Research Journal of Applied Sciences 11 (1): 1-6, 2016
ISSN: 1815-932X

Thermosyphon Heat Exchanger for Cooling of Hydraulic Oil in Sugarcane Harvester

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Abstract: This research aims to study the application of a thermosyphon heat exchanger for cooling of hydraulic oil in sugarcane harvester. The objective was to control hydraulic oil temperature to reduce an over-heat problem for the engine and the hydraulic system. The thermosyphon heat exchanger was made of 90 copper tubes with inner diameter of 18 mm. The evaporator and condenser section length were equal to 200 mm and adiabatic section length of 100 mm. R134a, ethanol and water were used as working fluids with a filling ratios of 30, 50 and 80% by total volume. The air flow rate inlets at the condenser were 2.3, 2.6 and 2.8 m $\sec^{-1}$. In the testing, hot hydraulic oil passed through the evaporator section and air passed through the condenser section. The results show that the thermosyphon heat exchanger reduced the hydraulic oil temperature from 80 to 62°C. The maximum heat transfer rate and effectiveness were occurred as an air velocity of 2.3 m $\sec^{-1}$ with R134a as working fluid and filling ratio of 50% by total volume.

Key words: Themosyphon, hydraulic system, sugarcane harvester, evaporator, ethanol

INTRODUCTION

Sugarcane is the important raw material for sugar manufacturing. The Northeast region of Thailand is considered to be the large producer of sugarcane (Sornpoon *et al*., 2014). Thai agriculture of Thailand relies heavily on human labor which results in low productivity so it wastes a lot of time on working process. Labor shortage tends to be a serious problem, cost of labor and rapid agricultural industrial development. Resulting development of the agricultural machinery used to harvest (Moontree *et al*., 2012). Sugarcane harvester is a great advantage to harvest for lagers region. The hydraulic system of several sugarcane harvesters was to lift, break and transmission mechanism. For the ordinary function, the sugarcane harvester was operated over 8 h a day. Those make the hydraulic oil become over heat or long time heated operation which has oil temperature should not exceed 80°C. The temperature ranging from 60-70°C are the best working conditions for the hydraulic system due to constant pressure (Khridsadakhon, 2007). According this subject, the failure of the hydraulic parts was usually found, leak of the seal, leak of the pipe or joint, the degradation of the strainer. Moreover, the high heating operations under the long time, the hydraulic oil will rapidly degradation. For solving this problem, the oil cooler was applied to a sugarcane harvester. The thermosyphon has been proved as a promising heat transfer device with very high thermal performance. It consists of three parts which include the evaporator, adiabatic and condenser section. Thermosyphon is a closed container charged with the working fluid. Here, the heat is applied to the evaporator section which causes the working fluid to vapourize and moves upwards to the condenser section. After that, the vapour transfer the heat to a heat sinks such fresh air. As a result, the vapour condenses to a liquid goes down along the surface of the tube wall to evaporator section due to gravitational force.

The thermosyphon has been proved to be a promising heat transfer device with very high thermal conductance. A two-phase closed thermosyphon is used to transfer a large amount of heat at a higher rate with a small temperature difference. Thermosyphons are being used in many applications such as electronic cooling (Toyoda and Kondo, 2013), waste heat recovery (Yodrak *et al*., 2011), solar collector (Liu *et al*., 2012) and air condition system (Ma *et al*., 2013). Moreover, the

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thermosyphon can be used to directly heat, these systems do not use any external source for power to reducing energy consumption.

As of the many advantages of the thermosyphon, the objective of this paper was to study the application of a thermosyphon for control oil temperature in hydraulic system of the sugarcane harvester at working temperature about 60°C.

MATERIALS AND METHODS

Thermosyphon Heat Exchanger (TPHE): Figure 1 shows a sugarcane harvester using small engine with its width of 1.4 m, length of 2.6 m, engine of 90 hp engine (67 kW) at 2500 rpm and the machine has the ability of 40-50 tons of sugarcane per day. A harvester is designed for a small-farming group, low cost and the labor shortage tends to be a serious problem (Moontree, 2010). When the sugarcane harvester was operated a long time caused over-heating of the hydraulic oil. Figure 2 shows Thermosyphon Heat Exchanger (TPHE) designed for cooling hydraulic oil of sugarcane harvester. The physical parameters of the thermosyphon heat exchanger are also shown in Table 1. TPHE was made of copper tubes with inner diameter of 18 mm and the evaporator and condenser equal length of 200 mm. The TPHE heat exchanger in this experiment was designed under condition for reducing temperature of hydraulic oil if sugarcane harvester from 80 to 60°C. From these conditions, the heat transfer rate will be calculated from modeling of the heat transfer rate (Anonymous, 1980) after that the number of installed thermosyphons in the heat exchanger can be solved. It can be formulated as the correlation of the actual heat transfer (Q), the total thermal resistance (Z_{total}) and the temperature difference between the heat source and the heat sink (ΔT) as follows:

$$Q_{Th} = \frac{\Delta T}{Z_{total}}$$

The overall thermal resistance can be represented by an idealized network of thermal resistances Z_1-Z_{10} as shown in Fig. 3 and can be divided into three groups. Each of the resistances can be explained as:

- External resistance (Z_1 and Z_9)
- Resistance from material property (Z_2 and Z_8)
- Internal resistance (Z_3, Z_4, Z_5, Z_6, Z_7)

$$Z_{total} = Z_1+[(Z_2+Z_3+Z_4+Z_5+Z_6+Z_7+Z_8)^{-1}+(Z_{10})^{-1}]^{-1}+Z_9$$

Fig. 1: Small sugarcane harvester

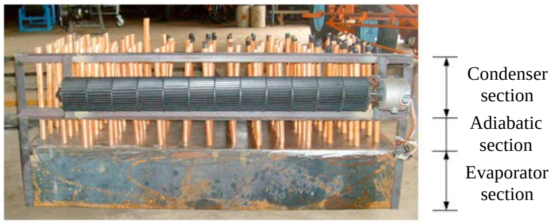

Fig. 2: Thermosyphon heat exchanger

Table 1: The physical parameters of the thermosyphon heat exchanger

Items	Details
Material	Copper tube
Evaporator and condenser length	200 mm
Adiabatic length	100 mm
Diameter of thermosyphon	18 mm
Arrangement	Staggered array, $S_L = S_T = 80$ mm
Number of tube row	9
Number of column	10
Working fluids	R134a, ethanol and water
Filling ratio of working fluid	50% of evaporator section
Flow arrangement	Counter flow
Total number of the thermosyphons	90 tubes

Experimental set-up: Figure 4 and 5 show the experimental setup. In order to study the thermosyphon heat exchanger TPHE, for cooling hydraulic oil, the TPHE was installed at hydraulic system of sugarcane harvester. Hundred thermosyphons attached to a pass condenser and evaporator section using water, ethanol and R134a as a working fluid with a filling ratio of 30, 50 and 70% of evaporator volume having a 6×15 staggered tube bank arrangement. The temperature at the hydraulic oil inlet to the evaporator section was 80°C while another centrifugal fan used for cool air to flow through the condenser section of 2.3, 2.6 and 2.8 m sec^{-1} and cool air was measured by a pitot tube (Testo 445 with ±0.1 m sec^{-1} accuracy). The inlet and outlet temperatures of the condenser sections were measured using type-K thermocouples (Omega with ±1°C accuracy). When

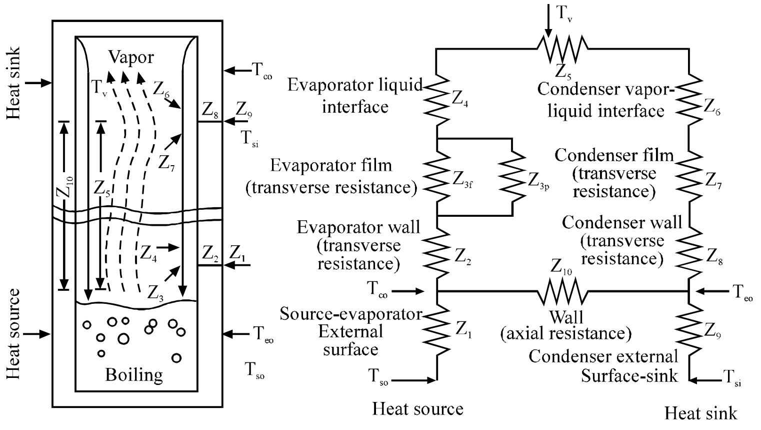

Fig. 3: Schematic of the thermosyphon and thermal resistance network

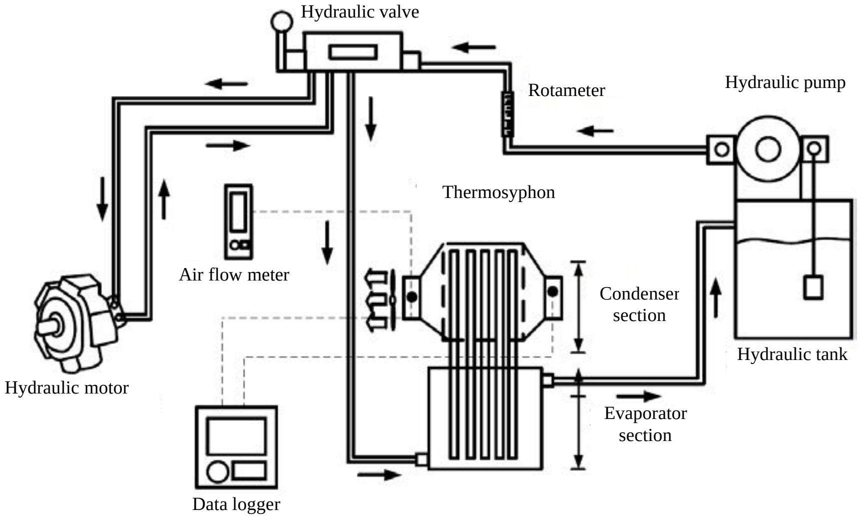

Fig. 4: Schematic diagram of the experimental set-up

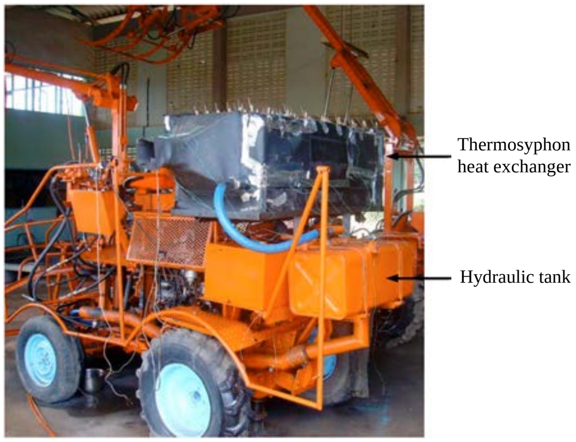

Fig. 5: The prototype: thermosyphon heat exchanger and experimental rig

steady state was achieved, the temperature at the inlet and outlet of condenser sections was recorded by a data logger (Yokogawa DX200 with ±0.1°C accuracy, 20 channel input and -200 to 1100°C measurement temperature rang). The following equations were used to calculate the heat transfer rate (Q) and the effectiveness (ε) are given by:

$$Q = \dot{m}C_p(T_{co}-T_{ci})$$

And:

$$\varepsilon = \frac{Q}{Q_{max}} = \frac{\dot{m}C_p(T_{co}-T_{ci})}{C_{min}(T_{hi}-T_{ci})}$$

Where:

m = Mass flow rate (kg/sec)

C_p = Specific heat capacity (kJ/kg °C)

T_{ci} and T_{co} = Inlet and outlet temperature of condenser section, respectively

C_{min} = Minimum heat capacity (kJ/°C sec)
T_{hi} = Inlet temperature of evaporator section

RESULTS AND DISCUSSION

The thermosyphon heat exchanger reduced the hydraulic oil temperature from 90 to 70°C. The maximum heat transfer rate of 8.84 kW/m^2 and effectiveness of 0.42 was occurred as an air velocity of 2.3 m sec^{-1} with R134a as working fluid and filling ratio of 50% by total volume. The results as follows:

Effect of air velocity on heat transfer rates and effectiveness: Figure 6 and 7 show the effect of air velocity on heat transfer rate and effectiveness. In the condenser section, the air velocities were 2.3, 2.6 and 2.8 m sec^{-1} with R134a, ethanol and water as working fluids. It was found that when the air velocity decreased from 2.8, 2.6 and 2.3 m sec^{-1} with R134a as working fluid, the heat transfer rate (8.85, 6.94 and 6.54 kW, respectively) and the effectiveness also rises (0.42, 0.38 and 0.32, respectively). This is because the hot-air inlet-temperature increases with a lower velocity, the air outlet-temperature also increases. Thus, the temperature difference between the inlet and the outlet air-temperature also increases and the actual heat-transfer rate will be high. Moreover, at the lower air velocity, the capacity was absorb large amounts of heat. On the other hand, when the air velocity of condenser section increased, the TPHE ability was received heat is reduced.

Effect of filling ratios on heat transfer rates and effectiveness: Figure 8 and 9 show the effect of filling ratio on heat transfer rate and effectiveness. The fill ratio was varied from 30, 50 and 70% of evaporator volume with R134a, ethanol and water as working fluids. It was found that the maximum heat transfer rate and effectiveness (8.85 kW and 0.42, respectively) was occurred at the filling ratio of 50% with R134a as working fluid. Filling ratios of 30 and 70% presumably caused dry out and flooding of the evaporator (Noie, 2005; Ong *et al*., 2014). At low fill ratio (30% of evaporator volume), dryout occurring for the filling ratio is relatively small when the working received heat from a heat source at evaporator secion, the vapor flowing from the evaporator to the condenser section. The condensate falls down along the wall and reaches the evaporator and the thickness of the condensate film is thinner. It eventually dries out. At high fill ratio (70% of evaporator volume), flooding occurring for the filling ratio is relatively high when the generated vapor then moves upwards to the condenser section. The condensate film flowing downward on the tube surface

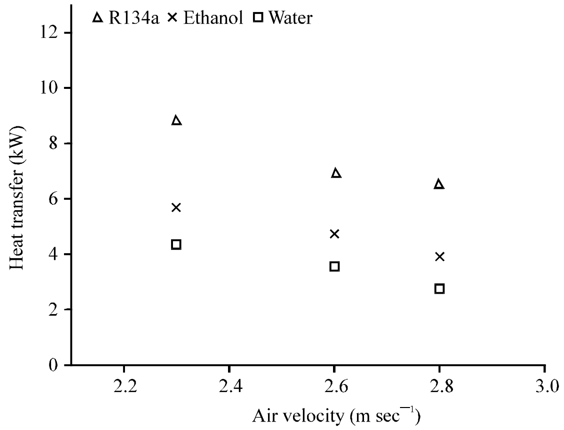

Fig. 6: Effect of air velocity on heat transfer rate of TPHE heat exchanger

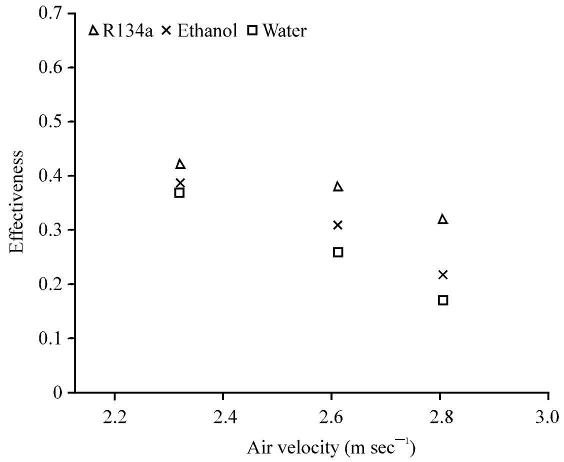

Fig. 7: Effect of air velocity on effectiveness of TPHE heat exchanger

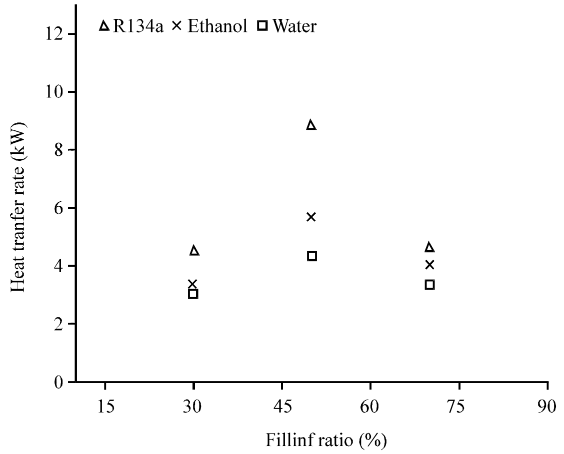

Fig. 8: Effect of filling ratios on heat transfer rate of TPHE heat exchanger

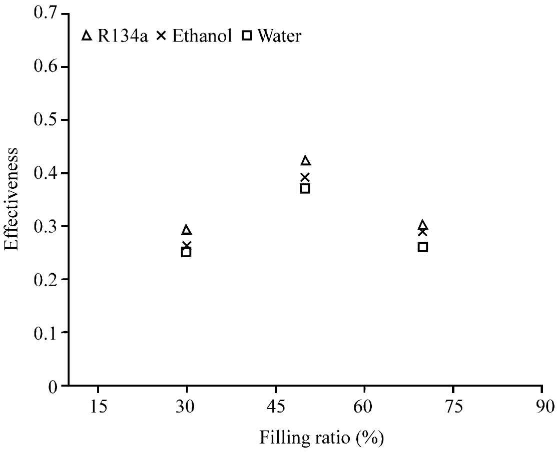

Fig. 9: Effect of filling ratios on effectiveness of TPHE heat exchanger

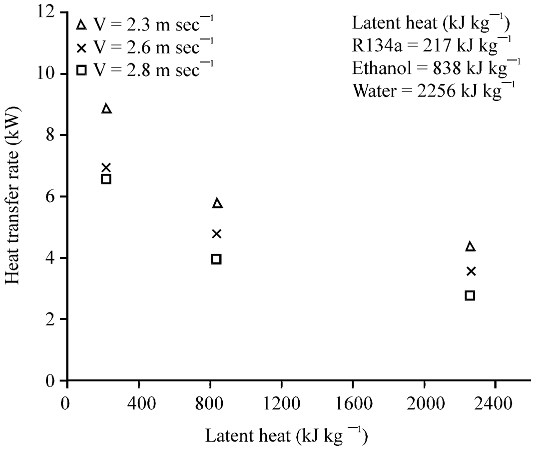

Fig. 10: Effect of working fluids on heat transfer rate of TPHE heat exchanger

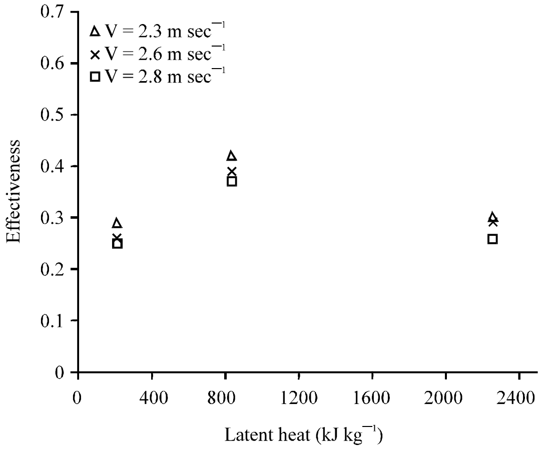

Fig. 11: Effect of working fluids on effectiveness of TPHE heat exchanger

and vapor flow by a high value moving upward through the tube coreand shear forces from counter flowing vapor, the flooding limit occurred.

Effect of working fluid on heat transfer rates and effectiveness: Figure 10 and 11 show the effect of working fluid on heat transfer rate and effectiveness. R134a, ethanol and water were used as working fluids. It was found that the highest heat transfer rate and effectiveness when R134a was used as the working fluid in the TPHE heat exchanger. This is beacause the latent heat of vaporization is the major property that has the greatest effect on the generated vapor to the condenser section. When heat is applied to the evaporator section, R134a as working fluid cause rapid evaporation. As results, the heat transfer rate and effectiveness were increases.

CONCLUSION

In this research, application of the thermosyphon heat exchanger for cooling of hydraulic oil in sugarcane harvester. Major results are summarized as follows:

- The thermosyphon heat exchanger reduced the hydraulic oil temperature from 80 to 62°C from the maximum heat transfer rate of 8.84 kW/m^2 and effectiveness of 0.42 was occurred as an air velocity of 2.3 $m\ sec^{-1}$ with R134a as working fluid and filling ratio of 50% by total volume
- The air velocity decreased from 2.8, 2.6 and 2.3 $m\ sec^{-1}$, the heat transfer rate (8.85, 6.94 and 6.54 kW, respectively) and the effectiveness also rises (0.42, 0.38 and 0.32, respectively)
- The maximum heat transfer rate and effectiveness (8.85 kW and 0.42, respectively) has occurred at the filling ratio of 50% with R134a as working fluid. Moreover, filling ratios of 30 and 70% presumably caused dry out and flooding phenomena
- The highest heat transfer rate and effectiveness when R134a was used as the working fluid in the TPHE heat exchanger

ACKNOWLEDGEMENT

The research has been supported generously by Heat Pipe and Thermal Tool Design Research Unit (HTDR), Faculty of Engineering, Mahasarakham University, Mahasarakham, Thailand.

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