Investigation of Evaporation Characteristics in Single Micro Tube Steam Engine Based on Flow Visualization

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Abstract: This paper describes an experimental investigation of evaporation characteristics in single micro tube steam engine. Present steam engine consists of a single micro tube, a syringe and piston-crank mechanism. One of the features of this engine is that there's no need to use pump, turbine and valves. Mechanical work can be obtained from the balance between volume change and the pressure which results from evaporation and condensation. In present study, Pyrex glass tube was used as a test tube to visualize inside the heating section, and a series of images were recorded with a high speed camera. Visual observation provides information for understanding basic features of this heat engine. The results show that bubble expansion and liquid spreading produce high pressure and large mechanical work.

1. Introduction

Over the last several decades, global warming has proceeded seriously because of huge fossil fuel consumption. Moreover, a large amount of energy is just wasted as heat. For example, waste heat with temperature above 300℃ accounts for approximately 7% of the whole primary energy supply in Japan. Hence, efficient energy utilization is strongly desired. Waste heat recovery is one of the promising solutions to overcome energy issues. However, in general, waste heat is spatially distributed. In addition, conventional heat recovery system is still too expensive. For this reason, small and low cost energy utilization devices are required.

Yatsuzuka et al. (2011) reported that Single micro tube steam engine is promising for recover mechanical work from waste heat economically and efficiently, because of simplicity. This engine consists of a single micro tube with heating, adiabatic and cooling section, and thus needs no pumps, turbines and valves. Oscillating liquid column evaporates in the heating section, and the vapor condensates in the cooling section. Mechanical work can be obtained from the pressure change. Kanno et al. (2011) reported that evaporation considerably affects this engine performance. However, research on oscillating two-phase flow with phase change is very limited, and its mechanism is not fully understood. In this study, the heating section of single micro tube steam engine is visualized to investigate the evaporation characteristics of oscillating flow.

2. Experimental procedure

Figure 1 shows the schematic diagram of the experimental setup. Heating, adiabatic and cooling sections are made of a Pyrex glass tube, whose inner and outer diameters are 1 and 1.3 mm, respectively. One end of the tube is sealed. The other end is connected to the syringe. Ethanol is used as a working fluid. Hot air heats the heating section. The adiabatic section is covered by glass wool for thermal insulation. Cooling water circulates through the concentric double tube in the cooling section. Thermostatic tank keeps the cooling water temperature constant at 50°C. Five thermocouples are used to measure outer wall temperature along the axial direction of the heating section. Distances of each thermocouple are 1 mm.

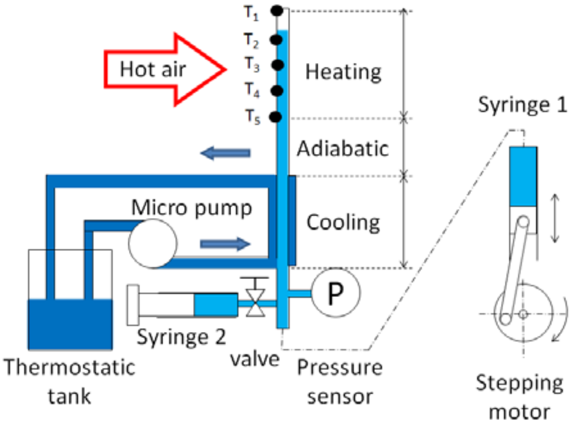

Figure 1. Schematic diagram of the experimental

Stepping motor controls the frequency of the oscillating piston. Frequencies in the present study are 1 and 2 Hz. A high speed camera is used to record a series of images of evaporation at 1000 frames per second. In the present study, outer wall temperature at the third thermocouple T_3 is fixed at 290 °C.

3. Results

Pressure volume diagram is shown in Figure 2. In the heating section, pressure sharply increases because of ethanol evaporation. During the expansion process, pressure gradually decreases. In the cooling section, condensation takes place and pressure decreases. From Fig. 2, two typical modes are observed. Mode 1 shows high pressure in the heating section, while the other shows only a mild increase (mode 2). Much larger mechanical work is obtained for mode 1. Figures 3 and 4 show a series of images of evaporation in the heating section at 2 Hz. Measured time of each image corresponds to the cycle phase shown in Fig. 2. Measured indicated mechanical works for 1 and 2 Hz are presented in Table 1. The ratio of mode 1 to mode 2 is about 1.2. In mode 1, bubble shows rapid expansion and liquid spreads deeply inside the heating section. On the other hand, bubble expansion is very weak in mode 2. The amount of liquid which spreads inside the heating section is considered to be an important parameter which characterizes cycle performance.

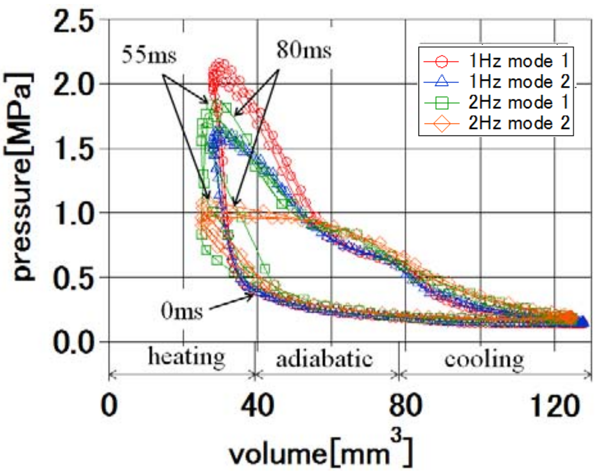

Figure 2. P-v diagram at 1 and 2 Hz

Table 1. Measured indicated mechanical work

work[W]	mode 1	mode 2	mode 1 / mode 2
1Hz	0.0485	0.0413	1.17
2Hz	0.0888	0.0716	1.24

4. Conclusion

In the present paper, evaporation inside the heating section of single micro tube steam engine is visualized, and its effect on cycle performance is investigated. It is considered that bubble expansion and liquid spreading considerably affect cycle performance. Strong bubble expansion and resulting liquid spreading wets the heating section widely and generates high pressure. This results in large mechanical work. To achieve high performance, it is required to maintain large liquid spreading observed in mode 1. Further work will be carried out to investigate bubble expansion and liquid spreading in oscillating flows.

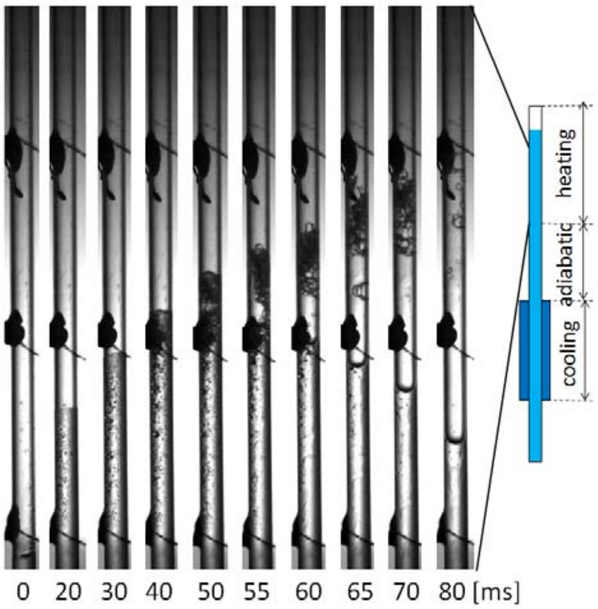

Figure 3. Evaporation pattern in mode 1

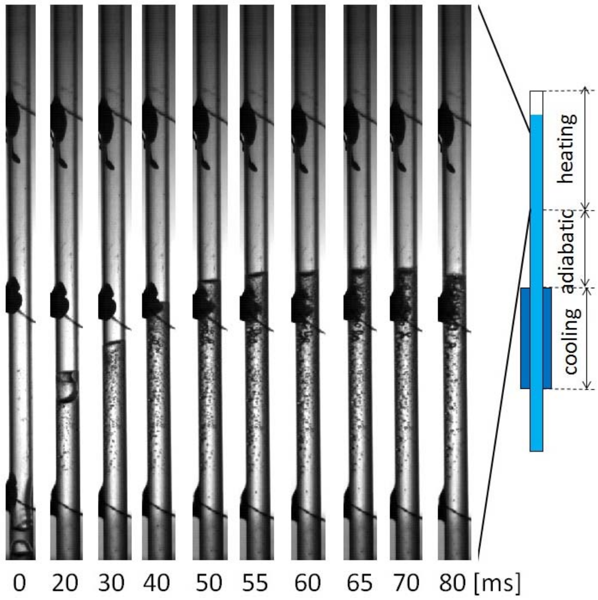

Figure 4. Evaporation pattern in mode 2

5. References

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