# HEAT TRANSFER ON BOILING A FREON-22–DIBUTYL PHTHALATE SOLUTION

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Experimental data on the boiling heat transfer of a Freon-22-dibutyl phthalate solution have been obtained on a special apparatus. The dependence of the heat-transfer coefficient on the heat load, pressure, and solution concentration has been established.

The possibility of designing a Freon absorption-refrigerating machine operating on an F-22-dibutyl phthalate (DBP) solution was demonstrated in [1–3].

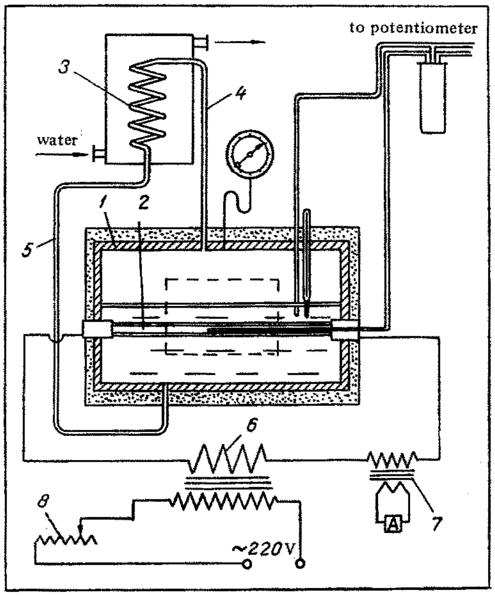

Fig. 1. Diagram of the experimental apparatus: 1) boiler; 2) experimental tube ($d_{out} = 7.4$ mm); 3) cooler; 4) vapor line; 5) liquid line; 6) stepdown transformer; 7) UTT-5 current transformer 8) laboratory autotransformer.

Subsequent tests on an experimental model of such a machine confirmed that it could operate on this solution with a sufficiently high thermal coefficient ($\zeta = 0.50–0.65$).

For design purposes it is necessary to know the heat-transfer coefficients for this solution, on which there are no published data.

Accordingly, we investigated the heat transfer of an F-22-DBP solution boiling in a horizontal tube. Our investigation included the determination of the heat-transfer coefficient in the industrial range of variation of the parameters. In the experiments we established the relationship between heat-transfer coefficient and the heat load, and the effects of pressure and concentration of the solution on heat transfer.

The experimental apparatus (Fig. 1) consisted of boiler 1, covered with insulation to prevent heat losses; experimental tube 2; cooling coil 3; and connecting tubes. The principal element of the apparatus is the boiler, a horizontal cylinder 220 mm in diameter and 270 mm long with two observation windows measuring 200 × 70 mm. The experimental tube, 0.25 mm thick, which at the same time serves as heater, is placed at the center of the cylinder. The ends of the tube are inserted and sealed into massive copper caps mounted in the cylinder by means of special glands. These glands, with textolite sleeves that fit over the caps and an oil-resistant rubber packing, isolate the experimental tube from the boiler housing. Low-voltage alternating current is supplied to the free ends of the caps from a welding transformer (220 × 1.6 V).

To vary the heat load on the experimental tube, a laboratory autotransformer was connected to the primary of the welding transformer.

As the material of the experimental tube, we used low-carbon steel with a normally oxidized surface.

The dimensions of the experimental tube and the power of the stepdown transformer made it possible to obtain heat loads up to 32 000 $W/m^2$.

The current flowing through the experimental tube was measured with a current transformer with a turns ratio of 120 and a class 0.5 astatic ammeter.

The voltage drop in the experimental tube was measured by means of a voltmeter with a tube amplifier, which was connected in parallel with the working section.

To measure the temperature of the inside wall of the tube, we used copper-constantan thermocouples, whose emf's were measured by means of a class 0.015 R-306 low-resistance potentiometer with an "Etalon" GPZ-2 null galvanometer.

The temperature of the solution in the boiler was measured with a copper-constantan thermocouple, whose hot junction was positioned 40–50 mm from the heat transfer surface, and a thermometer graduated in 0.1° C.

The pressure in the boiler was measured with a reference manometer. The pressure in the circulation loop was varied by varying the rate of flow of coolant through the condenser. The boiling process was observed visually through the observation windows.

Different concentrations were created as follows. A certain amount of DBP was introduced into the evacuated circulation loop. Then a certain quantity of Freon-22 ($CHClF_2$) was added to give the calculated mass concentration. After carrying out experiments at this concentration, we added a further amount of Freon-22 and repeated the experiments, etc. Concentration measurements were made at the beginning and end of each experiment.

The boiling heat-transfer coefficients were calculated from the formula

$$\alpha = \frac{IV}{\pi d_{out} l_w (t_{wall} - t_{sol})}. \qquad (1)$$

Before the main experiments were performed, the experimental apparatus was tested with water.

In the first experiments we determined the heat-transfer coefficient of pure DBP under free-convection conditions at atmospheric pressure in the temperature range 20–80° C. The results of these experiments are well described by the equation

$$\alpha = Cq^{0.535}. \qquad (2)$$

The coefficient C depends on the temperature of the DBP and can be calculated from the formula

$$C = 3.0 - 0.0655t + 0.00203t^2. \qquad (3)$$

Experiments on a boiling solution of F-22-DBP were conducted at five Freon concentrations: 0.095; 0.167; 0.240; 0.320; 0.390 in the range of heat loads from 2000 to 32 000 $W/m^2$ and at pressures of 2.3–8.7 bar.

The results of these experiments are presented in Table 1.

We will consider the effect of heat load, pressure, and concentration on the heat-transfer coefficient for a boiling F-22-DBP solution.

The experimental data $\alpha = f(q)$ for four pressures at a concentration of 0.24 are presented in Fig. 2. Clearly, the experimental data are well described by an equation of the form

$$\alpha = Cq^n. \qquad (4)$$

The same picture is also observed at other concentrations.

It is also clear from the graph that at constant concentration the lines of different pressures are almost parallel, which indicates that the exponent n of the heat load q is independent of the Freon pressure.

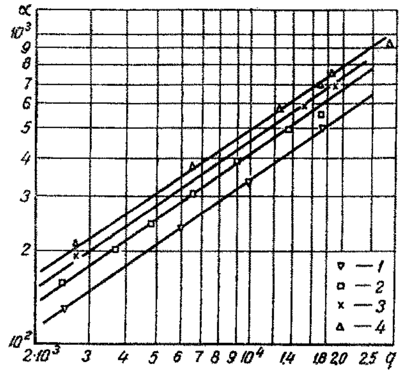

Fig. 2. Heat-transfer coefficient ($W/m^2 \cdot$ deg) of a boiling F-22-DBP solution as a function of the heat load ($W/m^2$) and pressure at a concentration of 0.24: 1) p = 2.65 bar; 2) 4.5; 3) 5.4; 4) 6.3.

An analysis of the experimental data for identical pressures but different concentrations shows that the slope of the lines in logarithmic coordinates does not remain constant, but varies somewhat, depending on the concentration of the solution. In the concentration range investigated, the exponent n in Eq. (4) can be expressed, correct to 3%, by the equation

$$n = 0.7 - 0.15\xi_F. \qquad (5)$$

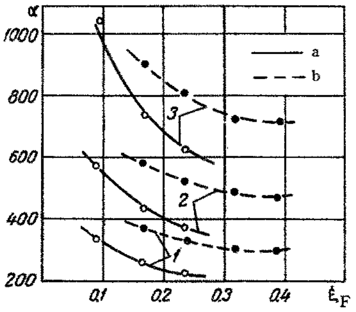

Fig. 3. Effect of the concentration of an F-22-DBP solution on the boiling heat transfer: 1) q = 5800 $W/m^2$; 2) 11 600; 3) 23 000; a) p = 2.65 bar; b) 6.2.

From the material presented in Table 1 it is clear that as the pressure increases the heat-transfer rate also increases. Thus, for example, at a solution concentration of 0.167, as the pressure increases from 2.65 to 6.1 bars, the heat-transfer coefficient α increases by 25%. The same holds true at other concentrations.

The increase in α with increase in pressure at $\xi_F$ = const is attributable to a decrease in the viscosity of the solution as a result of the rise in temperature.

An analysis of the experimental data (Fig. 3) shows that when the investigated solution boils while the concentration increases at p = const, the heat transfer first falls, reaches a minimum, and then begins to increase. A similar picture is also observed in connection with boiling water-ammonia and water-lithium bromide solutions.

The fall in the heat-transfer coefficient α with increase in concentration is attributable to the fact that as the latter increases at constant pressure, the temperature of the solution falls. Owing to the fall in temperature, the viscosity of the solution increases, which leads to a decrease in α.

At high concentrations of the low-boiling component, the effect of the temperature factor diminishes, the number of evaporation centers increases and α is observed to increase with concentration.

The experimental data on the boiling of an F-22-DBP solution as a function of heat load and concentration are approximated by curves described by the equation

$$\alpha = Cq^{0.7 - 0.15\xi_F}. \qquad (6)$$

In this equation, the coefficient C depends on the pressure and the concentration of the solution, and is given by the formula

$$C = A + Bp. \qquad (7)$$

## Table 1

### Experimental Data on Heat Transfer for the Boiling of an F-22-DBP Solution

| $q$, W/m$^2$ | $\Delta t$, °C | $\alpha$ W/m$^2\cdot$deg |
|---|---|---|
| $\xi_F = 0.095$; $p = 2.25$ bar | | |
| 2590 | 14.0 | 183 |
| 4170 | 15.8 | 264 |
| 6150 | 17.9 | 345 |
| 9950 | 20.9 | 475 |
| $\xi_F = 0.095$; $p = 2.65$ bar | | |
| 9900 | 19.5 | 507 |
| 13350 | 19.4 | 688 |
| 14400 | 19.8 | 726 |
| 18200 | 21.0 | 868 |
| 19850 | 21.2 | 935 |
| 21200 | 23.6 | 900 |
| $\xi_F = 0.167$; $p = 2{,}65$ bar | | |
| 3670 | 18.2 | 202 |
| 4930 | 19.1 | 258 |
| 7050 | 22.3 | 315 |
| 11600 | 26.8 | 432 |
| 18250 | 31.7 | 575 |
| $\xi_F = 0.167$; $p = 3.92$ bar | | |
| 6320 | 19.3 | 327 |
| 9270 | 22.3 | 415 |
| 14500 | 25.4 | 571 |
| 19200 | 28.0 | 689 |
| 24600 | 29.0 | 848 |
| $\xi_F = 0.167$; $p = 6.10$ bar | | |
| 3640 | 13.6 | 267 |
| 6500 | 16.6 | 392 |
| 12400 | 19.4 | 638 |
| 22500 | 24.3 | 927 |
| $\xi_F = 0.240$; $p = 2.65$ bar | | |
| 2530 | 18.8 | 133 |
| 6100 | 24.6 | 248 |
| 10050 | 29.4 | 342 |
| 17600 | 35.2 | 502 |
| $\xi_F = 0.240$; $p = 4.50$ bar | | |
| 2460 | 15.5 | 159 |
| 3600 | 17.7 | 203 |
| 4660 | 18.6 | 250 |
| 6420 | 20.9 | 308 |
| 9150 | 23.4 | 392 |
| 11400 | 25.0 | 453 |
| 13600 | 28.1 | 483 |
| 17500 | 32.7 | 535 |
| $\xi_F = 0.240$; $p = 5.40$ bar | | |
| 2750 | 14.1 | 195 |
| 15600 | 27.5 | 570 |
| 19800 | 29.2 | 680 |
| $\xi_F = 0.240$; $p = 6.30$ bar | | |
| 2750 | 13.4 | 209 |
| 6600 | 17.1 | 387 |
| 12750 | 22.1 | 578 |
| 17730 | 25.5 | 696 |
| 18900 | 25.3 | 750 |
| 29000 | 30.9 | 940 |
| $\xi_F = 0.320$; $p = 6.10$ bar | | |
| 2840 | 14.4 | 197 |
| 4930 | 17.8 | 278 |
| 9500 | 22.5 | 424 |
| 14000 | 25.9 | 540 |
| 19800 | 30.0 | 660 |
| $\xi_F = 0.320$; $p = 7.35$ bar | | |
| 2870 | 11.4 | 250 |
| 6200 | 15.0 | 415 |
| 8270 | 16.7 | 494 |
| 13100 | 19.5 | 621 |
| 16700 | 22.7 | 737 |
| 22200 | 24.8 | 895 |
| 32400 | 33.8 | 960 |
| $\xi_F = 0.320$; $p = 8.50$ bar | | |
| 2740 | 9.5 | 288 |
| 5050 | 11.3 | 448 |
| 12200 | 16.3 | 750 |
| 23000 | 22.4 | 1020 |
| 31400 | 25.8 | 1215 |
| $\xi_F = 0.390$; $p = 6.30$ bar | | |
| 2710 | 14.5 | 187 |
| 4230 | 16.9 | 250 |
| 7550 | 20.6 | 366 |
| 13350 | 25.0 | 535 |
| $\xi_F = 0.390$; $p = 7.35$ bar | | |
| 3020 | 12.3 | 245 |
| 4650 | 14.3 | 325 |
| 8000 | 17.3 | 462 |
| 13350 | 22.0 | 610 |
| 34800 | 28.6 | 1220 |
| $\xi_F = 0.390$; $p = 8.50$ bar | | |
| 5600 | 13.0 | 430 |
| 10500 | 15.5 | 680 |
| 17300 | 18.6 | 930 |
| 30700 | 23.9 | 1280 |

Values of the coefficients A and B are presented in Table 2.

Visual observation showed that at low Freon concentrations, even at heat loads above 14 000 W/m$^2$, the number of evaporation centers is small and the bubbles have dimensions of the same order as for pure Freon. As the concentration increases to 0.167, the dimensions of the bubbles appear to decrease sharply, although the number of evaporation centers remains approximately as before. With further increase in concentration at the same heat loads and pressures, a decrease in the number of evaporation centers is observed.

As the pressure in the system increases at constant heat load, the heat-transfer process is intensified, owing to the rise in temperature and the increase in the number of evaporation centers in the solution.

Thus, visual observations of a boiling F-22-DBP solution are in qualitative agreement with the $\alpha = f(q, p, \xi_F)$ relations obtained.

## NOTATION

$d_{out}$ is the outside diameter of experimental tube; $l_w$ is the working length of experimental tube; p is the pressure; $t_{wall}$ is the temperature of the tube walls; $t_{sol}$ is the temperature of the solution; q is the heat load; $\xi_F$ is the Freon concentration in the solution; $\alpha$ is the heat transfer coefficient; V is the voltage; I is the current.

Table 2

Values of the Coefficients A and B in Equation (7)

| $\xi_F$ | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 |
|---|---|---|---|---|---|
| *A* | 0.87 | 0.65 | 0.57 | 0.416 | —0.07 |
| *B* | 0.064 | 0.07 | 0.087 | 0.122 | 0.203 |

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