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Suspended nanofluid droplet evaporation

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Abstract. The experimental research of suspended droplet evaporation process in air flow was conducted for distilled water (DW) with different silicon oxide (SiO_2) nanoparticle concentration. The data obtained allowed comparing droplet volume and temperature alteration dynamics with that in pure DW at different temperatures and flow rates.

Introduction

The evaporation process is used in technology for liquid mixtures separation and substance purification. It serves a basic process in steam power engineering, refrigerators, evaporation, and other systems, as well as material drying processes. Study of these processes is of great importance to highlight process enhancement methods and increase electric power installation efficiency.

New fundamental knowledge concerning gas-droplet flows with phase transformation is required for development of high-performance heat exchange apparatus, increase spray cooling effectiveness, liquid fuel combustion, and other practical applications. It is necessary to understand the heat and mass exchange mechanisms during nanofluid evaporation of flows with phase changes. There are a significant number of articles concerning complex droplet evaporation problem [1], but there is no universal theory concerning complex mixture droplet evaporation which could combine all principles experimentally obtained.

The aim of experiments was to obtain the data regarding solid admixture concentration impact on liquid carrier evaporation rate from the droplet surface in heated air flow.

Experimental setup

The experimental equipment consists of vertical cylindrical air channel with a stainless steel confuser (l = 0,5 m, d = 50 mm, outlet nozzle d = 10 mm), and heat exchanger with electrical heater distributed along the entire air channel with thyristor power regulator [2]. To decrease thermal loss the heat exchanger and the air channel are covered with thermal insulation. The heat exchanger combined with power regulator is capable of air flow heating within the range from room temperature (20 ^{0}C) up to 150 ^{0}C. The air flow is regulated with reducing gearbox at the start of the heating system within the range from 0,1 up to 5 m/s. After heating section, the air flow passes through initial lining by honeycomb

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(cell step 0,5 mm) placed next to an adapter between the heat exchanger and the vertical air channel. Secondary linearization is performed with a grid (cell step 0,2 mm) installed in front of the outlet nozzle. A liquid droplet is suspended on a carrier at a distance of 20 mm from the center of confuser outlet. A polytetrafluoroethylene (PTFE) cylinder (d = 0,1 mm) serves as the carrier. A liquid droplet is formed with the BP96131 pipette (0,5 – 5 μl, 3 % accuracy). A mixture was prepared using DW and SiO_2 nanoparticles ~ 200 nm size with mass fraction m_{SiO2}/m_{H2O} equal to 2, 3, 4, 5, 6, and 7 %. Base liquid and nanoparticle mass was measured with weighing machine (with accuracy of 1%). Prior to an experiment nanomixture was placed into the ultrasonic bath for 30 min. After the ultrasonic mixing nanofluid was left to cool down to room temperature. A nanofluid droplet with diameter 2 ± 0,3 mm was the research object.

Air flow rate was measured with anemometer at the nozzle outlet and with rotameter placed in air line. When the flow temperature exceeded the maximum anemometer temperature (more than 50 ^{0}C), the flow rate was controlled with the rotameter, with air parameters dependent on temperature that was taken into consideration. Anemometer ("KIMOinstruments" VT110) and rotameter precision was 3% for the flow rates ranged from 0,15 to 3 m/s.

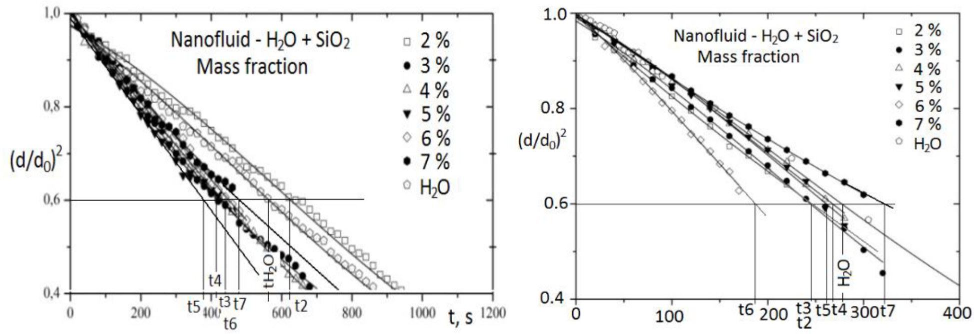
Air flow temperature was recorded by means of three detectors. Two platinum resistant thermometers were stationary placed in the upper and lower parts of vertical channel in front of the air flow linearizing grids. The third thermometer (thermocouple) was temporary inserted into the air flow before the experiment to control the temperature near the outlet nozzle. Temperature measurement accuracy for each of the sensors was 1,5 %. Relative air flow humidity was measured with the hygrometer Model 872 (with accuracy of 4 %) before the experiment.

Droplet diameter was captured during the evaporation process using DigiScopeIIv3 microscope. Droplet diameter was determined after the experiment processing digital images. Droplet diameter determination accuracy was 7,5 %. Droplet surface temperature on the thermal images, acquired by Thermo Tracer thermoimager, was determined with a use of special software. Average droplet surface temperature accuracy for this method was found to be 10 %.

Experiments were carried out at ambient pressure. The ambient temperature changed from 20 up to 30 ^{0}C. Air flow rate around the droplet ranged from 0 to 3 m/s depending on selected regime, temperature ranged from 20 up to 100 ^{0}C with relative air flow humidity not exceeding 1 % during each experiments.

Results

Experiments were conducted to estimate air flow rate and temperature influence on suspended nanofluid droplet evaporation rate (DW + SiO_2 mixture, nanoparticle mass fraction from 2 to 7 %, three air flow rates). Nanofluid droplet evaporation dynamics is shown on Fig. 1 for DW + SiO_2 in comparison with DW droplet evaporation (initial conditions: air flow rate u_0 = 0,2 m/s (a) and 1,5 m/s (b), ambient and air flow temperature $t_{0g} = t_{0s}$ = 23,4 ^{0}C, air flow relative humidity φ = 1%, ambient pressure P = 1 atm).



a. b.

Fig. 1. Nanofluid droplet evaporation dynamics. Experimental conditions: u_0 = 0.2 m/s (a), 1.5 m/s (b), temperature $t_{0g} = t_{0s}$ = 23 ^{0}C, φ = 0 %, P = 1 atm. t2, t3, t4, t5, t6, t7, tH_2O – evaporation time when droplet diameter was 60 % of initial droplet diameter.

As shown on Fig. 1, water evaporation time for the mixtures (t2, t3, t4, t5, t6, t7) is significantly different from that for the DW(t_{H2O}) prior to checkpoint (d/d_0 = 0,6). It is necessary to emphasize, that droplet volume measurement accuracy did not exceed Δd ~ 3 %, resulting in evaporation time detection Δt_{ev} ~ 5 % at the time point when 40 % of liquid evaporated. Ratios acquired let us analyze nanomaterial admixture influence on liquid evaporation rate with sufficient accuracy. Applying current analysis, it can be noted, that increase in air flow rate (1,5 m/s) significantly reduced nanofluid droplet evaporation time, while evaporation rate differences were present (Δt ~ 40 %).

Nanofluid droplet evaporation dynamics is shown on a Fig. 2 (air flow temperature raised up to t_{0g} = 100^{0}C, u_0 = 1 m/s, t_{0s} = 23^{0}C, φ = 0%, P = 1atm).

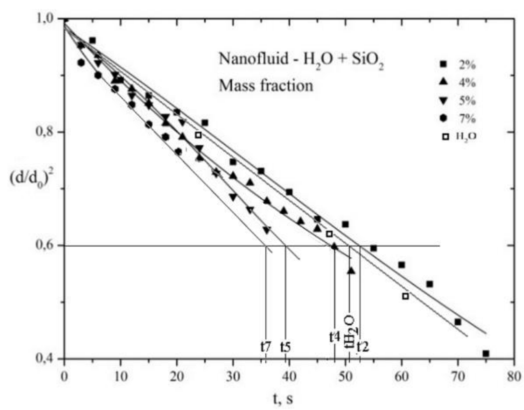


Fig. 2. Nanofluid droplet evaporation dynamics. Experimental conditions: u_0 = 1 m/s, T_{0g} = 100 ^{0}C, T_{0s} = 23 ^{0}C, φ = 0 %, P = 1 atm. t2, t4, t5, t7, tH_2O – evaporation time when droplet diameter was 60 % of initial droplet diameter.

Experimental results of droplet evaporation of water with suspended carbon nanotubes (mass fraction ~ 0,1 %) are presented in an article [3]. Based on these data it can be concluded that nanoparticle addition to base liquid (DW) slightly affects heat-and-mass transfer mechanism. Submitted experimental data concerning nanomaterials (different SiO_2 concentrations in base liquid) demonstrate that nanofluid droplet evaporation dynamics curve has an interval of accelerated evaporation when flow rate increases. The dependence of the ratio between relative nanofluid evaporation time and base liquid evaporation time (60 % of initial diameter) on nanofluid concentrations is shown in Figure 3, where f = (tn –

tH_2O) / tH_2O, tn – is nanofluid evaporation time. It can be noted, that air flow with temperature lower than 100 ^{0}C affects evaporation intensity given that admixture concentration ranges from 3 up to 7 %.

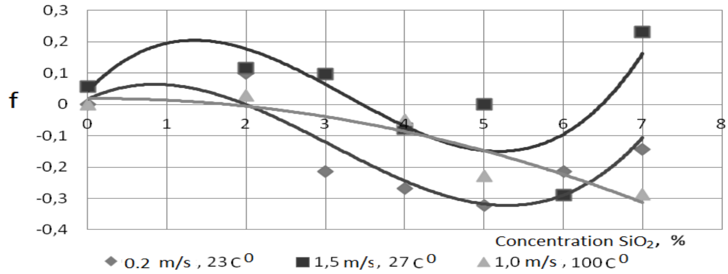


Fig. 3. Nanofluid droplet evaporation dynamics.

With the air flow temperature being ~ 100 ^{0}C, the opposite effects can be detected, so that droplet evaporation rate increase is observed within the entire concentrations range (Figure 3). These data correlate with results published in [4].

Conclusion

SiO_2 nanoparticle supplementation up to 3% concentration does not lead to remarkable reducing of nanofluid droplet evaporation time in comparison to the base liquid when air flow rate and temperature increase. Nanoparticle concentration rise over 3 % decreases evaporation time when air flow rate (temperature range from 20 up to 30 ^{0}C) increases in comparison with base liquid droplets. Moreover rise of the evaporation rate is not a monotone value in the current concentration range. Monotone decrease of nanofluide droplet evaporation time appears when air flow temperature is 100 ^{0}C given that nanoparticle concentration is over 3 %. The results obtained show, that in distillation processes there is an opportunity to use more effective mixture separation (up to 30 %).

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