2011 International Conference on Communication Engineering and Networks
IPCSIT vol.19 (2011) © (2011) IACSIT Press, Singapore

Experimental Study on Waste Heat Recovery from the Pyrolysis Stack using Heat Pipe

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Abstract. In this research, experimental study on waste heat recovery from the pyrolysis stack using heat pipe with both wick and wickless heat pipe has been investigated. The heat pipe is fabricated from the straight copper tube with the outer diameter and length of 15 and 600 mm respectively. The operating temperature inside the heat pipe is monitored at various flow rates of cooling water. The air-to-water heat pipe heat exchanger is designed, constructed and tested under operating conditions of pyrolysis oven using water as the working fluid. Effects of water flow rate, heat pipe tilt angle and heat pipe configuration (wick and wickless) on the thermal efficiency of heat pipe are considered. Considering the fact that this is one of the first practical applications of heat pipe waste heat recovery from the pyrolysis stack, it has given informative results and paved the way for further research.

Keywords-Heat pipe; Heat transfer; Waste heat recovery

1. Introduction

Pyrolysis can be defined as the thermal decomposition of organic material through the application of heat in the absence of oxygen. The Pyrolysis process is an advanced conversion technology that has the ability to produce a clean, high calorific value gas from a wide variety of waste and biomass streams. The hydrocarbon content of the waste is converted into a gas, which is suitable for utilisation in either gas engines, with associated electricity generation, or in boiler applications without the need for flue gas treatment. Waste heat from pyrolysis process (200-300°C) can be used to heat the water, which is suitable for the household in order to use instead of adding a separate water heater.

Heat pipes are devices that efficiently transport thermal energy from their one point to the other. A heat pipe is hermetically sealed tubes containing a working fluid in both the liquid and vapor phases. Heat pipe utilizes the highly efficient thermal transport process of evaporation and condensation to transport heat from one end to the other where the heat can be dissipated through a heat sink. It utilizes the latent heat of the vaporized working fluid instead of the sensible heat. As a result, the effective thermal conductivity may be several orders of magnitudes higher than that of the good solid conductors.

Renewable energy is a high profile and rapidly emerging technology which is attracting financial incentives. While waste heat found in the exhaust gas of various processes such as pyrolysis and can be used to heat the water. This is one of the basic methods for recovery of waste heat. Currently, there are many different technologies in operation. However, heat pipes are more desirable than conventional systems, when considering system efficiency, reliability, and the ease and cost of manufacturing.

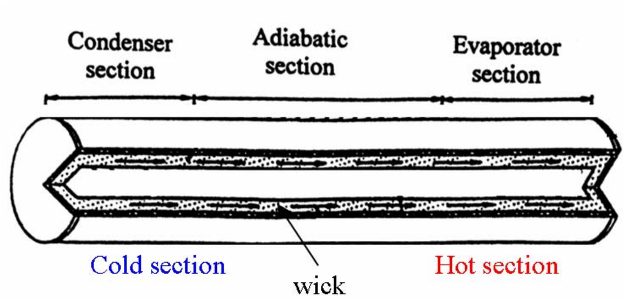
Heat pipes are also one of the most effective devices for waste heat recovery. A major advantage of using heat pipes over conventional methods is the possibility to transport large quantities of heat through a small cross-sectional area over a considerable distance with no additional power input to the system. Furthermore, simplicity of design and manufacturing, small end-to-end temperature drops, maintain performance over a wide temperature range and the ability to control and transport high heat rates at various temperature levels are unique features of heat pipes [1-3]. There are many researches presented the heat transfer characteristics of the heat pipe [4-7].

Although the operating condition of a heat pipe is simple, its appropriate design and construction is complicated. In order to recover waste heat from the pyrolysis stack, the parameters concerned should be controlled and experimental investigations are very important.

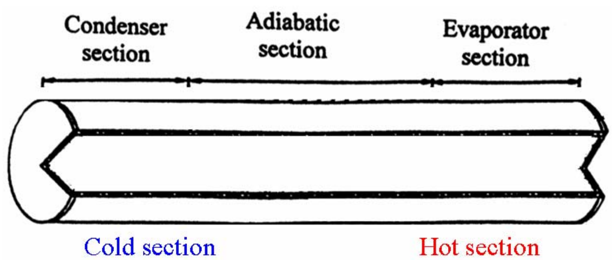
In this research, the air-to-water heat pipe heat exchanger is designed, constructed and tested under operating conditions of pyrolysis oven, using water as the working fluid. Effects of water flow rate, heat pipe tilt angle and heat pipe configuration (wick and wickless) on the thermal efficiency of heat pipe are considered. In order to reduce the impact of temperature fluctuation, the operating temperature of the pyrolysis stack is maintained over a range of from 200°C to 220°C.

2. Experimental Apparatus and Procedure

The heat pipes both wicked and wickless types are designed and manufactured to carry out the tests depicted in Figure 1. The heat pipe is fabricated from the straight copper tube with the outer diameter and length of 15and 500mm, respectively, as shown in Figure 2.



Wick heat pipe



Wickless heat pipe

Figure 1. Wicked and wickless heat pipes

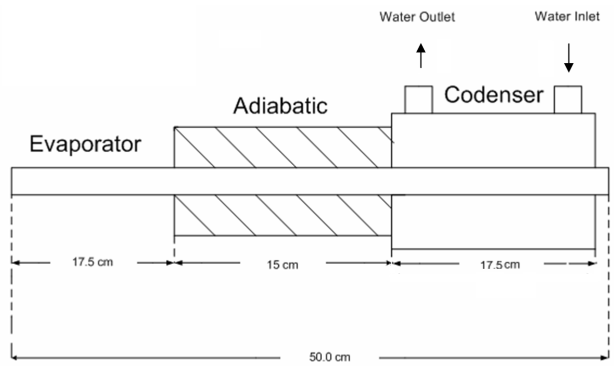


Figure 2. The heat pipe dimensions

Before being charged, the pipe is cleaned thoroughly with methanol to remove any traces of fluid, grease, or oil from the inner surface. The heat pipe is then filled using a glass syringe. Vacuum gauges were fitted to both heat pipes (wick and wickless). They were evacuated down to 0.001 mm Hg before filling with their respective fluids. All tubes were sealed by providing vacuum valves after filling. Any leakage during operation would be detected by the vacuum gauges. After charging the heat pipe with the working fluid and purging for non-condensable gases, the heat pipe is prepared for experiments. Fill liquid is distilled water at 50% fill ratio.

The heat pipe is equipped with a total of ten T-Type thermocouples to monitor the temperature distribution along the length of the heat pipe and position in relation to the heat output/input interfaces. Finally, the operating temperature inside the heat pipe is monitored, equipped with a T-Type thermocouple, onto the evaporator (lower) end of the heat pipe. The evaporator end is equipped with a high-temperature pyrolysis stack capable of providing approximately 200°C of temperature into the heat pipe. The condenser section (top) is fabricated to allow for a water flow heat exchanger to be sealed over it. The stack inlet temperature for the high-temperature experiments is around 200°C, and it is around 30°C for the water experiments.

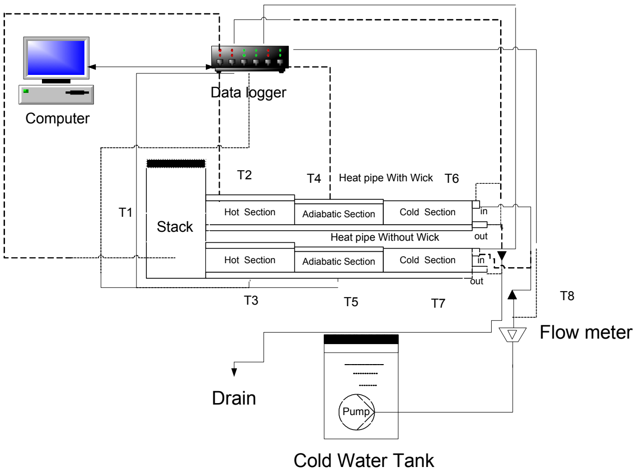


Figure 3. Schematic diagram of the testing facility

A schematic diagram of the experimental apparatus is shown in Figure 3 .The test loop consists of a test section, refrigerant loop, water supplied system and data acquisition system. The water is pumped out of the storage tank, and is passed through a flow meter, test section (condenser section). The flow rates of the cold water are controlled by adjusting the valve and measured by the flow meter.

Experiments were conducted at various water flow rates, and tilt angles of the heat pipe. In the experiments, tile angle of heat pipe is increased in small increments while the supplied temperature of the pyrolysis stack at evaporator section of the heat pipe is kept constant. The temperatures at each position were recorded three times by a data acquisition system.

3. Results and Discussion

The operation test was conducted to study the efficiency of the heat pipe by using two different heat pipe configurations (wick and wickless), with heat pipe tilt angle of 0-90° at water flow rate 0.5, 1.0, and 1.5 l/min.

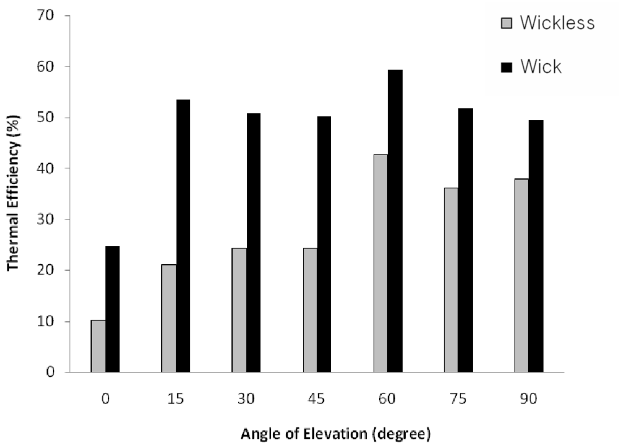


Figure 4. Variation of heat pipe thermal efficiency with tilt angle of heat pipe at water flow rate of 0.5 l/min

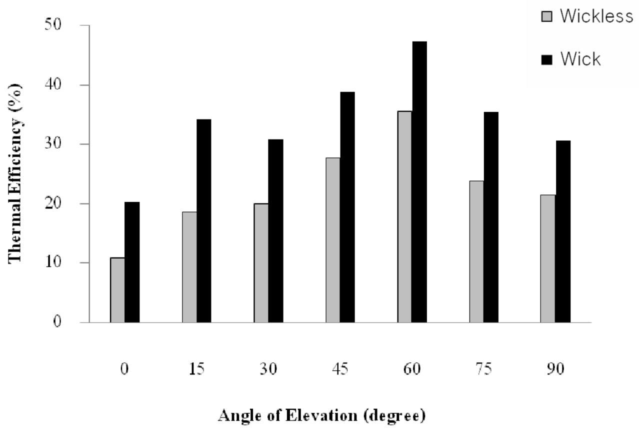


Figure 5. Variation of heat pipe thermal efficiency with tilt angle of heat pipe at water flow rate of 1.0 l/min

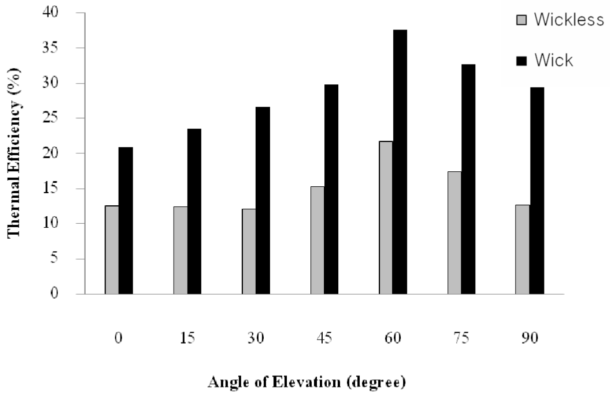


Figure 6. Variation of heat pipe thermal efficiency with tilt angle of heat pipe at water flow rate of 1.5 l/min

Figures 4-6 show the variation of heat pipe thermal efficiency with heat pipe tilt angle of heat pipe with wick and wickless, respectively. It is found that the heat pipe efficiency relates to tilt angle. This is because the gravitational force has a significant effect on the thermal efficiency of the heat pipe. For both heat pipe configuration (wick and wickless), when the heat pipe has a tilt angle of 60°, the heat pipe will has maximum thermal efficiency. Moreover, the results found that the water flow rate influences the pipe thermal efficiency as shown in Figure 7. It is found that when the heat pipe tilt angle is kept constant at 60°, the heat pipe thermal efficiency increases with decreasing water flow rate.

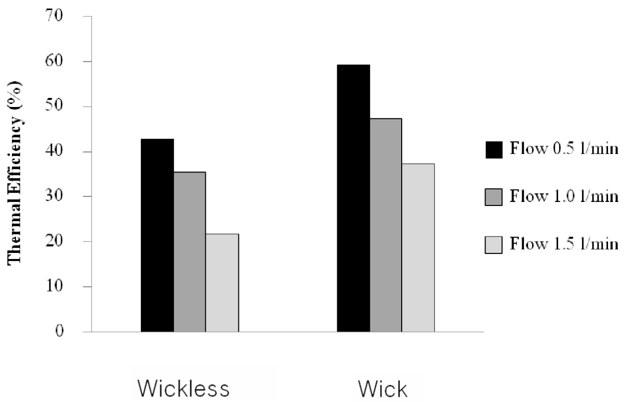


Figure 7. Variation of heat pipe thermal efficiency with heat pipe configuration (wick and wickless) for different flow rate

For comparison of thermal efficiency of heat pipe with wick and wickless, it is found that the thermal efficiency of heat pipe with wick is obviously greater than in the case of the wickless heat pipe.

4. Conclusion

This paper investigated the experimental study on waste heat recovery from the pyrolysis stack using heat pipe both with wick and wickless. The results showed that, for both heat pipe configuration (wick and wickless), the heat pipe has maximum thermal efficiency when the heat pipe has a tilt angle of 60° and thermal efficiency of heat pipe with wick heat pipe is greater than in the case of the wickless heat pipe. The heat pipe with wick achieves thermal efficiency 25-40% higher than that of the wickless heat pipe by enhancing the capillary action of the fluid to the evaporator side and helps the fluid adhere to the internal walls of the tube to increase surface area. The results of this study clearly support widening the application of heat recovery of a stack by using a heat pipe to use with water heating system in the general way. Future research should develop the unit in industrial level.

5. Acknowledgment

The authors wish to express their sincere to Dr. Sombat Teekasap, Sitthichai Wanasit, Phanupong Roipila, and Pongsak Intawong of the mechanical engineering department, Eastern Asia University for helping us with this research. The authors wish to express our gratitude to Eastern Asia University for all its support.

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