ABSTRACT

The first part of this paper deals with surface tension of pure water at temperatures below 0°C and with the basic theory of surface tension of liquids. The second part of the paper describes a device, which we developed for the realization of accurate measurements. The third part deals with results and data are presented there. Measured data are compared with IAPWS data in this part.

KEY WORDS
Supercooled water, homogenous, nucleation, condensation, supercooled, water

1. PRELIMINARY

The surface tension of pure water is well known at temperatures above 0°C, but this is not the case for temperatures below 0°C. Data for supercooled water exist, but are not consistent with each other. The subject of my research is surface tension of supercooled pure water. The purpose of the present work is to test the applicability of the capillary rise method. The aim is to obtain accurate and reliable data of surface tension of supercooled water, enabling engineering calculations as well as development and testing physical theories of supercooled state.

The phenomenon of surface tension of liquids can be observed in many examples in nature. For example, on a summer morning one can see dew on plants leaves in the form of drops, which have different diameters. The diameter is dependent on surface tension and on the contact angle $\beta$. When looking at water droplets on different surfaces, one of two characteristic shapes can observed. The shape of a droplet on a hydrophobic surface ($\beta > \pi/2$) is in Fig. 1a, a droplet on the wetted surface ($\beta < \pi/2$) is on Fig. 1b. Water wets glass perfectly ($\beta=0$).

The physical principle of the phenomenon of surface tension of liquids is explained below. Fig. 2(a) shows a molecule in the bulk liquid, surrounded by neighbouring molecules. Attractive “Van der Walls” forces exist between the central molecule and the neighbours. The forces are balanced. But if the molecule is on the surface of a liquid, the situation is different. The molecule is surrounded on the upper side by molecules in gas phase and on the lower side by molecules of liquid phase. The attractive forces on the liquid side are stronger than attractive forces between molecules of gas phase and molecules in liquid phase. To maintain equilibrium of forces the surface layer of liquid moves toward the bulk of the liquid. This situation is illustrated in Fig. 2(b).
2. PRACTICAL UTILIZATION OF SUPERCOOLED WATER SURFACE TENSION

As an example it is possible to mention droplets in clouds, which are often exposed to temperatures lower than 0°C. Surface tension is one of the most important properties used to understand the behaviour of the crystallization of water droplets. It is also a very important property in homogeneous condensation [1].

Kelvin ratio KR was introduced as a saturation ratio for equilibrium size of a droplet (no growth no evaporation):

$$K_R = \frac{p_d}{p_s} = \exp\left(\frac{4\sigma M}{\rho R T d'}\right)$$  \hspace{1cm} (1)

where \(\sigma\) is surface tension, \(M\) is molecular weight, \(\rho\) is density of droplet liquid, \(R\) is gas constant, \(T\) temperature in Kelvin scale, \(d'\) is equilibrium diameter of droplet.

3. BASIC KNOWLEDGE FOR REALIZATION ACCURATE MEASUREMENTS

The water to be used during measurement must be very pure and must not contain any surface active impurities [2]. The presence of surface active impurities would cause distortion of results. The water has to be sterilized using UV radiation in order to prevent organic pollution (algae).

The most suitable method for measuring surface tension of supercooled water is the capillary rise method. It requires only a small volume of liquid sample. This is very important, because with a decrease of liquid sample volume the probability of formation of ice nuclei during the observation time decreases [3]. This is one of the reasons why we selected a capillary with a small internal diameter. A second reason is that when a capillary with a smaller internal diameter is used, then measurements are more sensitive (there is a higher column of water sample in the capillary). Another reason is that the small volume of the liquid sample can change its temperature in a very short time, because a small capillary and water sample have very small heat capacity. For measurements we chose the capillary rise method as used Floriano and Angell [4] for their measurements in the 1980s.

The measuring device is shown in Fig. 3. The devices consist of simple components. Dry nitrogen flows into a “cold” heat exchanger where it is cooled down to using cold ethanol, supplied by a circulation cryostat. The cool nitrogen then flows into a glass chamber, where it cools the capillary to the required temperature. After that nitrogen flows out of the chamber. A second heat exchanger is used to heat the capillary again in case that water freezes. For changing the temperature of the capillary, the direction of flow in the chamber is switched over.

The glass chamber has side walls made from a special glass, which must be of high optical quality, (index of refraction and thickness must be constant). The upper and lower walls of the chamber are made of porous glass, to minimize the thickness of the boundary layer at those walls. The temperature field in the chamber was calculated for optimal temperature field in the chamber volume. The aim was also minimize the nitrogen consumption, which affects the cost of the project. The glass chamber will be observed by cathetometer.
4. RESULTS

Experiment was made with capillary of internal diameter 363 µm, cathetometer KM 6, fresh distilled water. We had to pay special attention to the measurement not to be affected by temperature balance of experimental laboratory, quality of distilled water and cathetometer accuracy. The blue line represents results obtained by my measurement. The pink line represents data obtained by extrapolation of IAPWS equation for surface tension.

[Graph 1: Graph of measured data and data extrapolated from IAPWS equations]

5. CONCLUSION

My experimental results are from first measurement. The curvature of measured data is little different from extrapolated curve for surface tension by IAPWS. One can say what means the step at -8ºC. Hacker noticed, that the dependence of surface tension on temperature changes its tangent around -8ºC. This effect did not noticed Floriano and Angell. I need to do a lot of measurements to obtain reliable data. I need to do some improvements on the measurement device. There are still some things, which can be better.
Acknowledgement

Work was realized with support by grant of Grant Agency of the Czech Republic, project number 101/05/2214/4

General references