Energy Harvesting from Pool Boiling Using Electromagnetic Induction: Experimental Study and Numerical Simulation

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ABSTRACT

In this study, a method has been proposed for energy harvesting from waste heat. A magnet was floated on the liquid in the coiled container and the system was placed on the heat source. By pool boiling of the liquid and according to the Faraday's induction law, voltage was induced in the coil by movement of the magnet. Excess temperature, dimensions of the container, liquid height in the container and the frame shape and diameter have been selected as effective parameters. Effect of these parameters on peak-to-peak voltage and root mean square voltage have been investigated experimentally. Obtained results showed that the maximum energy was harvested at higher values of excess temperature, liquid height, coil turn and frame diameter with spherical frame shape. Highest measured parameters were 532 mV and 95.65 mV for *Vpp* and *Vrms*, respectively. In the second part, the numerical method is used to simulate the proposed system. Effect of various parameters on interface characteristics has been investigated. The results showed that the trend of changes in the interface parameters, including its pressure and height, were consistent with experimental data. Therefore, this method can be used to design and predict the performance of the energy harvester.

KEYWORDS

Energy harvesting, boiling, Faraday's induction law, magnet, coil.

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1. Introduction

Using of new energy sources is inevitable due to the limited fossil fuels and their harmful effects on the environment. Energy harvesting is the process by which energy from other sources such as solar energy, thermal energy, wind energy and kinetic energy is harvested and stored for small, wireless devices such as those in wearable electronics and wireless sensor networks [1].

The use of fluid movements as a source for energy harvesting has been considered by various researchers [2-4]. In one of the most recent studies, the energy harvesting of the fluid sloshing phenomenon has been studied experimentally [5]. One of the processes that seems to be able to harvest energy due to fluid movements is the pool boiling of liquids. Yamada and Kato experimentally investigated the energy harvesting from pool boiling phenomenon [6]. In another study, Deguchi et al. Studied energy harvesting from fluid phase change by piezoelectricity. In his study, low boiling temperature fluid has been used as the operating fluid [7].

The main goal of this study is to harvesting energy from the pool boiling of a fluid using the phenomenon of electromagnetic induction. Few studies have been done on energy harvesting from liquids boiling. The combination of experimental and numerical methods is another innovation of the present work in the field of energy harvesting.

2. Materials and Methods

In the first part of this study, energy harvesting from liquid boiling has been studied experimentally. The test method is that the main container was wound by copper wire and in each of the studied cases, water with a certain height was poured into the container. Then the container was placed on the heater to raise the temperature to boiling point. After boiling the fluid and reaching the conditions to steady state, the magnet was placed inside a frame and was floated on the fluid (see Fig. 1).

Due to the movements of the fluid interface during the pool boiling, the frame containing the magnet moves and as a result, according to the Faraday's law of induction, voltage is induced in the coil around the container. The experiments were performed in different conditions and the results were stored by an oscilloscope. The studied variables are given in Table 1.

Numerical modeling has been used to simulate liquid boiling and the Navier-Stokes equations have been considered as the governing equations. Also, the two-phase volume of fluid (VOF) model was used to capture the interface. Structured grids have been used for meshing the computational domain which an example is shown in Fig. 2.

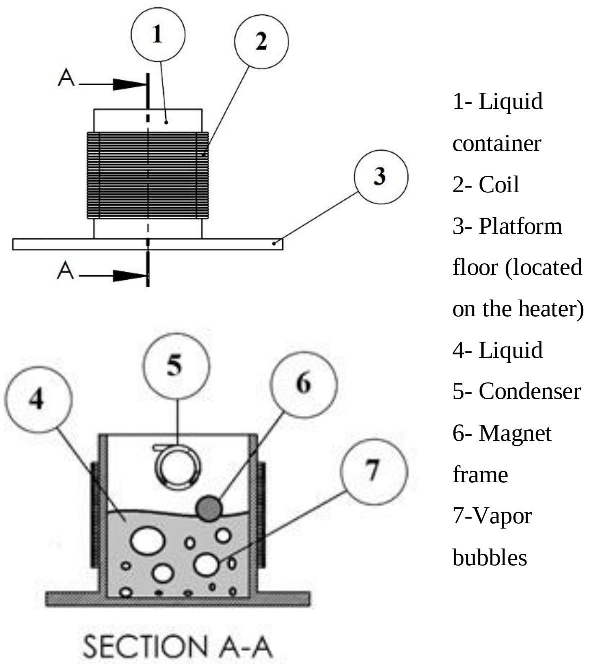


Fig. 1. Interior view of the container

Table 1. Effective parameters in this study

Frame shape	Excess temperature [℃]	Fluid height [cm]	Frame diameter [cm]	Coil turn
Different shapes	5-60	5-12	4-7	420-830

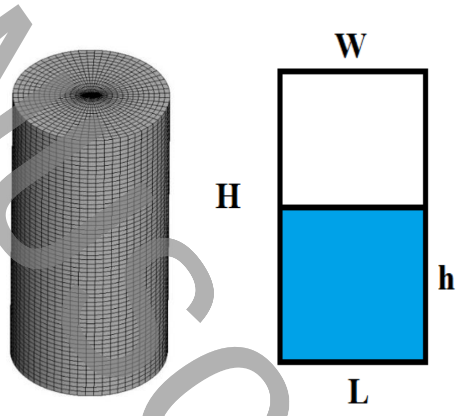


Fig. 2 Studied geometry and used mesh

Table 1 Effective parameters in the numerical part

Parameter	$T_w - T_{sat}$	*W/L*	*H/L*	*h/H*
Studied values	5-80	0.5-2	0.5-2	0.25-0.75

3. Results and Discussion

Firstly, the induced voltages were measured to evaluate the efficiency of the proposed system (Fig. 3).

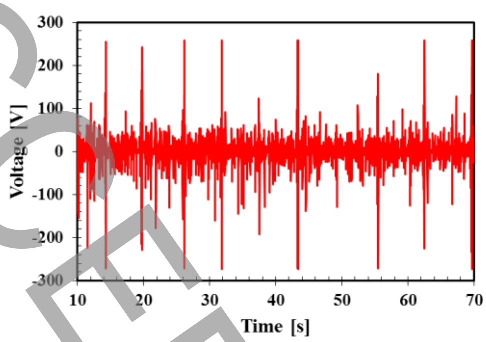
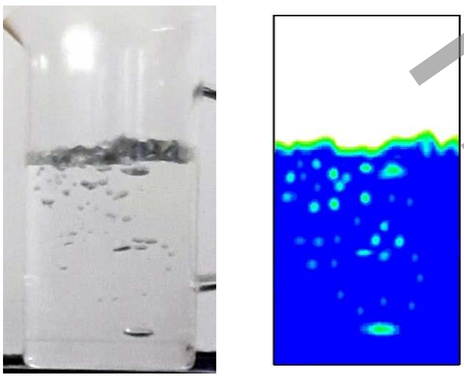


Fig. 3 Induction voltage changes with time ($\Delta T = 40°C$)

To evaluate the accuracy of the used numerical method, a comparison between experimental observations and modeling results was performed (Fig 4). it can be expected to predict the experimental observations by mean of behavior of the interface and its parameters. A comparison between variations of the selected interface parameters and harvested voltages were made and is shown in Fig. 5. There are many qualitative similarities between numerical graphs and experimental data.



(a) (b)

Fig. 4 Liquid surface profiles due to boiling at ΔT=20℃: a) Experimental, and b) Numerical.

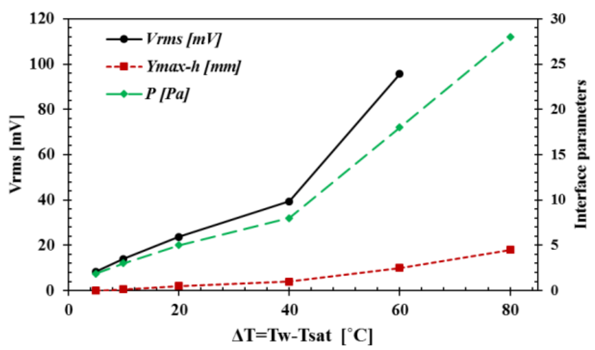


Fig. 5 Comparison between variations of the selected interface parameters and the harvested voltages

4. Conclusion

In this study, a method was suggested for energy harvesting from waste heat. The findings indicated that: 1) Induced voltage was increased by increasing the excess temperature, liquid height in the container and turn coil of copper wire. 2) Highest measured parameters in this study were 532 mV and 95.65 mV for *Vpp* and *Vrms*, respectively, 3) There were many qualitative similarities between numerical graphs and experimental data. Consequently, a preliminary estimate of the possible energy harvesting can be obtained from the interface parameters, 4) Interface parameters increased by decreasing the *W/L* ratio, increasing the aspect ratio of the container (*H/L*) and the dimensionless height of the liquid (*h/H*).

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