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Copper water heat pipe applied for Stirling engine

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1. Introduction

Humanity intends, in the coming decades, to build mission bases on the surface of Mars and the Moon. However, this requires the advancement of efficient and long-lasting energy generation technologies. The TERRA project conducted by the Institute for Advanced Studies (IEAv) researches technologies for the future development of advanced fast microreactors. A microreactor is a small, portable reactor unit. This system uses the heat generated by nuclear fission to be converted to electricity using thermoelectric converters such as Stirling engines. It is a thermal machine that converts heat applied externally into electrical energy. The use of a nuclear source requires to shield the Stirling from neutron radiation. Therefore, it is necessary to use an intermediary device that transfers heat from the nuclear source to the engine. The heat pipe is one of such devices. It is a passive, two-phase flow sealed device, which rapidly transports a large amount of heat with the minimum drop in temperature [1].

A heat pipe scheme shown in Fig. 1 consists of a sealed metal pipe with a capillary structure (wick) and a small amount of fluid in a partial vacuum. The length of the heat pipe is divided into three parts: evaporator, adiabatic, and condenser section. Heat inserted externally into the evaporator vaporizes the working fluid. The vapor expands towards the condenser carrying latent heat. In the condenser, the vapor condenses into a liquid, rejecting latent heat. The liquid is returned to the evaporator by gravity (thermosyphons) or by capillary forces in the wick (heat pipes). This cycle continues as long as there is a temperature gradient (hence pressure) between the evaporator and the condenser [2].

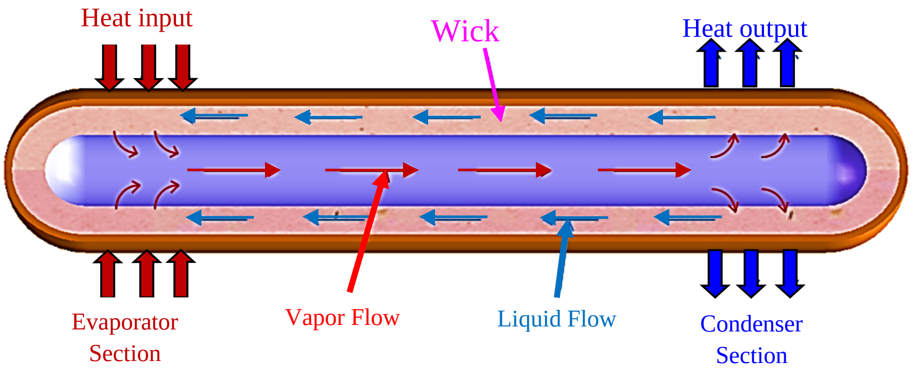

Figure 1: Heat pipe components [1].

The main applications of heat pipes are in the cooling of electronic devices and in the thermal control of gas pipelines and furnaces [1]. However, the practical application in Stirling engines and small reactors is still little discussed in the literature. Most are NASA research, such as the DUFF, KILOPOWER, and KRUSTY experiment [3]. In this context, the IEAv developed a Free Piston Stirling engine and 30 and 100 mesh copper water heat pipes [4-6].

The IEAv intends to use heat pipes to transport heat from a nuclear source to a Stirling engine and thus produce electricity as shown in Fig. 2. However, heat pipes are not designed for such an application. Thus, it was necessary to understand the heat pipe and adapt it for such an application. The objective of this work is to test experimentally if a copper heat pipe can carry the necessary heat to activate the Stirling engine. The pipe was heated using an electrical thermal belt. This experiment will serve as a basis for future work using a real nuclear source.

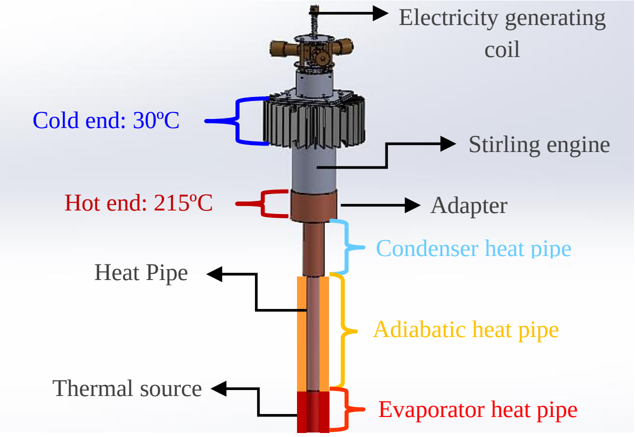

Figure 2: Drawing of the assembly: heat pipe, adapter and Stirling engine [2].

In previous works, it was obtained by simulation in the ANSYS transient thermal software that the pipe condenser should exceed a temperature of 215º [2]. This value is sufficient to conduct heat to the adapter and activate the Stirling engine. In this project, the pipe has the function of transporting and not dissipating heat. Therefore, a minimum temperature difference between the evaporator and the condenser is required. The authors tested the existing heat pipes in the IEAv at different angles and amount of working fluid [6]. After all these tests, it was defined that the pipe chosen for the final test was the 100 mesh heat pipe, in the vertical position and in the evaporator temperature range up to 270ºC.

2. Methodology

The heat pipe shown in Fig. 3 is composed of a copper envelope, a Brass screen-capillary structure and 69.8 mL of water as the working fluid.

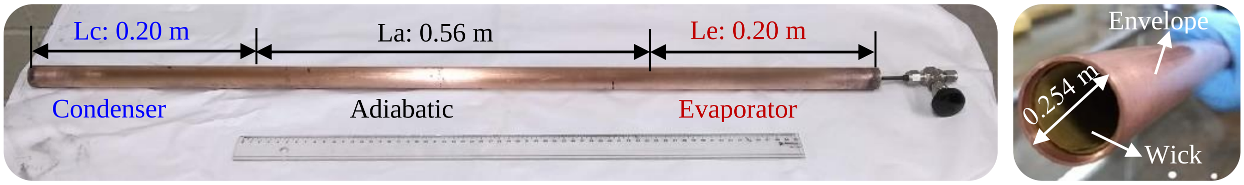

Figure 3: Dimensions of the IEAv 100 mesh Heat Pipe used in this experiment.

The adiabatic region of the pipes was isolated with an alumina ceramic fiber blanket (thickness 25 mm and thermal conductivity of 0.071 W/ (m K)). The evaporator region was heated using a thermal heating belt (220 V) with a power controller. In addition, the belt was isolated by a ceramic fiber blanket. The condenser region was connected to the copper adapter. Finally, the adapter was attached to the base of the Stirling engine and fixed to the support table. The setup of the experiment is shown in Fig. 4 (A). Seven T-IOPE thermocouples were calibrated for temperatures range between 20 ºC and 300 ºC (Instrument uncertainty ± 0.92 ºC and coverage factor, k = 2). The T thermocouples were connected to the predetermined pipe positions shown in Fig. 4 (B). The NI PXIe-1082 chassis shown in Fig. 4 (A) was used for temperature data collection. The software used to collect pipe temperatures was developed in Labview.

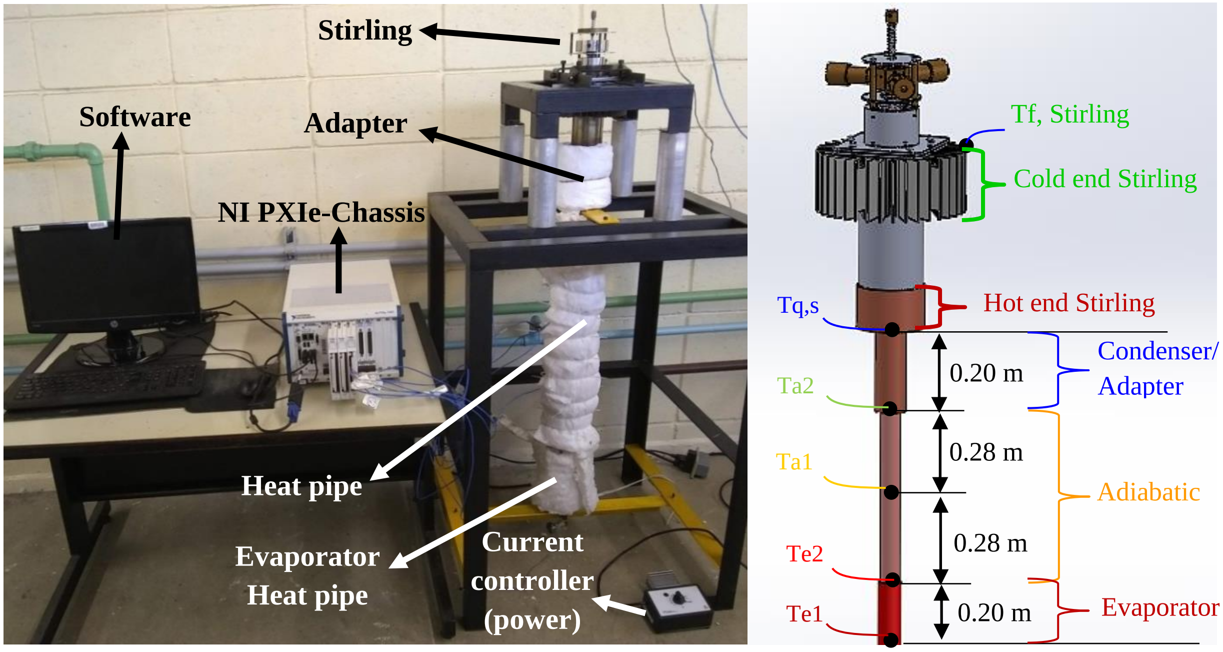

Figure 4: In (A) Experiment setup and in (B) representation of thermocouple positions.

3. Results and Discussion

Tests performed with the separate heat pipe (uncoupled at Stirling) showed that for it to reach 215°C on the condenser, the evaporator would need at least 250°C. Thus, in the test with the complete set (Heat pipe, adapter, and Stirling), the evaporator temperature was gradually increased from 23°C to 252°C. Test time was approximately 6.5 hours. The temperature distribution along the heat pipe coupled to the Stirling engine is shown in Fig. 5. The heat pipe coupled to the Stirling presented thermal behavior very similar to the tests performed with it separately. However, in the case of the heat pipe connected to the Stirling, more thermal energy is needed. The separate pipe requires an electrical current of 1.25 A and 220 V to reach 250°C on the evaporator. The heat pipe with Stirling required 1.53 A. This occurs due to greater heat dissipation to the adapter than uncoupled heat pipe (dissipates to the environment).

The thermal power from the heat pipe to Stirling was 39.8 W. This value considers the external resistances with the environment. This value is considered good because a grooved titanium-water heat pipe used in Kilopower carries 125 W. The evaporator reached 250 °C, and the condenser reached approximately 210 °C. Therefore, the Stirling engine activated at 210 °C. This temperature was close to the thermal simulation in thermal transient ANSYS [2] code. The engine ran continuously without interruption. It was possible to light LED lamps to demonstrate the generation of electricity.

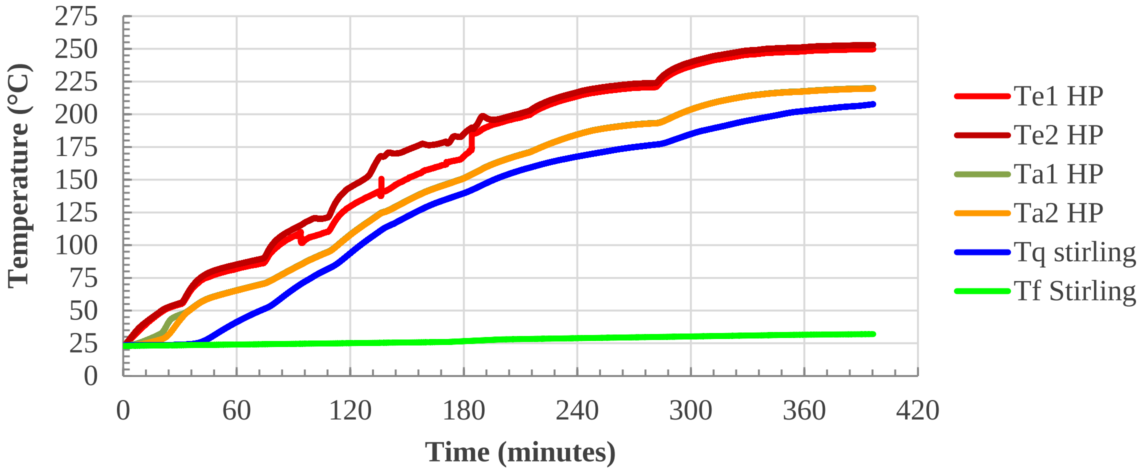

Figure 5: Temperature distribution along the heat pipe (HP) and in the Stirling:

4. Conclusions

With this work it was possible to prove that the copper heat pipe is capable of transferring the thermal energy needed to activate the Stirling engine. The pipe applied to the engine showed similar thermal behavior, when compared to its separate thermal behavior. The Stirling engine ran continuously when the heat pipe evaporator temperature reached 250 °C. Finally, the data obtained will serve as a basis for the study of the application of a nuclear source in the heat pipe evaporator.

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