EVALUATING EFFECTIVENESS OF MICROWAVE HEATING AND CONVENTIONAL HEATING FOR LIQUID FUEL

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Abstract - This article presents a study of experiments to evaluate effectiveness of microwave heating compared to heating based on the use of the Ni-Cr alloy resistance wire, which comes in two forms – straight and round. The power supply for both systems was fixed at 20w. The heating effectiveness was evaluated via the temperatures of fuels in the storing chamber in the direction of its height and diameter. The experimental results show that the new heating method brings higher efficiency – up to 32%; in the vertical direction, the traditional heating method is the most effective one; the least effective one is the rolled wire heating method.

Key words - microwave; heating; resistant wire; ethanol; cold-start

1. Introduction

Regulations of exhaust emissions from cars become more and more severe in order to reduce negative influence on the environment and human health. Using renewable fuels and less emissions engine for cars is one of the most trends to adapt those problems. As an alternative fuel of gasoline, ethanol attracts attention, especially bio-ethanol. But as the calorific value of gasoline is 43MJ/kg, whereas the calorific value of ethanol is less - 26.7MJ/kg, and the latent heat of vaporization of gasoline is about 0.33MJ/kg, whereas the large latent heat of vaporization of ethanol is 0.86MJ/kg, to get energy equivalent of gasoline ethanol, much more heat is required. On this account, improvement of the heat utilization efficiency becomes important in effective use of ethanol fuel.

To overcome the ethanol cold start difficulties, some fuel-heating systems with conventional heating methods, for example, electrical heating wires [1-2] were performed. In such a heating system, as thick wires were necessary to supply large energy and to widen the heating surface area, it was difficult to build them in a small volume and energy efficiency as well as responsiveness were not enough. Other way to solve this problem is to use gasoline during the start-up period of the ethanol engine [3] that needs a gasoline reservoir and a gasoline supply system to be equipped for the engine.

In recent years, the acceleration of application of microwave techniques for material heating in several industrial areas have been reported [4-6]. For fuel heating, D.R. Baghurst and D.M.P. Mingos [7] made some experiments on heating several solvents, such as ethanol, methanol, and water by using microwave. They found that microwave made those solvents get superheating rapidly and maintain the temprature above the boiling point of 4ºC, 13-26ºC, and 20ºC higher than the normal boiling temperature for water, methanol, and ethanol respectively.

In our study we implement the comparison between the two methods of heating that is external heating with wires using Ni-Cr alloy and our developing heating device applying microwave heating mechanism. The results will be used to assess the effects of our device on fuel heating.

2. Experimental apparatus and procedures

2.1. Schematic Experimental Apparatus

Figure 1 schematically shows the experimental apparatus including fuel supply system, record section, flow measurement section, and heating section. The experimental device mainly consists of the following parts:

1. Microwave oscillator to generate microwave.
2. Microwave transmission to transmit the microwave from oscillator into heating chamber to heat the supplied liquid.
3. Fuel supply section that refrains liquid temporarily, and sends it to the heating section with constant flow rate.
4. Flow measurement section that measures the flow rate of liquid exhausted from the heating section.
5. Record section amplifies the thermocouple output, collects and stores it.

The heated fuel is guided by a supply line into the heating chamber from the fuel container. The level of supplying fuel in the container is adjusted in constant so that the fuel flow rate is keep in constant. The exhausted fuel is led to the burette by a nylon tube and to measure the flow rate.

2.1.1. Heating section

Details in the heating section are shown in Figure 2 (a, b, c). The microwave that has been produced from the oscillator was transmitted through the coaxial cable and irradiated to the liquid supplied in the heating fuel chamber. The material of the heating fuel chamber is brass, which has a very small microwave loss. As a result, the microwave led in the heating fuel chamber will not leak outside. The heating fuel chamber is also heated by the Ni-Cr wire via emitted heat from the top of the fuel chamber. The diameter and length inside the heating chamber are 16mm and 65mm respectively, on account of the experiment space of laboratory.

Thermometer sides from the bottom of the fuel chamber can be inserted inside a pair of holes 5, 10, 15, 30, 45, and 60mm away. Two Ni-Cr wires were prepared for comparison with microwave heating. Figure 2 shows the details of the heat sections.

The heating temperature in the fuel chamber is measured by a K-type thermocouple of 1.0mm diameter sheath. The thermo-couple has been set up and adjusted not to touch the tube.

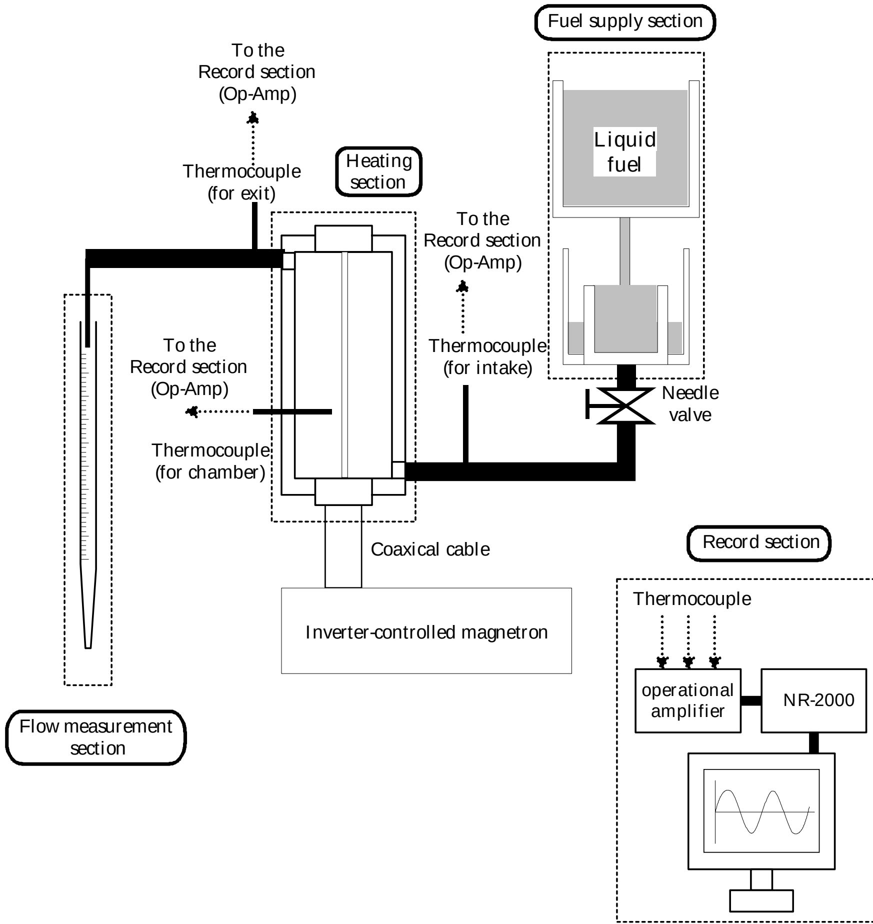
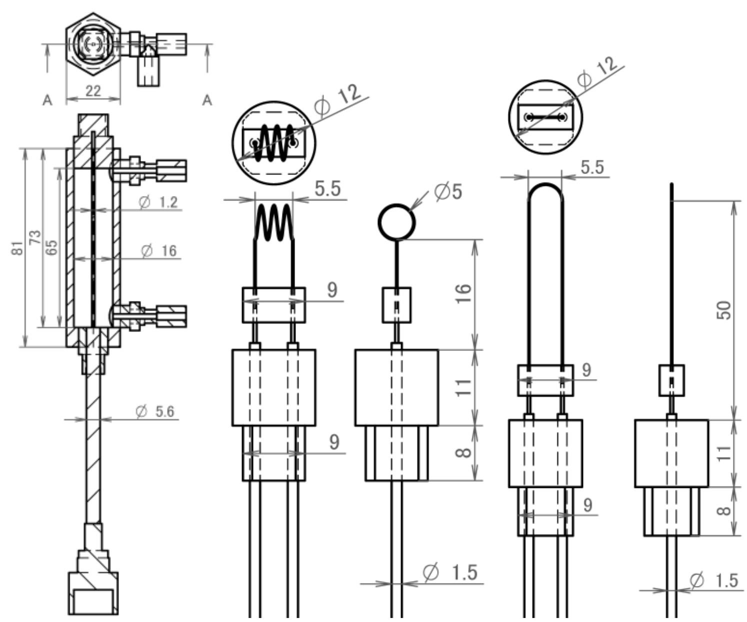


Figure 1. *Schematic experimental apparatus*



(a) Microwave coaxial heater *(b) rolled Ni-Cr heater* *(c) straight Ni-Cr heater*

Figure 2. *Details of heat section*

2.1.2. Liquid supply section

The liquid entering the fuel chamber is pushed by the atmospheric pressure. The flow rate of the liquid is adjusted with a stainless steel valve, and led to the heating fuel chamber through a nylon tube. To keep the flow rate in constant, the liquid level in the fuel container is always adjusted to a fixed position because the liquid pressure changes when a liquid level changes, the flow rate is thereby to change. In this experiment, ethanol is used as fuel because it is easy to heat in a microwave of 2.45GHz.

2.1.3. Record section

The record section measures the output of the thermocouple for measuring the temperature before and after heating of liquid, and records it. The NR2000 device is used to measure the output voltage of the thermocouples. The measurement duration is 1 second at the initial state before heating, and at 300 seconds after heating, the total time is 301 seconds. The thermocouple output voltage is very small, so it is needed to amplify by using an operational amplifier μPC4574, and then amplified voltage inputs into NR2000.

2.2. Experimental procedures

The experiment procedure is shown as below.

1. Switch on the microwave oscillator and the op-amp, at this stage, the microwave oscillator is in an idling state without oscillation.
2. Start the personal computer, and NR2000.
3. Put the liquid into the liquid supply fuel chamber, the valve is opened, and the liquid is thrown. The liquid will be discharged through the heating chamber. Make the temperature of the heating fuel chamber and the liquid container in the same value by draining liquid for a while before measuring.
4. While the liquid exhausted, making the fuel level in the liquid fuel chamber constant by adjusting the flow rate through a burette to 0.5cc/s, the flow rate is adjusted with the valve.
5. Begin measuring the output of the thermocouple by NR2000.
6. Turn on the output of a microwave oscillator or the Ni-Cr wire power supply one second after a measurement startss and heats the liquid in the fuel heating chamber. The power of heating is set to be 20W in consideration of the load of the coaxial cable.
7. The measurement is conducted with a frequency of 10Hz.
8. After 300 seconds of measurement, turn off the power supply of the microwave oscillator or the Ni-Cr wire.
9. Write the data of NR2000 in a Microsoft Excel file.
10. Turn off the power supply of the microwave oscillator and the operational amplifier.
11. Remove the liquid from the heating chamber and close the valve of the fuel container.

After finishing the experiment, wait for enough time to cool down the heating fuel chamber. To observe the temperature of the fuel before and after heating in the microwave or Ni-Cr wire heating at the fuel supply, the temperature inside the heating chamber is measured using a thermocouple. In all these experiments, an initial temperature of the heating fuel chamber and the liquid is room temperatures. Figure 3 shows the position that can be measured in the heating chamber.

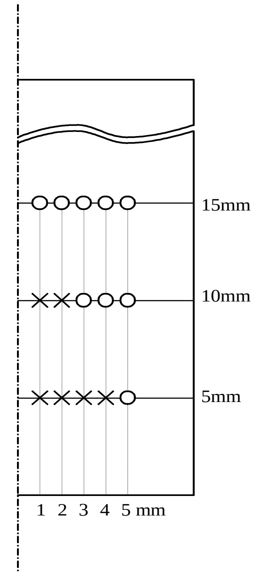


Figure 3. *Measured positionsin heating chamber*

2.2.1. Temperature history of the fuel

The influence on the temperature rise of the liquid along the time by the heating methods is examined. In case of using Ni-Cr heating, the shape of the Ni-Cr wire used is rolled.

The measurement position was assumed to be 30mm in length and 5mm in the radius.

2.2.2. Longitudinal temperature distribution

In the experiment, the influence on the fuel temperature distribution along the longitudinal direction in the heating fuel chamber by two heating methods is examined.

The microwave and the Ni-Cr wire heating are both measured according to the time base range. Moreover, experiments will conduct on two kinds of Ni-Cr wire heating, the rolling wire and the straight wire, to consider the difference in the influence of the wire shape on the liquid. The location of measurement was assumed to be 5, 10, 15, 30, 45, 60mm in length, and 5mm in radius.

2.2.3. Radial temperature distribution

The influence on the temperature distribution in the radial direction of the liquid heating chamber by two heating methods is examined. The fuel will be heated by using the Ni-Cr wire, and the microwave heating. The experiment can only be conducted with the Ni-Cr straight because the thermal-couple will be touched with the rolled wire.

The microwave and the Ni-Cr wire heating are both measured based on time range. The positions of measurement are 30mm in length and 1mm, 2mm, 3mm, 5mm, and 7mm in radius.

3. Results and disscution

3.1. Temperature history of fuel using microwave heating and Ni-Cr wire heating

Figure 4 shows the time history of the heating chamber temperature measured from three directions and the outlet temperature of the fuel using microwave heating. The horizontal axis is microwave irradiation time and the vertical axis is the temperature difference between the initial temperature and the current temperature. The result shows the rapid temperature rise in the oscillation until about 50 seconds later, at which there is a transient in temperature rise. However, the temperature has increased smoothly without difference from the location of measurement when exceeding approximately 100 seconds. There is some temperature fluctuation in three directions of the thermocouple in the chamber at that time.

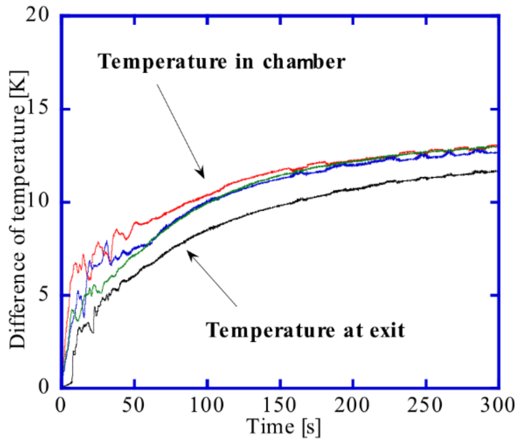


Figure 4. *Fuel temperatures using microwave heating*

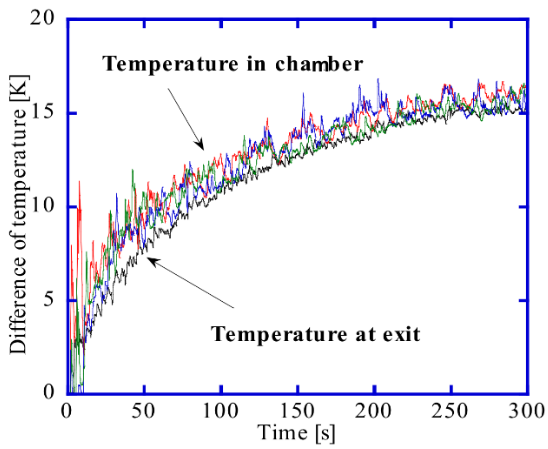


Figure 5. *Fuel temperatures using Ni-Cr heating*

Figure 5 shows the time history of the temperature inside the heating chamber that was measured from three directions and the exit temperature in case of using Ni-Cr wire. The result shows that there is a rapid temperature rise immediately after the beginning of heating and the rise is unsteady. It also indicates at the exit the temperature rise is smoother than that inside the chamber

3.2. Longitudinal temperature distribution

The temperature distribution in the longitudinal direction of the heating chamber by the microwave heating and the Ni-Cr wire heating is shown in Figure 6. The horizontal axis expresses the location of measurement and the vertical axis is about increasing temperatures. As shown in the Figure, after 15mm in length, temperature increase by microwave heating hardly changed. It is understood that this fuel heating chamber with 15mm in length is enough for this kind of heating.

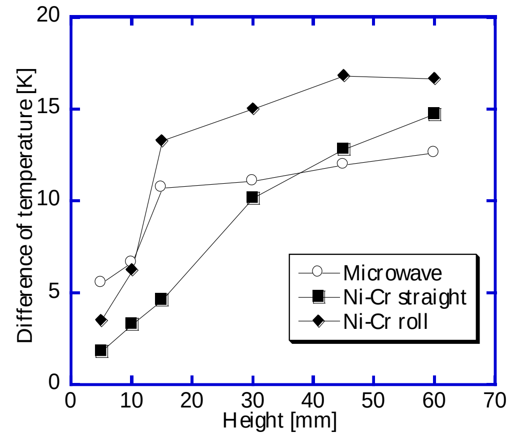


Figure 6. *Temperature distribution along with height of fuel heating chamber*

The temperature rise is found in a position of 5mm length and the point of temperature rise is growing small in proportion to length is similar. For the Ni-Cr wires, there is a different in the temperature distribution according to shape. A temperature rise occurs suddenly at the length of 15mm of the rolled Ni-Cr wire heating is because this area is close to the heating element. Temperature distribution of microwave heating is found to be a certain temperature and temperature increase is less than the length of Ni-Cr wire heating.

3.3. Radial temperature distribution

Radial temperature distribution in the fuel heating chamber by using the microwave heating and the Ni-Cr wire heating is shown in Figure 7. The temperature rise begins to decrease from the center to the bound of the chamber in both microwave and wire heating, and there is no significant difference in tendency between the two types of heating. However, it is not too different in the radius of 1mm and 2mm. It was expected that there was a great difference of 1mm in the radius and 2mm for electric field strength to attenuate theoretically with $1/r^2$ in the microwave heating. This phenomenon can cause thermal conduction.

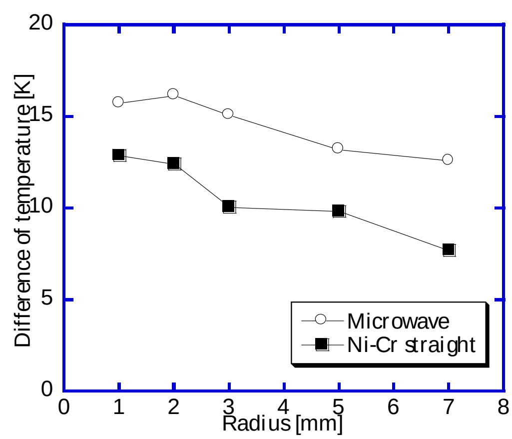


Figure 7. *Temperature distribution with radius of fuel heating chamber*

4. Conclusions

According to the results obtained, microwave energy could be used for heating fuel more steadily than the wire heating method, but wire heating gives a larger amount of temperature rising during a period of heating time.

The microwave heating method gives higher effectiveness of 32% in temperature rise that distributes along with the radius of the heating chamber than the Ni-Cr wire heating

For the distribution of longitudinal temperatures, the straight wire heating is the most effective method, followed by microwave, and the rolled wire heating method respectively.

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