20th Australasian Fluid Mechanics Conference
Perth, Australia
5-8 December 2016

# CFD-Simulation on the Effect of Heat-Pipes Attached to an Evaporator and Condenser of an Air-Cooled-Air-Conditioner.

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## Abstract

Cooling technology with normal vapour compression cycle relies on electricity to increase and decrease the pressure hence the temperature, within its cycle. Passive cooling using heat pipe heat exchangers is being applied to the refrigeration cycle components to assist with temperature reduction of the cooling process. The return and supply air temperatures of an evaporator and condenser are being precooled by passive cooling equipment to assist in reducing the compressor work done. Computational fluid dynamics software is being used to run simulations and results are presented in terms of temperature, contour, velocity vectors and flow patterns. The objective of this study is to investigate and simulate air around a circular air cooled evaporator and condenser tube for an air conditioning system. The tube from the evaporator is a row of five copper tube (10mm OD) exposed to a room temperature of 297K and the tube for the condenser is exposed to an ambient air of 300K. The system is set to an evaporating temperature of Te=278K and the condensing temperature of Tc=319K. An air gap between the heat pipe heat exchanger and the tube where the simulation of heat transfer is assumed to be the key process is discussed. The end results of the air outlet of the evaporator and condenser with the effect of the heat pipe heat exchanger attached to it are discussed. It is found that the operating temperature reduced when a heat pipe heat exchanger is attached to the components. Increasing the heat transfer rate between the heat pipe and the component's tube will increase the system capacity.

## Introduction

Heat exchangers play an important role in the refrigeration cycle to absorb and remove the heat of indoor to the outdoor, or vice versa. A refrigerant is compressed by a compressor for the purpose of increasing its pressure and temperature compared to the ambient condition. Heat transfer between the ambient airs occurs on the condenser surfaces when removing heat and turns the refrigerant inside the condenser tube to the liquid phase of a reduced temperature. Adversely, the expansion valve drops the refrigerant temperature in the evaporator to absorb the room heat, and in the process turns the liquid to vapour phase.

The heat pipe heat exchanger is a device that transfers the surrounding heat by absorbing and desorbing heat through its tube. Tubes are filled with refrigerant, to be evaporated and condenses from liquid to vapour state from one end of the tube to the other. In the evaporator section of the tube, the cool refrigerant liquid absorbs the surrounding heat and evaporates the liquid into vapour. The evaporated vapour moved to the condenser section of the tube and releases the heat to the surrounding, which in turns condenses the refrigerant vapour back to a liquid phase. With gravitational force and the capillary action of a wick inside the tube, the liquid moves back to the evaporator section and repeat the cycle. In a steady state operation, a heat pipe with a metal working fluid will have a high thermal conductance compared to a solid metal conductor. Among the unique characteristics of a heat pipe are a small temperature drop, wide temperature application range and the ability to control and transport high heat rates at various temperature levels [1]. Although heat pipe heat exchanger had been applied in a variety of heating, ventilation and air conditioning system and energy recovery process, but only the application to the refrigeration cycle will be discussed in this paper. A numerical study using ANSYS Fluent and CFD-ACE + are being used to view the behaviours of refrigerant R134a, the heat transfer medium in the tubes, the temperature profile of the air passing through the heat pipes and then through the refrigeration condenser and evaporator.

## 1. Application of Heat Pipe Heat Exchanger Attached to a Condenser and Evaporator Coils in a Refrigeration System

Heat pipes were capable of converting a differential change of heat by transferring heat to one end to the other. Ong et al [2] made an experiment with long heat pipes air heat exchangers, and compared the bath temperature to the evaporator temperature and recorded a differential of 1K to 5K. Tom Brooke [3] experimented an air conditioning system with a wraparound heat pipe installed, and found that the air can be pre-cooled from 35°C (308K) to 25.8°C (298.8K) and can be re-heat from 12.8°C (285.8K) to 22.8°C (29508K). Figure 1 shows the heat pipe technology and the model of heat pipes used.

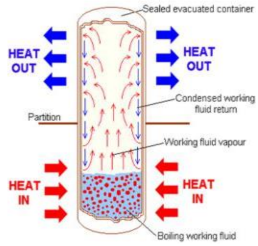



Figure 1: The Heat Pipe Heat Exchanger. The refrigerant liquid in the heat pipe heat exchanger at the bottom of the tube absorbed heat at the evaporator section and release it at the condenser at the upper section. The liquid evaporates to vapor phase in the evaporator and move towards the condenser section, which in turns change back to liquid phase by releasing the heat to the surrounding.

## 2. Problem Description

An air-cooled refrigeration cycle condenser coil of 319K and an evaporator of 278K are being simulated. In the condenser coils, the condensing temperature drops from 319K to 315K while the evaporating temperature increase from 278 to 282K. Suggested by [4], [5], author used the maximum temperature of 319K for the condensing temperature and 278K for the evaporating temperature. A heat pipe heat exchanger is installed 100mm before the coils and act as a heat sink to reduce the air temperature and pre-cooled the flowing air. Attaching the heat pipe to the front air intake of the refrigeration coils will have lowered the ambient air temperature before touching the surface of the coils. Passive cooling technologies had been studied by [6], [7], [8], and [9] has proposed a passive cooling system technology using methanol as the cooling medium. This 2D computational study focused on air flows, crossing a condenser and an evaporator. Only the evaporator side of the heat pipe heat exchanger which absorbs the surrounding heat is shown in the simulation. The condenser side of the heat pipe is separated on the outside ambient air to release heat out. Three model of each coil are simulated; a simulation of a coil for reference, a heat pipe attached close to the coil and a heat pipe separated 100mm away from the coil by monitoring the air outlet that crosses the heat pipe and crossing off the coils. Figure 3 shows the proposed idea of a closed tube heat pipe heat exchanger with R134a as a refrigerant medium, used to transfer heat from one end to the other, attached to a coil side of a refrigeration system.

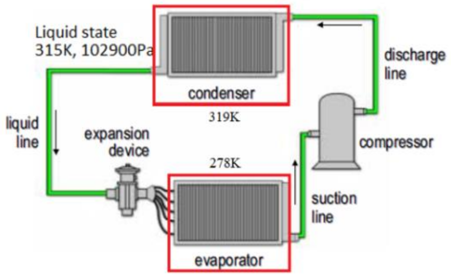



Figure 2: The Refrigeration Cycle. The condenser coil is a heat exchanger used to reject heat of the refrigerant to the surrounding. The evaporator coil absorbs room heat and lowers the room temperature.

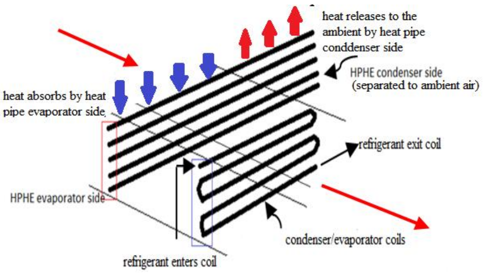



Figure 3: Schematic of a refrigeration coil with the application of straight horizontal heat pipe showing the inlet and outlet of air paths. An evaporation temperature of 295K is being used for the simulation of heat pipe heat exchanger.

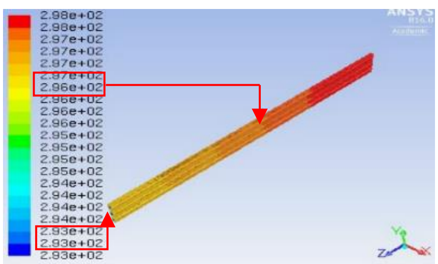


Figure 4: Simulation on heat pipe heat exchanger by ANSYS Fluent using R134a as a medium. The average temperature taken at the evaporator side of the heat pipe is taken as 295K.

## 3. Simulation Models/Mesh

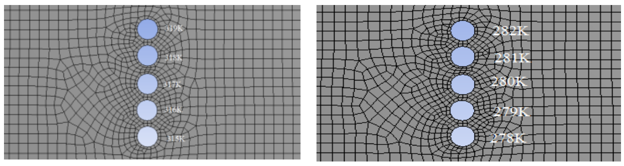
Several attempts are taken when testing with the mesh distribution as at Table 2 and Figure 5 to 7. A small number of meshes cells is used for the 2D simulation although the mesh grid sizing is set to fine. Some grid convergence tests have been performed to ascertain the adequacy of grid pattern used.

| Domain | Specification |
|---|---|
| **Case 1** | Air at 300K flows on the surface of an air cooled condenser/evaporator. |
| **Case 2** | Air at 300K flows on the surface of a heat pipe and a condenser/evaporator that is attached closely together. |
| **Case 3** | Air at 300K flows on the surface of a heat pipe and a condenser/evaporator that are separated 100mm apart. |

Table 1: Problem description for all cases

| Domain | Nodes | Elements |
|---|---|---|
| **Case 1a, b** | 1572 | 1447 |
| **Case 2** | 1817 | 1643 |
| **Case 3** | 1623 | 1455 |

Table 2: The specification of nodes and elements for condenser




Case 1a Case 1b

Figure 5: Case 1a for condenser and 1b for evaporator.

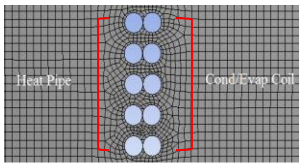



Figure 6: Case 2.

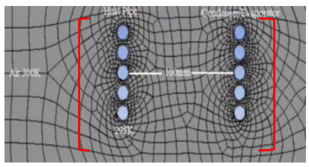


Figure 7: Case 3.

## 4. Boundary Conditions

| Domain | Heat Pipe + Condenser/Evaporator |
|---|---|
| **Dimension 2D** | Serial Options |
| **General** | Pressure based, Absolute velocity, Time: steady, 2D planar, Gravity: Y direction -9.81 $m/s^2$ |
| **Model** | Energy: on, Viscous: standard k-ε |
| **Material** | Fluid: air, Solid: copper |
| **Boundary conditions** | Velocity magnitude: 1m/s, Thermal: 300K. Pressure outlet, Back pressure: 300K. Condenser tube temp 315K to 319K. Heat pipe tube temp 295K |
| **Wall** | Surface body: stationary wall, No slip |
| **Solution Methods** | Scheme: simple, Gradient: Least square cell based, Pressure: Standard, Momentum: Power law, Energy: Power law |

Table 3: Boundary condition runs on ANSYS Fluent.

The 3D Navier-Stokes continuity and energy equation are used as the mathematical model for the computational solution for turbulent flow as suggested by [10], [11] and [12];

$$\frac{\partial U_j}{\partial x_j} = 0 \tag{1}$$

$$\frac{\partial U_i}{\partial t} + U_j\frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\nu\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) - \overline{u_i u_j}\right] - \beta(T - T_{ref})g_i \tag{2}$$

$$\overline{-u_i u_j} = \nu_t\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) - \frac{2}{3}K\delta_{ij}$$

$$\rho c\left(\frac{\partial T}{\partial t} + U_j\frac{\partial T}{\partial x_j}\right) = k\frac{\partial^2 T}{\partial x_j \partial x_j} - \rho c\frac{\partial}{\partial x_j}\left(\overline{u_j T'}\right) + \Phi + \emptyset \tag{3}$$

$$\overline{u_j T'} = \frac{\nu_t}{\sigma_t}\left(\frac{\partial T}{\partial x_j}\right)$$

$$\Phi = \mu\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\frac{\partial U_i}{\partial x_j}$$

$$\emptyset = \mu\left[\overline{\left(\frac{\partial u_i}{\partial x_j}\right)\left(\frac{\partial u_i}{\partial x_j}\right)} + \overline{\left(\frac{\partial u_i}{\partial x_j}\right)\left(\frac{\partial u_j}{\partial x_i}\right)}\right]$$

$$\frac{\partial K}{\partial t} + U_j\frac{\partial K}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\nu + \frac{\nu_t}{\sigma_K}\right)\frac{\partial K}{\partial x_j}\right] + \nu_t\left[\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\frac{\partial U_i}{\partial x_j} + \frac{\beta}{\sigma_t}g_j\frac{\partial T}{\partial x_j}\right] - \varepsilon \tag{4}$$

$$K = \frac{1}{2}\overline{U_i U_j}$$

$$\varepsilon = \nu\,\overline{\left(\frac{\partial u_i}{\partial x_j}\right)\left(\frac{\partial u_i}{\partial x_j}\right)}$$

$$\frac{\partial \varepsilon}{\partial t} + U_j\frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\nu + \frac{\nu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + C_1\frac{\varepsilon}{K}\nu_t\left[\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\frac{\partial U_i}{\partial x_j} + \frac{\beta}{\sigma_t}g_j\frac{\partial T}{\partial x_j}\right] - C_2\frac{\varepsilon^2}{K} \tag{5}$$

Where subscript t refers to turbulence

$$\mu_t = \rho C_\mu K^2/\varepsilon\,;\; \nu_t = \mu_t/\rho;$$

Cμ=0.09; C1=1.44; C2 =1.92; σK =1.0; $\sigma_\varepsilon$=1.3; reference temperature = 300K. For the simulation, the pressure assumed to be constant, the K and ε value at inlet used;

$$K = \frac{3}{2}(U_{ave}T_i)^2 \tag{6}$$

$$\varepsilon = \frac{C_\mu^{3/4}K^{3/2}}{KL} \tag{7}$$

Where $U_{ave}$ is inlet velocity, $T_i$ is turbulence intensity (here taken to be about 2%), $L$ is here taken to be a "reasonable length" of 1m and κ = 0.41 is the Von Karman constant.

## 5. Solver

ANSYS Fluent solver is used in this case, to solve the governing equations that are related to the flow physic problem, based on the given material properties, flow physic model and the boundary conditions. All properties and conditions are satisfactorily converging using Finite Volume Method to solve velocity components, pressure and k - ε (epsilon) scheme.

Fluid properties used for simulation process with heat pipe heat exchanger are corresponding to constant air at 293K. Several attempt using water, acetone and R134a were simulated. To show the flow of the air when moving passing the tube, a 0.2 m/s of flow rate are applied. Fluid properties used in the heat pipe-condenser simulation processes are corresponding to constant air at 300 K and standard pressure at sea level of 101.3 kPa, where the temperature inlet through the heat pipe heat exchanger is assumed to be 300 K and the ventilation flow is assumed to be in +X direction. Boussinesq approximation where the fluid density concerning the buoyancy force is affected by temperature change is assumed, with reference temperature $T_{ref}$ is 300K and Vol. Coef. Th. Exp. is 0.003333 1/K. Other molecular properties include ρ = 1.1614 kg/m3, μ = 1.846 x 10-5 N-s/m2, ν = 1.589 x 10-5 m2/s.

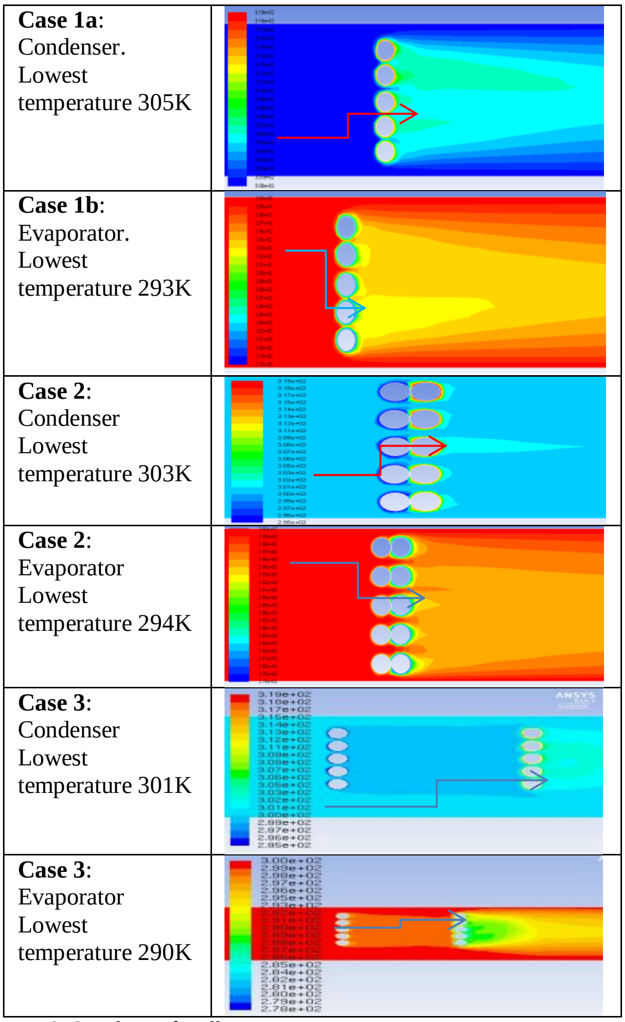


Figure 8: Simulation for all cases.

## 6. Result And Discussion

The purpose of this study is to study the temperature decreasing effect of a heat pipe heat exchanger by simulating an air flow to an air cooled air-conditioner coils. Heat pipe is being used to investigate the possibilities of reducing supply air temperature to the coils. The flow pattern is recorded by simulation software ANSYS Fluent. Previous simulation shows a difference of 5K is obtained when R134a is used as a refrigerant medium in the heat pipe. From the simulation of heat pipe to the coils of an air cooled system, it is found that efficiency can be increased with the attachments of the heat pipe to the inlet of an air flow of coils. When simulated, an air cooled condenser is recorded to reject heat at about 12K to 15K, and the evaporator coils lowered to 8K. Table 5 shows the inlet and outlet temperature profile of three cases to point out the capability of heat pipe in transferring heat.

| Condenser | Case 1 | Case 2 | Case 3 |
|---|---|---|---|
| Inlet, K | 300 | 300 | 300 |
| HP, K | | 295 | 295 |
| Cond. $T_c$ K | 315-319 | 315-319 | 315-319 |
| Outlet, K | 305-307 | 303-304 | 301-303 |
| Different, K | 10 | 12 | 14 |

Table 4: The table shows the comparison of temperature different between cases at a condenser coils. Case 3 shows the best result.

| Evaporator | Case 1 | Case 2 | Case 3 |
|---|---|---|---|
| Inlet, K | 300 | 300 | 300 |
| HP, K | | 295 | 295 |
| Evap. $T_e$ K | 278-282 | 278-282 | 278-282 |
| Outlet, K | 293-294 | 294-295 | 290-292 |
| Different, K | 11 | 12 | 8 |

Table 5: The table shows the comparison of temperature different K between cases at an evaporator coils. Case 3 shows the best result.

Base on the pressure-enthalpy diagrams of an air cooled refrigeration system corresponding to an evaporating temperature of $T_e$ = 5°C (278K), condensing temperature $T_c$ = 46°C (319K) [14], with 10K superheat and 20K sub cooling; compared to a condensing temperature of $T_c$'= 32°C (305K) using heat pipe, the work done can be calculate as;

Evaporator work done $Q_e = h4 - h1$ (8)

Condenser work done, $Q_c = h3 - h2$ (9)

Compressor Work Done, $W = h2 - h1$ (10)

Coefficient of performance, $COP = h4 - h1 / h2 - h1$ (11)

| Parameters | Coils | HP + Coils |
|---|---|---|
| Evaporating $T_e$ (°C) | 5 | 5 |
| Condensing $T_c$ (°C) | 46 | 32 |
| Condenser Surface Temp (°C) | 58 | 45 |
| Superheat (different K) | 10 | 10 |
| Sub cooled (different K) | 20 | 20 |
| Evaporator Work Done $Q_e$ (kJ/kg) | 173.8 | 193.3 |
| Condenser Work Done $Q_c$ (kJ/kg) | 200.5 | 211.7 |
| COP | 6.5 | 10.5 |
| Compressor Work Done W (kJ/kg) | 26.73 | 18.42 |

Table 6: The table shows the comparison of normal refrigeration cycle compared to coils with heat pipe.

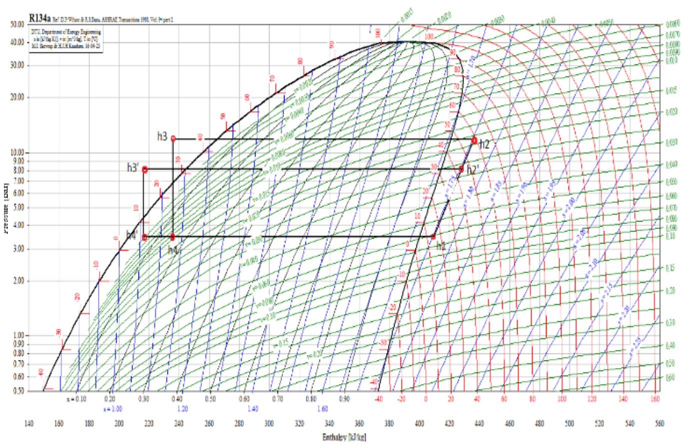



Figure 9: Pressure enthalpy chart of an air cooled condensing system compared to a system attched with a heat pipe heat exchanger.

## 7. Conclusion

From the refrigeration cycle plotted, it is found that, the evaporating capacity and the condensing capacity can be increased, with the fall of condensing temperature $T_c$. The heat pipe effect can be seen more on condenser, rather than the evaporator side of the refrigeration cycle. Heat pipe heat exchanger may be used as one of the solution to decrease the condensing temperature to the ambient. Other simulations using different refrigerant medium in the heat pipe heat exchanger should be tested.

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