Applied Thermal Engineering 125 (2017) 29–34

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

A second view on the possible enhancement of distillation efficiency with nanofluids

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ARTICLE INFO

Article history:
Received 5 January 2017
Revised 11 May 2017
Accepted 28 June 2017
Available online 29 June 2017

Keywords:
Solar radiation
Nanofluid
Thermal separation
Distillation
Evaporation
Condensation

ABSTRACT

A considerable increase in thermal separation by the use of radiation induced evaporation of binary base fluids using nanofluids has been reported. It was shown for the water-ethanol system, that the vapor phase composition was enhanced about 20 wt% of ethanol above the thermodynamic equilibrium value. Even the azeotropic point seemed to disappear. This paper aims to reproduce the reported results and it tries to analyze possible mechanisms explaining these findings that appear anomalously at first sight.

1. Introduction

Enhancement of thermophysical properties of liquids by dispersion of nano-sized particles has been discussed intensely in the past two decades. Motivated by reports about improved thermal conductivities [1–3] nanofluids were attributed great potential especially as heat transfer fluids in technical applications [4,5]. In addition to the convective heat transfer capabilities some authors suggested to use the possibility to tune the absorbance spectrum of nanofluids in a way that enables an efficient, volumetric absorption of light [6–10], so steam can be generated [11–14]. Among them are porous materials that use capillary effects to enhance evaporation efficiency [15,16].

Lately Neumann et al. showed an experimental setup that allows for the use of radiative energy absorbed by nanofluids for thermal separation of liquid binary mixtures as basefluids [17]. The authors built a solar still in which sunlight is concentrated onto a vacuum insulated glass container with Au nanoshell particles ($2.5 \cdot 10^9$ particles/ml) dispersed in a binary ethanol-water mixture. After a short period of time the radiative energy initiated the evaporation process in the nanofluid. By measuring the temperature inside the glass container, the authors showed that the boiling process is confined to a small fluid volume where the radiative flux is maximum, whereas the rest of the fluid remains at lower temperatures below the boiling point. Neumann et al. collected the vapor and analyzed the composition in a Hewlett-Packard 5890 gas chromatograph. The authors noticed an amount of the more volatile component (ethanol) in the condensate that considerably exceeded the composition which is predicted by thermodynamic equilibrium calculations (see Fig. 1). Furthermore, the authors could not see any limitation any more to the radiation induced separation process which are normally caused by the azeotrope of the water-ethanol mixture.

Inspired by the unexpected results Neumann et al. improved their experimental setup and confirmed the enhanced separation efficiency [18]. Instead of solar radiation the authors installed a laser heating device with a wavelength of 808 nm, which corresponded to the resonance wavelength of the Au-nanoshell nanoparticles. With the new setup Neumann et al. reported enhanced ethanol concentrations in the distillate, even compared to results reported before. For further testing the basefluid was exchanged with a binary water-1-propanol mixture. In these experiments no unusual phase separation behavior could be detected and the results agreed with those expected from phase equilibrium calculations. This procedure confirmed the measured effect by showing that the setup is suited for the measurement of phase equilibria. As a possible explanation for their findings the authors suggest that the nanoparticles that are present in the liquid phase would destroy or weaken the hydrogen bonding and thus influence the evaporation behavior of the liquid [18].

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http://dx.doi.org/10.1016/j.applthermaleng.2017.06.136

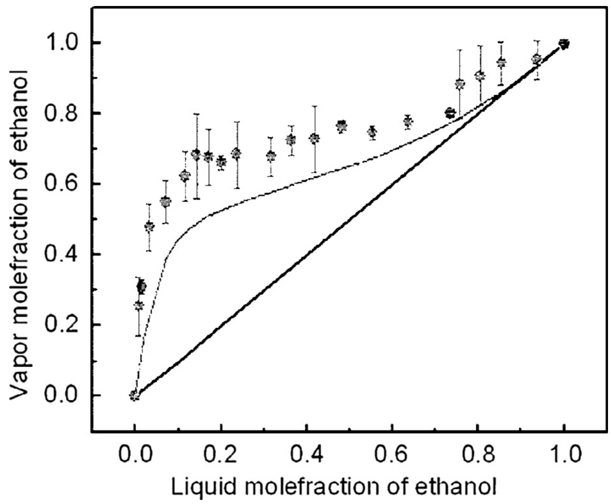

Fig. 1. The vapor collected in the distillation process contained more ethanol than predicted by thermodynamic equilibrium. The dots mark measured values, the continuous line represents thermodynamic calculations. No separation limit at the azeotrope can be seen [17].

We are surprised that these results raised only little attention in the community. In process engineering techniques for optimized separation of fluids is of great importance. With more efficient separation of light ends and heavy ends the dimensions of unit operations can be reduced, e.g. less stages in distillation columns would be necessary. Anomalies in phase separation techniques might bear great potential for process engineering.

2. Experimental

To gain more understanding of the mechanisms leading to the unexpected results we decided to conduct experiments similar to those described above. Our intention is not to precisely describe the mechanism of nanofluids evaporation which can be found in the literature [5,19]. Rather, we want to show that the measurements can be interpreted without any anomalous effects. We clearly want to state that only basic scientific interest is involved, no company has asked us or influenced us. Our measurement setup consists of a modified ebulliometer and is shown in Fig. 2. In the stirred glass container at the bottom the nanofluid mixture is evaporated either by concentrated halogen spots or by conventional heating. The temperature is measured in the liquid phase using a calibrated mercury thermometer. The generated steam ascends in the duct until reaching the condenser. To avoid condensation effects, which will be discussed later, the duct is insulated and additionally heated slightly above condensation temperature. The steam is condensed at the cooling surfaces, the condensate flows into an U-tube. At a certain filling level in the U-tube droplets of the condensed phase flow back into the evaporator. Another U-tube in this recirculation section makes sure that only evaporated and subsequently condensed fluid can reach the U-tube. At the

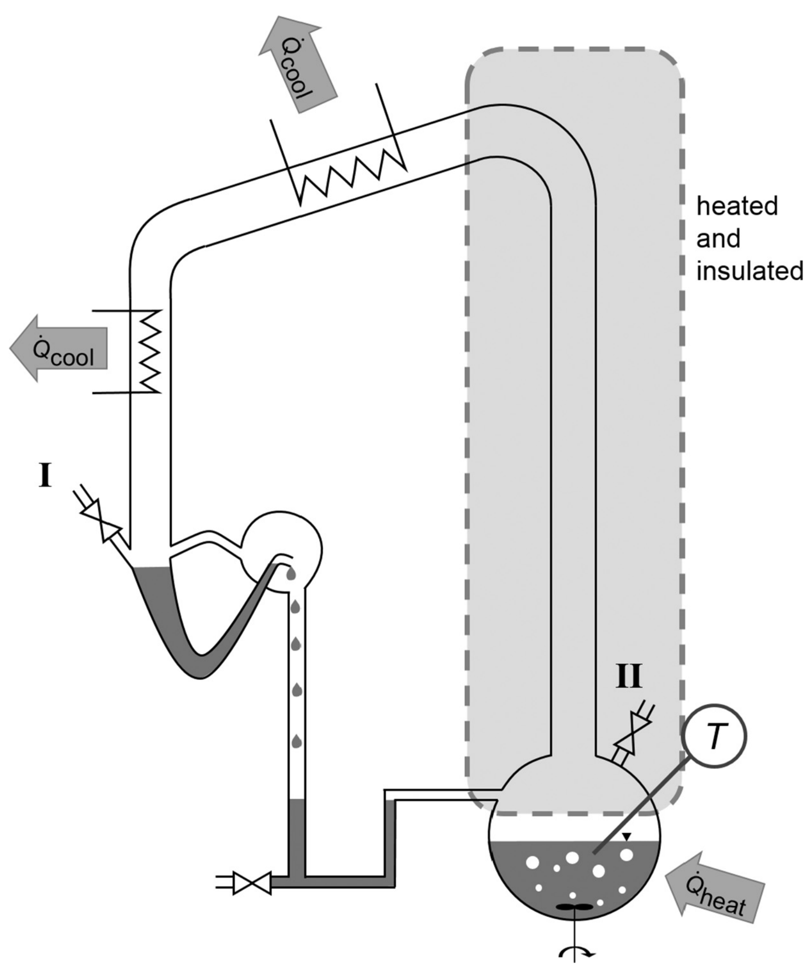

Fig. 2. Generated steam ascends in the heated duct and is condensed in the U-tube. The setup is closed and phase equilibrium, when established, can be measured quantitatively.