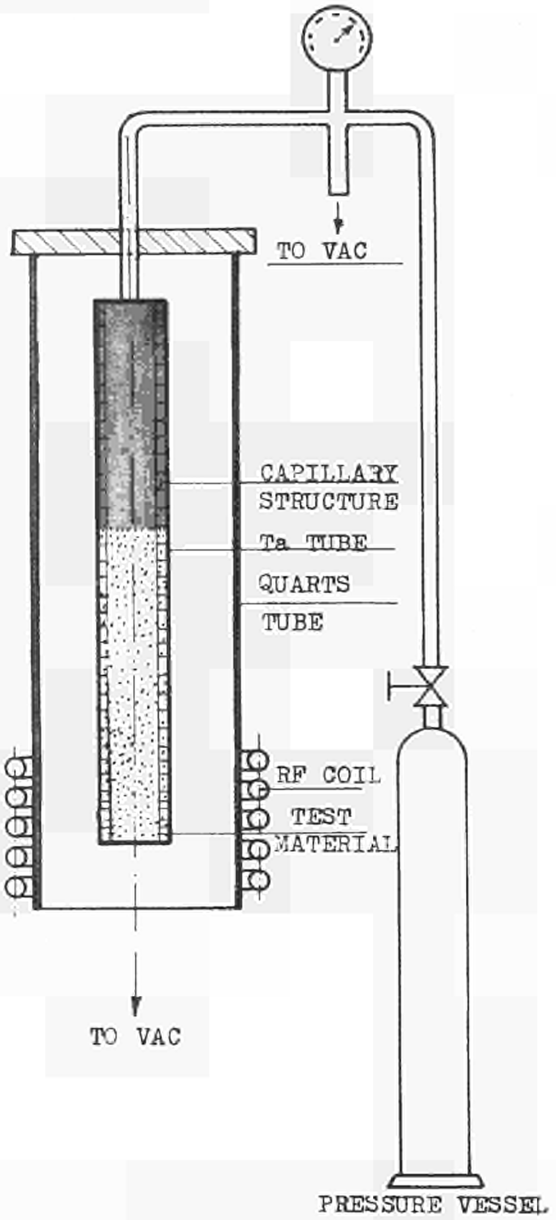


Fig 1. OPEN HEAT PIPE SYSTEM

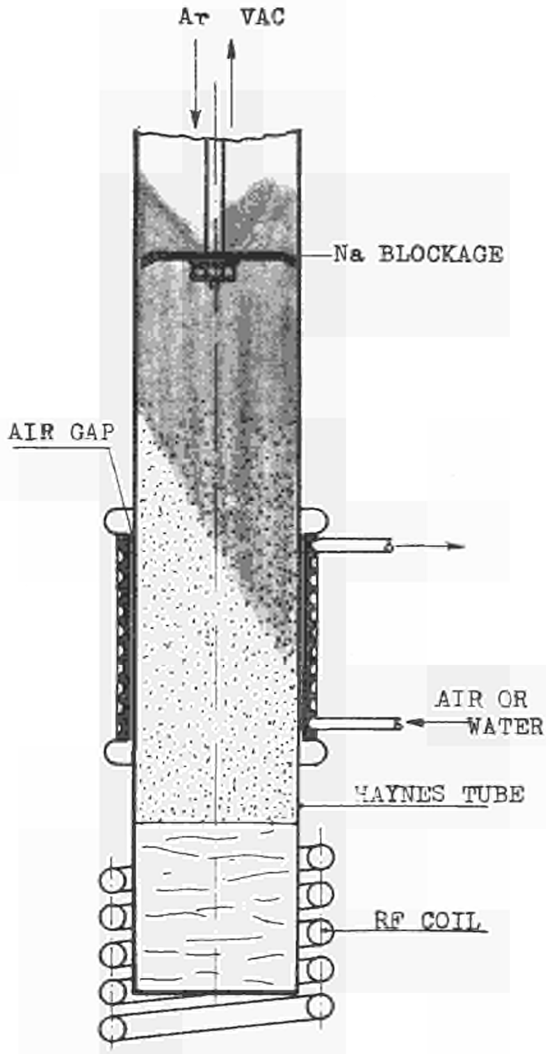


Fig 4 SIMPLE nA-POOL-BOILING SYSTEM

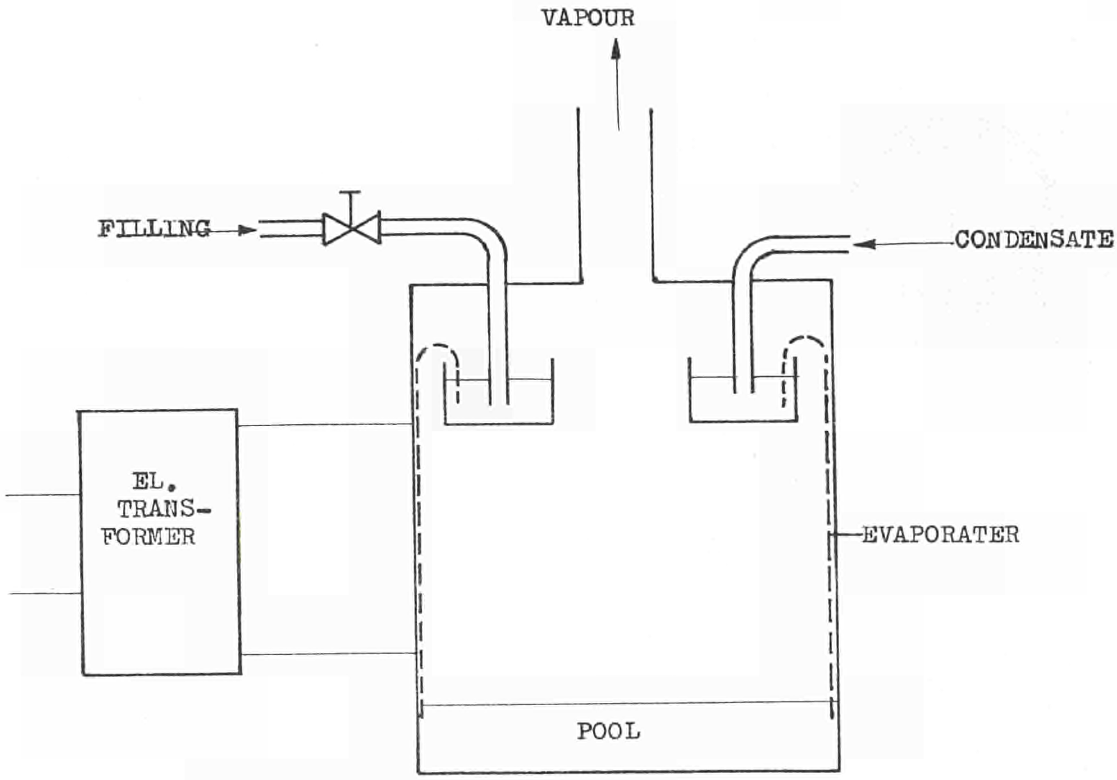


Fig 2 THIN FILM EVAPORATOR

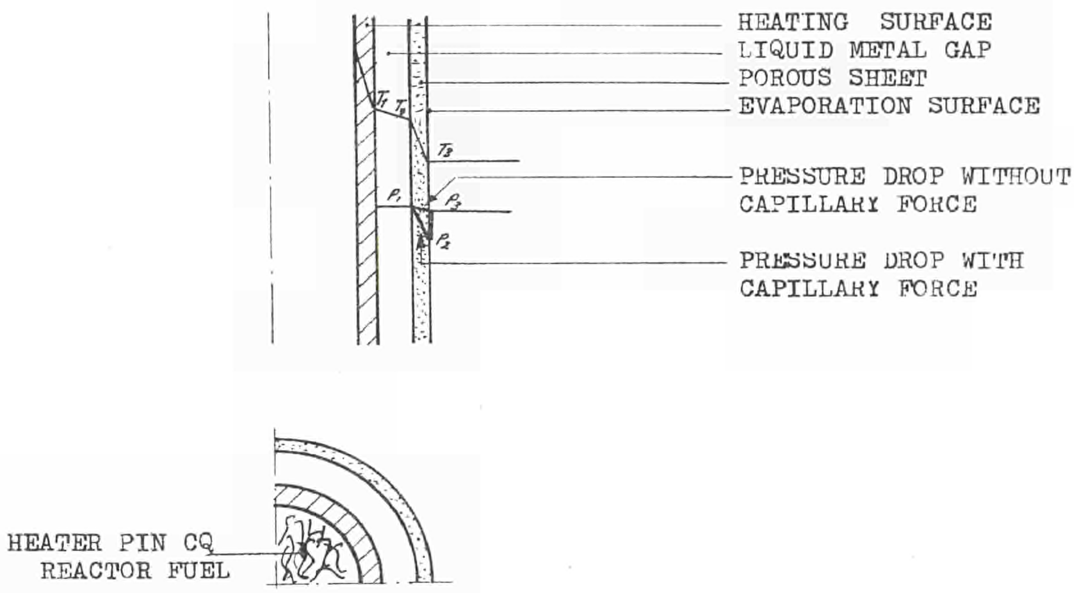


Fig 3 TRANSPIRATION EVAPORATOR

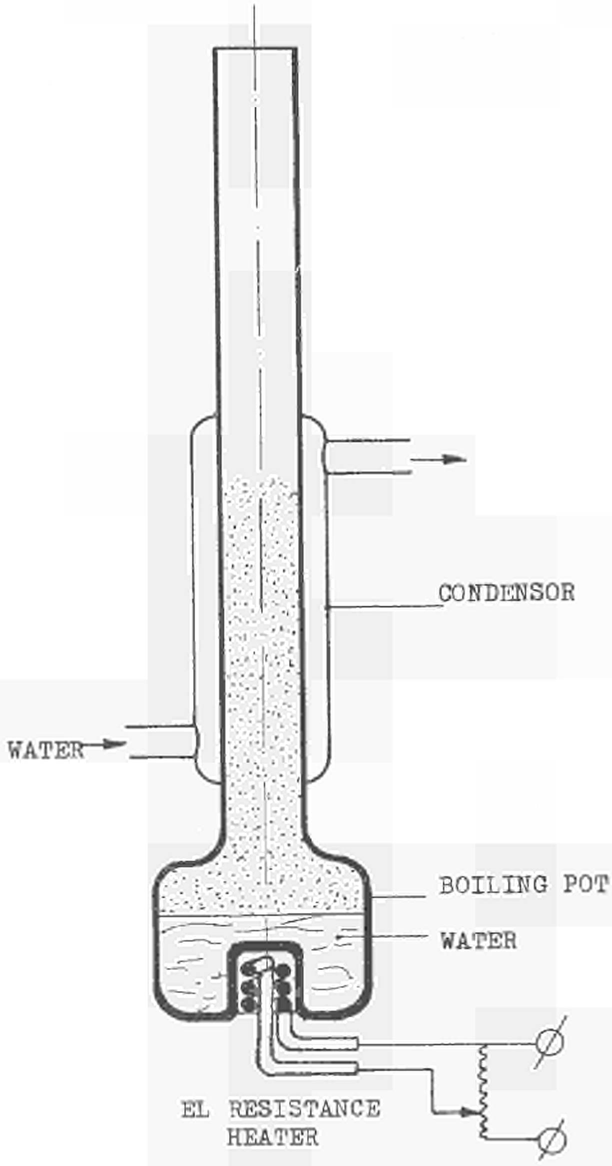


Fig5 SIMPLE WATER-POOL-BOILING SYSTEM

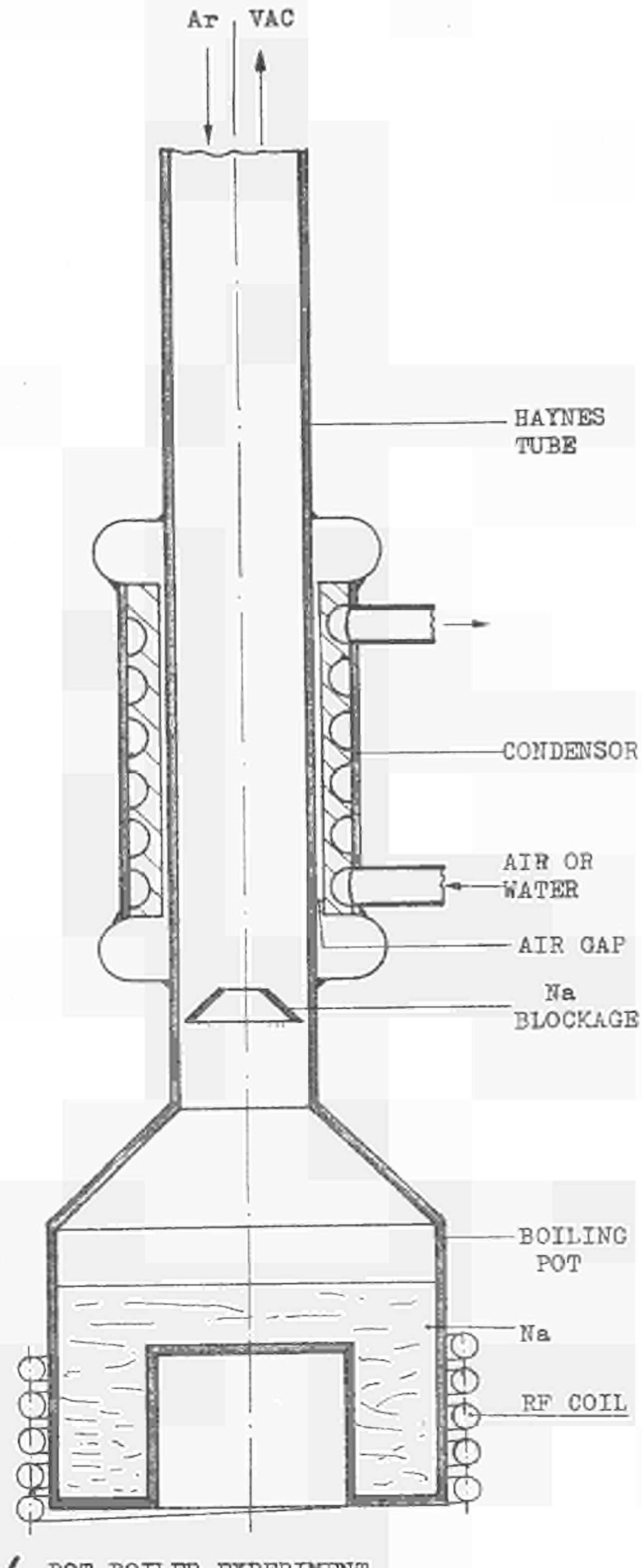


Fig6 POT BOILER EXPERIMENT

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Alfred Nobel

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