

account the shape and the dimensions of the siphon. As a general rule, the position of the bubble (if there is any static equilibrium at all) may be determined on the basis of a zero pressure difference (i.e. the heights) in the individual sections of the siphon.

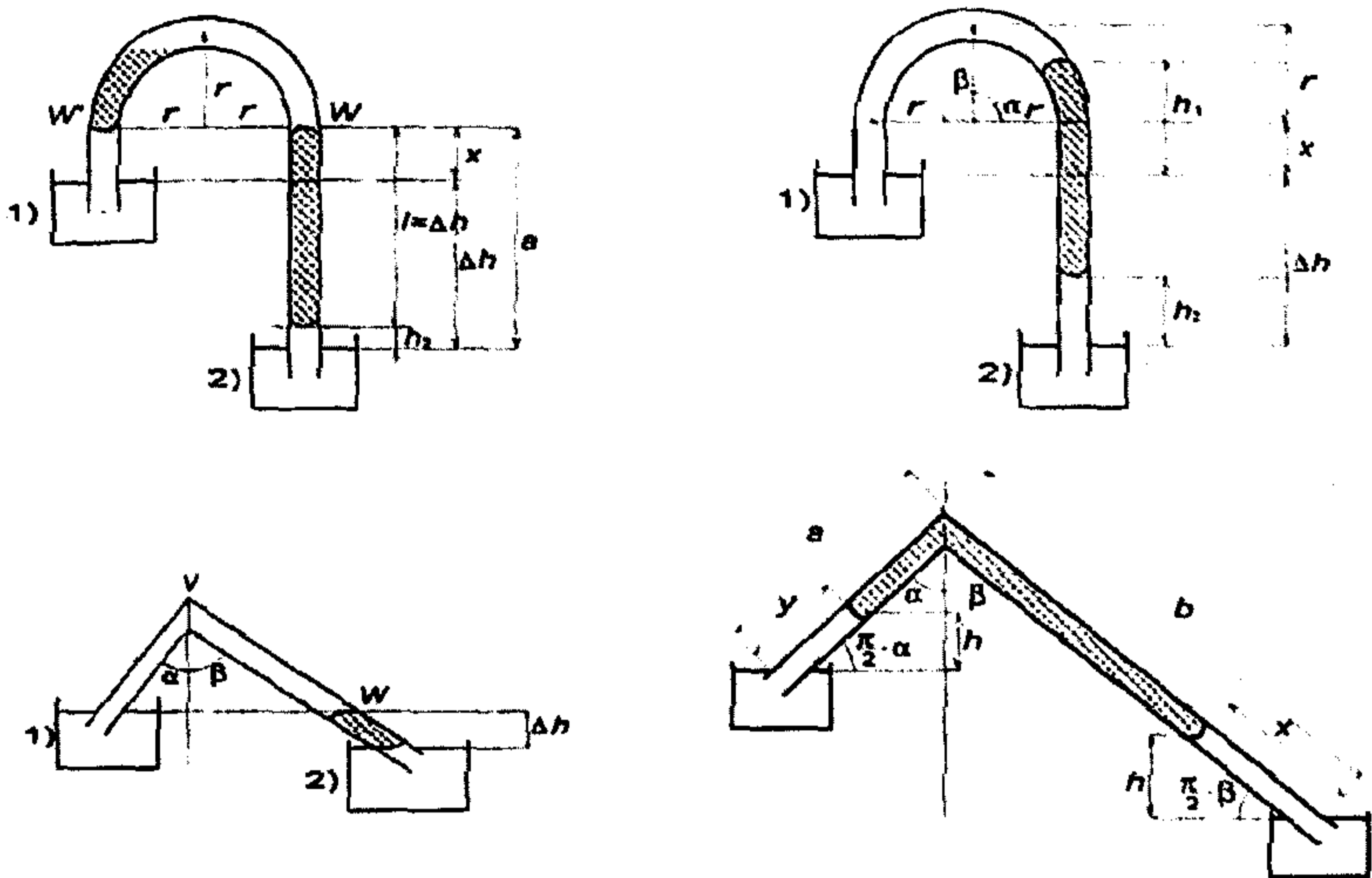


Fig. 19(a-d) Various possible positions of the bubble in the hose

## Problem No.12 – Boiling

This problem was solved experimentally as well as theoretically.

### Experimental part:

We inserted metal balls into a vessel containing water heated to  $90 - 100^{\circ}\text{C}$ . These balls had different radii and were heated to temperature  $150 - 200^{\circ}\text{C}$ . The balls were heated in an electric kiln with a stabilized temperature controlled by a switch mercury thermometer. The values of evaporation intensity we determined with the aid of a digital balance with graduations of  $0.01 \text{ g}$ . We plotted on a graph dependence of the measured evaporation intensity ( $\text{mg/s}$ ) on the time. The evaporation intensity was uniformly decreasing. After about 15 seconds, the evaporation intensity rapidly increased and within the following 4 seconds it dropped almost to zero.

### Theoretical analysis:

In the theoretical part of the solution, we supposed uniform heat conduction from the middle to surface of the metal ball, where it's transferred to water. The ball is composed of an infinite number of spheres of negligible width. The average surface area of the ball is  $S$ . The sum of heat that will be transferred to the liquid was divided into  $n$  parts. When the first part of the heat is abstracted, the temperature of the metal ball goes down, and the next part of the heat  $Q/n$  is abstracted for a longer time. From the known value of abstracted heat we determined the mass of evaporated water. Then we derive the theoretical dependence

of the intensity of evaporation on time. There is a difference between theoretical and experimental graph. This is because the decrease of the value of the evaporation intensity was greater than expected and according to the theoretical graph it should never reach greater evaporation intensity. In the theoretical analysis we supposed, that the heat is immediately transferred from the ball's surface to the water. This caused that deviation. Experimentally we observed that a small layer of water steam and air that was shielding heat transfer, which covered the surface of the metal ball. This layer was formed when the difference between the temperature of object inserted into the liquid and the temperature of liquid was too big. The formation of a gas layers which shields the evaporation is called **Leidenfrost's effect**. This type of boiling is called **membrane boiling**. As the temperature of the ball decreases, dynamic equilibrium between creation and destruction of this layer is disturbed, and by definite temperature (382 K) is the layer around the metal ball is taken off (point Z) (see Fig.20). It causes the rapid increasement of evaporation intensity. During the following **Bubble boiling** is dependence of intensity of evaporation on time in good agreement with the determined graph (see Fig.21).

Let us suppose, that specific thermal capacity of the metal ball increases with the temperature in an approximately linear fashion (Debye's function). At the temperature of 50 °C the specific thermal capacity is 452 J . kg<sup>-1</sup> . K<sup>-1</sup>, at 100 °C it is 475 J . kg<sup>-1</sup> . K<sup>-1</sup>, and at 200 °C it is 519 J . kg<sup>-1</sup> . K<sup>-1</sup>. (Landorf - Berneteir).

According to the values shown in graph 1 we determined the temperature of ball to be 200 °C when the temperature of water in the vessel is 99 °C. Average specific thermal capacity is:

$$c = \frac{c_1 + c_2}{2} = \frac{476 + 519}{2} = 496 \text{ J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$$

For the part one of the heat is valid:

$$\frac{Q}{n} = h \frac{S}{r} \delta T \delta t_1; \quad S = \frac{4}{3} \pi r^2$$

$h$  ..... thermal conductivity of the ball

$S$  ..... average surface of the ball

$r$  ..... ball's radius

$\delta T$  ..... difference between temperature of ball's centre and the temperature of the water

$\delta t_1$  ..... time of abstraction

After the abstraction of the part one of the heat there will be a new thermal gradient:

$$\delta T_1 = \delta T - \frac{Q}{n} \frac{1}{mc} = \delta T \left( 1 - \frac{1}{n} \right)$$

$m$  ..... mass of the ball

$c$  ..... average thermal capacity

Time of abstraction of this part of the heat is:

$$\delta t_1 = \frac{Q}{n} \frac{r}{Sh\delta T}$$

After the dissipation of the  $k$ -th part of the heat there will be a new thermal gradient:

$$\delta T_k = \delta T \left(1 - \frac{k}{n}\right)$$

For the  $k$ -th part of the heat is valid:

$$\frac{Q}{n} = h \frac{S}{r} \delta T \left(1 - \frac{k-1}{n}\right) \delta t_k$$

time for the abstraction of  $k$  parts of heat will be:

$$t_k = \sum_{i=1}^k \delta t_i = \delta t_1 \sum_{i=1}^k \frac{n}{n-i+1}$$

**Discussion:**

For a ball with greater radius made of the same material the dependence will be similar. The time of boiling will be greater, the mass of evaporated water will be higher. The intensity of the evaporation of water will be higher at the beginning of the boiling process. The time of transition between membrane boiling and bubble boiling will be higher than 15 s.

If we suppose a ball from a different material, then the graphs will be similar as well. A more exact prediction is not possible, because we don't know the material constants.



Fig.20 Bubble boiling

```
program KULE;
```

```
uses Crt, Dos;
```

```
const      n = 100
           cesta = 'c\tuf12.txt';
           cestal = 'c\tuf12all.txt';
```

```
var  Q, c, lam, S, Troz, Tpod, r, voda, delT, delT1, m, Tpodk
     poml                               : real;
```

```

ans, i, driver, mode, pom, j : integer;
casy                          : array [1..n] of real;
vypar                          : array [1..n] of real;
casyl                          : array [1..n] of real;
osax, osay                     : string;
vystup                         : text;
choice                         : char;

```

```

procedure BEZBLANY;

```

```

begin

```

```

  assign(vystup,cesta);

```

```

  rewrite(vystup);

```

```

  ClrScr;

```

```

  Write('Temperature of the ball [K]: '); Readln(Tpoc);

```

```

  Write('Temperature of the water [K]: '); Readln(voda);

```

```

  Write('Radius of the ball [m]: '); Readln(r);

```

```

  Write('Mass of the ball [kg]: '); Readln(m);

```

```

  Write('Thermal capacity of the ball: '); Readln(c);

```

```

  Write('Thermal conductivity: '); Readln(lam);

```

```

  Troz := Tpoc - voda;

```

```

  delT := Troz/n;

```

```

  Tpock:= Tpoc;

```

```

  for i := 1 to n do begin

```

```

    casy[i]:=((m . c . (Tpock-voda))/n).

```

```

    .(1/((4/3).pi.r.lam.(Tpoc-voda)));

```

```

    vypar[i]:=((delT.m.c)/(4180.(100-voda)+2260000))/casy[i];

```

```

    Tpoc:=Tpoc-delT;

```

```

    Troz:=Tpoc-voda;

```

```

  end;

```

```

  for i:=1 to n do begin

```

```

    str(casyl[i]:5:3,osax);

```

```

    str((vypar[i].1000):5:5,osay);

```

```

    {output is in g.s-1}

```

```

    writekn(vystup,osax,+', '+osay);

```

```

  end;

```

```

  close (vystup);

```

```

end;

```

```

procedure SBLANOU

```

```

begin

```

```

  assign(vystup,cestal);

```

```

  rewrite(vystup);

```

```

  ClrScr;

```

```

  Write('Temperature of the ball [K]: '); Readln(Tpoc);

```

```

  Write('Temperature of the water [K]: '); Readln(voda);

```

```

  Write('Radius of the ball [m]: '); Readln(r);

```

```

  Write('Mass of the ball [kg]: '); Readln(m);

```

```

  Write('Thermal capacity of the ball: '); Readln(c);

```

```

  Write('Thermal conductivity: '); Readln(lam);

```

```

  Troz := Tpoc - voda;

```

```

delt := Troz/n;
Tpock:= Tpoc;

for i := 1 to n do begin
  casy[i]:=((m.c.2.(Tpock-voda))/n).
  .(1/((4/3).pi.r.lam.(Tpoc-voda)));
  vypar[i]:=((delt.m.c)/(4180.(100-voda)+2260000))/casyl[i];
  Tpoc:=Tpoc-delt;
  Troz:=Tpoc-voda;
  if Tpoc<382 then begin
    poml:=i;
    i:=n;
    sound(880);
    delay(500);
    nosound;
  end;
end;

for i:=pom to n do begin
  if tpoc<=voda then exit;
  casy[i]:=((0.5.m.c.(Tpock-voda))/n).
  .(1/((4/3).pi.r.lam.(Tpoc-voda)));
  vypar[i]:=((delt.m.c)/(4180.(100-voda)+2260000))/casyl[i];
  Tpoc:=Tpoc-delt;
  Troz:=Tpoc-voda;
end;

for i:=1 to n do begin
  poml:=0;
  for j:=1 to i do
    poml:=poml+casy[j];
  casyl[i]:=poml;
end;

for i:=1 to n do begin
  str(casyl[i]:5:3,osax);
  str((vypar[i].1000):5:5,osay);
  {output is in g.s-1}
  writeln(vystup,osax,+', '+osay);
end;
close(vystup);
end;

begin
  repeat
    writeln('A - counting without layer boiling');
    writeln('B - counting with layer boiling');
    read(choice);
    if upcase(choice)='A' then BEZBLANY;
    if upcase(choice)='B' then SBLANOU;
  until ans=0;
end.

```



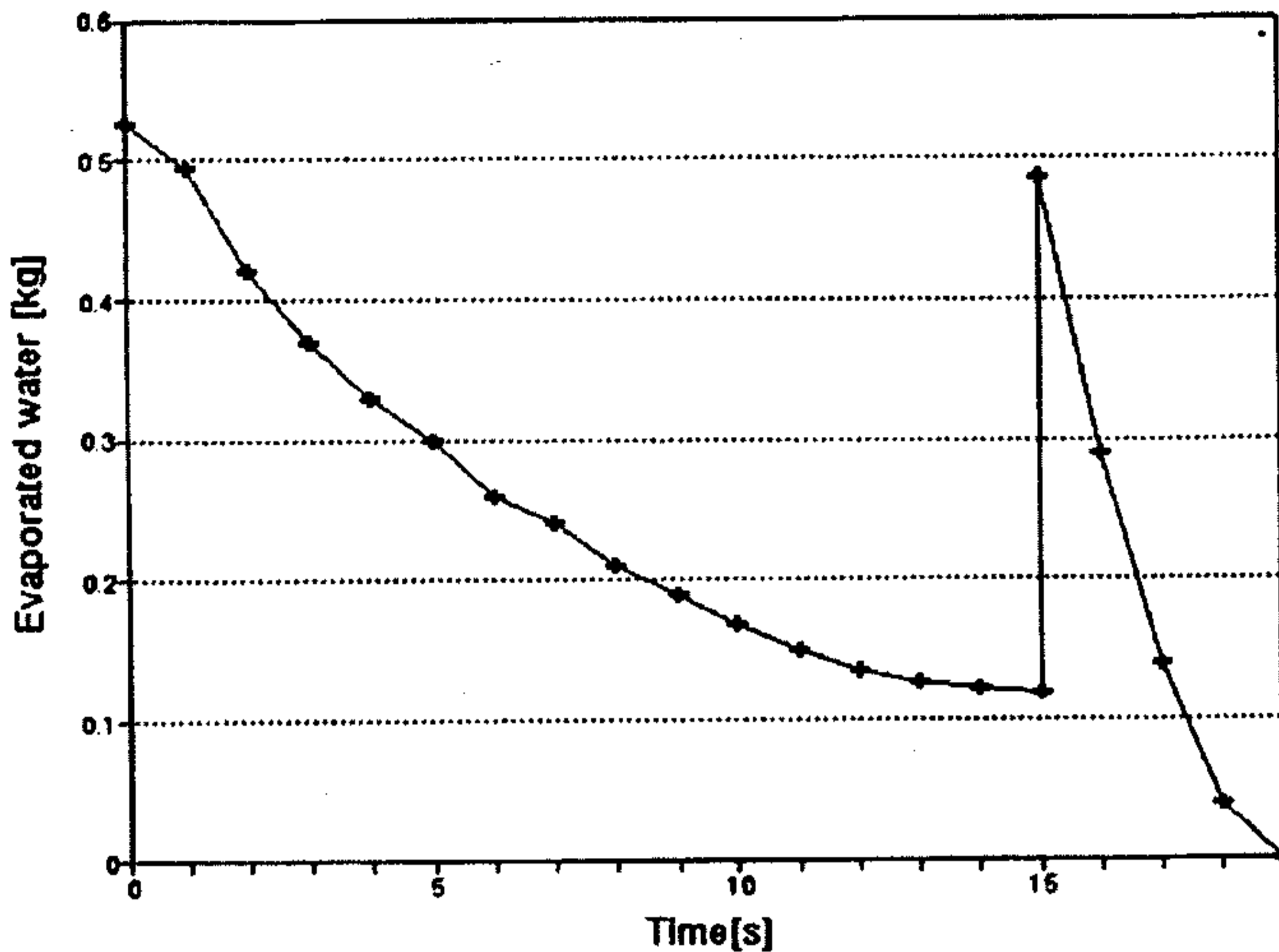


Fig.21 The dependence of the intensity of evaporation on time

### Problem No.13 – Spirits

Assuming a bottle is defined as transparent and a vessel as opaque, the concentration of ethylalcohol in the water may be determined by one of the following methods.

#### *Method I*

We can use the tabular values for the melting and solidification point temperatures of the water-ethylalcohol mixture in dependence on concentration (we have verified them – see Fig.22). The bottle will be cooled slowly in a cryostate, i.e. we will remove a known quantity of heat regularly and we will measure the temperature. The temperature will decrease gradually in a linear dependence on the removed heat. At the moment when the solidification temperature is reached, this linearity will be disturbed and the rest of the heat will be needed for the solidification of the mixture. The temperature will practically not change any more. The temperature corresponding to this state is dependent on the mixture concentration.

Using a reverse procedure, we can get another value which will allow us to obtain a more accurate determination of the mixture in the case that the bottle is not completely full. We will freeze the entire content of the bottle (vessel). Then we will regularly supply heat up to the point at what the temperature will stop changing (see above). It is necessary to determine this value because the mixture is marked by a difference between the melting and solidification point temperatures and because the tables give only values obtained by approximation of these two temperatures. The problem of this method is the existence of an eutectic point of this mixture, i.e. two concentration values are possible within a certain range for the same solidification point temperatures (see also Fig.22) – the melting temperature of the mixture which is given as a function of concentration, is not a simple function within a certain interval.