Experimental Investigation of Single Micro Tube Steam Engine

Kazuki Shimamoto[1], Young Bae Han[2], Naoki Shikazono[2], Hiroshi Kanno[1],
Shinichi Yatsuzuka[3], Yasunori Niiyama[3] & Kentaro Fukuda[3]

[1] Department of Mechanical Engineering, The University of Tokyo
[2] Institute of Industrial Science, The University of Tokyo
[3] Corporate R & D Division 2, DENSO CORPORATION

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Abstract: Due to the depletion of fossil fuel resources, more efficient energy conversion technologies are desired. On the other hand, most of the low temperature heat below 300°C is wasted, because such heat is spatially distributed in small amounts and its utilization is still expensive. In the present study, a single micro tube oscillating steam engine is investigated. This engine consists of a single tube with heating, insulated and cooling sections and oscillating working fluid. Pressure-volume (*P-V*) diagrams are experimentally obtained for heating temperatures of 170 and 180 °C. The frequency of engine is varied from f = 2 to 14 rps. Mechanical work of 0.6 W is obtained for a 1 mm tube engine at 180 °C.

1. Introduction

Due to the depletion of fossil fuel resources, more efficient energy conversion systems are desired. Currently, fossil fuel is mostly combusted to generate heat, and most of the exhausted heat is wasted except for supplying hot water and air conditioning. This is because waste heat is spatially distributed in small amounts and its utilization is still expensive. Therefore, it is very important to develop efficient and low cost heat recovery system. Recently, single tube oscillating steam engine is invented (Yatsuzuka et al., 2011; Kanno et al., 2011). This engine consists of a single tube with heating, insulated and cooling sections and a working fluid. Working fluid oscillates between heating and cooling sections. Working fluid is vaporized in the heating section, and the vapor expands and then enters the cooling section where it is condensed. Vapor volume decreases and working fluid finally returns to the heating section again. In this way, mechanical work is obtained from this cycle. The cycle characteristics strongly depend on the amount of evaporation and condensation. Thus, it is very important to understand the mechanism of heat transfer in oscillating two phase flow. However, research on oscillating two-phase flow with phase change is very limited, and its mechanism is not fully understood. In the present study, basic characteristics of single micro tube oscillating steam engine are experimentally investigated. The main objective of the present work is to investigate the effects of important parameters that affect cycle characteristics and to understand the basic mechanism of this steam cycle.

2. Experimental procedure

2-1. Experimental setup

Figure 1 shows the schematic of the experimental setup. A stainless steel test tube with inner diameter of 1 mm is vertically connected to a syringe, a crankshaft and a motor. The test tube consists of heating, insulated and condensing sections. The outer diameter of the heating section is 8 mm, and 6 mm for the other sections. A sheath flexible heater is bound around the heating section. Thermocouples are inserted in 0.5 mm diameter holes, and placed at positions 0.5 mm from the inner surface. The cooling section is composed of a double glass tube. Cooling water flows upward through the outer concentric tube. A reservoir tank keeps the cooling water temperature constant. Water is used as a working fluid in this study. Total amount of working fluid is adjusted by an actuator motor. Stepping motor is used to control the frequency of rotation. Pressure is measured from the port at the bottom of the cooling section.

2-2. Experimental parameters

Table 1 shows the experimental conditions. Initial amount of the working fluid is adjusted as follows. The position of the thermocouple is heated up to 170 °C or 180 °C, and the piston is actuated upward. It is assumed that the gas-liquid interface just reaches this thermocouple position when pressure reaches saturation pressure.

Table 1. Experimental conditions			
Inner Diameter	[mm]	D_L	1.0
Heating Section Temperature	[°C]	T_{heat}	170, 180
Cooling Water Temperature	[°C]	T_{cool}	80
Compression Rate	[-]	E	4.0
Frequency	[rps]	F	2 ~ 14

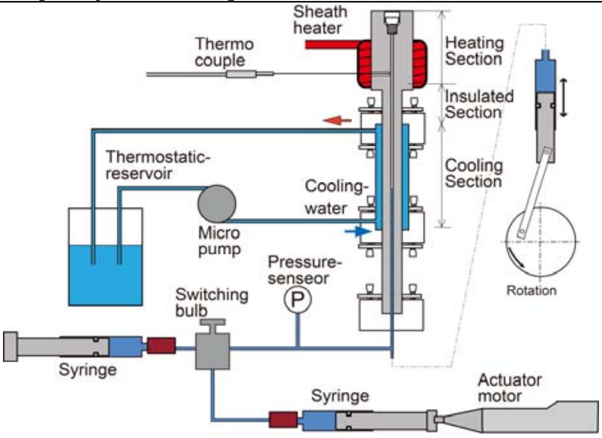

Figure 1. Experimental setup

3. Experimental results

Figure 2 shows measured *P-V* diagram for heating section temperature of 180 °C. At low frequency of 2 Hz, the maximum pressure is not high. This is because working fluid does not fully wet the whole heating section. While, at 6 Hz, liquid is supplied further deeply inside the heating section, and more liquid is evaporated, which leads to higher pressure. At 10 Hz, liquid surface velocity becomes too fast so that the liquid film in the heating section becomes thick (Han et al., 2009). Thick liquid film may degrade heat transfer. At highest frequency, the curve nearly follows adiabatic compression line, which indicates that the phase change heat transfer becomes relatively insufficient compared to the dynamic volume change.

The minimum pressure level at the cooling section increases with frequency. This is because condensation heat transfer is not fast enough to fully condensate the vapor when frequency is high.

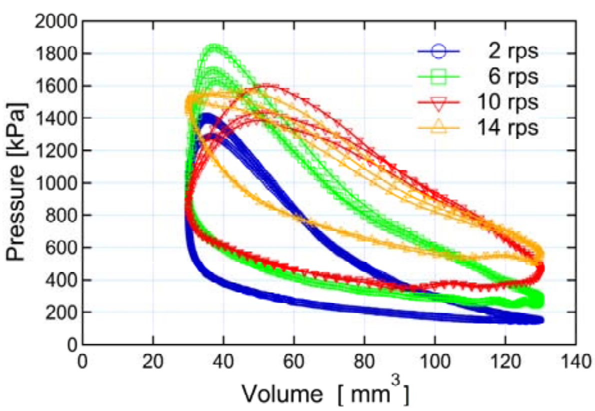

Figure 2. P – V diagram (T_{heat} = 180 °C, T_{cool} = 80 °C, ε = 4.0)

Figure 3 shows indicated work against different frequencies. Present cycle achieved about 0.6 W at 14 rps and 180 °C. Figure 4 shows the efficiency of the cycle. Efficiency is defined as the indicated work divided by the heater electrical input. The highest efficiency is about 1.2 %, which shows a maximum value against frequency. Indicated work and efficiency are higher for 180 °C than for 170 °C. It is considered that the heat transfer enhancement is essential to increase mechanical work and efficiency at higher frequencies.

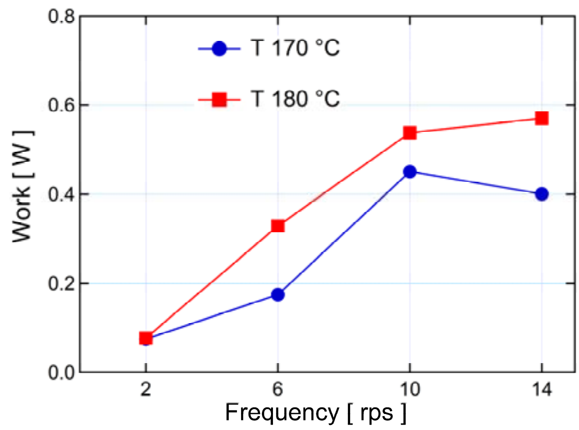

Figure 3. Measured indicated work

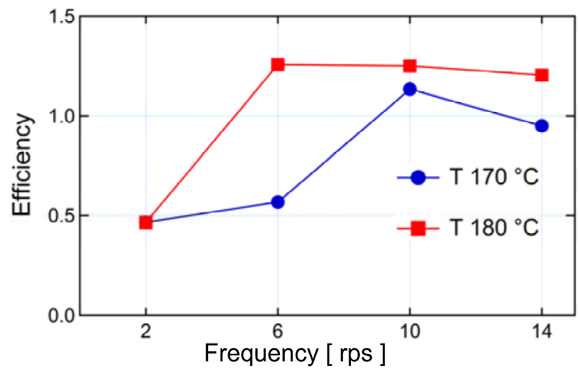

Figure 4. Thermal efficiency of the present cycle

4. Conclusions

In the present study, a single micro tube oscillating steam cycle is experimentally investigated. Following conclusions are obtained.

1. Micro steam engine with 1 mm inner diameter tube generates 0.6 W indicated work with efficiency of about 1.2 %.
2. Cycle characteristics largely depend on frequency. It is considered that the heat transfer enhancement is essential to increase mechanical work and efficiency at higher frequencies.

5. References

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