



Heat loss from hot water flowing in a copper pipe insulated using air enclosed with a PVC pipe

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ARTICLE INFO

Article History:

Received : 12 June 2017

Accepted : 30 July 2017

Available online: 1 January 2018

Keywords:

Heat loss

Copper pipe

Air

PVC pipe

Critical diameter theory



ABSTRACT

This paper presents investigations of heat loss from hot water flowing in an insulated copper pipe. Investigations were performed to know the heat loss from a copper pipe insulated using air enclosed with a PVC pipe. The fluid temperature used was kept at approximately 75°C in the entrance and its mass flow rate was around 12 g/s. The nominal copper pipe diameter was 6.35 mm; while the diameters of the PVC pipe were ranging from 12.7 mm to 5.08 mm. The length of the test section was approximately 3000 mm. The results show that the biggest heat loss is found using the bare copper pipe. When the copper pipe is insulated using air enclosed with a PVC pipe, the heat loss decreases with the increased PVC pipe diameters. The trend of the heat loss agrees with the critical insulation diameter theory.

INTRODUCTION

Industries need devices to support their works, operations and productions. For example in oil industries, a piping with a good insulation is usually required. Flowing oil from one place to another place at very low ambient temperature needs a pipe with a very good insulation, otherwise, it is frozen and jammed.

Many studies reported investigations on pipe insulations using several different materials, Hiller (2005), Ljubenko et al. (2011), Xiao et al. (2014). Meanwhile, insulations made of polyolefin or polyethylene, with thicknesses of either ½ inch or ¼ inch were also investigated by Hiller (2005). He used the polyolefin because its thermal conductivity was low; it was 0.02 Btu/hr ft F, which was suitable as a thermal insulation. Heat loss from hot water pipe lines had been investigated intensively; see Ljubenko et al. (2011). They suggested that the pipe lines should be covered

using polyurethanes. Furthermore, previous researchers, Xiao et al. (2014) suggested that to reduce the heat loss to the ambient, the pipe lines should be covered using materials that had a low thermal conductivity such as PPR (Polypropylene Random polymer) or plastics that had lower thermal conductivities. The PPR has a thermal conductivity of 0.24 W/m°C. More recent, insulations made of biomass composite were studied by Abdulkareem et al. (2016). They revealed that biomass composite insulations had thermal conductivities ranging from 0.0074 to 0.0127 W/m°C. Those values are lower than air thermal conductivity (0.024 W/m°C). Nevertheless, making biomass insulation is not simple and it should be made in an industry, otherwise, the uniform thickness cannot be obtained. Also, producing biomass insulation can be not as cheap as air insulation.

In hotels, many insulated pipes are used, material had been also reported in a published

Table 1 Properties of the PVC pipe

Property	Rigid PVC	Flexible PVC
Density (g/cm ³)	1.3–1.45	1.1–1.35
Thermal conductivity (W/m K)	0.14–0.28	0.14–0.17
Yield strength (psi)	4500–8700	1450–3600
Young's modulus (psi)	490,000	
Flexural strength (psi)	10,500	
Compression strength (psi)	9500	
Coefficient of thermal expansion (linear) (mm/mm °C)	5×10 ⁻⁵	
Vicat B (°C)	65–100	Not recommended
Resistivity (Ω m)	10 ¹⁶	10 ¹² –10 ¹⁵
Surface resistivity (Ω)	10 ¹³ –10 ¹⁴	10 ¹¹ –10 ¹²

e.g. hot water piping, HVAC (heating venting and air conditioning) piping. However, all insulations used for those purposes have been standardized and they have certain thermal conductivities. Usually their thermal conductivities should be as low as possible. The common materials used as insulation have thermal conductivities ranging from 0.026 to 0.065 W/m°C, see Morvay and Gvozdenac (2008). However, the material that has lower thermal conductivities becomes priority materials for insulations. In this study, the insulations that are examined are air enclosed by a PVC (Polyvinyl chloride) pipe. The reason for this is because of its prize. The air is free; however, the PVC price is still acceptable.

The fundamental purpose of the use of insulations is to prevent the heat leakage. However, in industry the use of insulation does not only consider the heat loss but also the insulation prices. Therefore, the cheapest price and the lowest thermal conductivity of insulation become famous targets for engineers. The price of the PVC pipe depends on the standard, thickness, and the diameter of the pipe. Nevertheless, in this study the PVC pipes used are commercial PVC pipes with the cheapest price. The properties of the PVC pipe are shown in Table 1.

Air as insulation is used in some cases, e.g. double glass windows, double walls, hollow bricks, hot water storage, and thermos. For these purposes, the air is used because it is free and has a very low thermal conductivity. In general, the air thermal conductivities are ranging from 0.012 to 0.052 W/m°C at temperatures ranging from -150°C to 400°C. An investigation of air as insulation

literatur, Sadauskiene et al. (2009). They performed experiments using a vertical air gap apparatus. The gaps were varied from 3 mm to 20 mm. They concluded that increasing the air gap increased the heat transfer rate. They presented their findings in a graph correlating the air gap and the measured air thermal conductivity.

The aim of this study is to know the effect of air gap as insulation on the heat loss to the ambient. However, the air gap is provided in a concentric pipe not as in the cavity between two plates.

EXPERIMENTAL SET UP

Experiments were conducted using a test rig as shown in Figure 1. Cold water was drawn from a reservoir and flowed using a centrifugal pump model 16WZR-16 Booster HA. The flow rate of water was adjusted using a valve and measured using a calibrated flow meter model FLR1012ST-D with an uncertainty of ± 0.5 g/s. After leaving the flow meter, the water was heated up utilizing a gas heater and an electric heater to ascend the water temperature reaching of approximately 80°C at the pipe entrance. In the pipe, the water released the heat to the environment through the copper pipe wall (Case A) and through the copper pipe and PVC pipe walls (Case B, C and D). Detail dimensions of the pipe/tube are presented in Table 2. All temperatures were measured using K-type thermocouples with an uncertainty of ± 0.1°C obtained from calibration. The positions of the thermocouple can be seen in Figure 1.

Heat transfer in this study is heat loss from the water to the environment trough the tube wall.

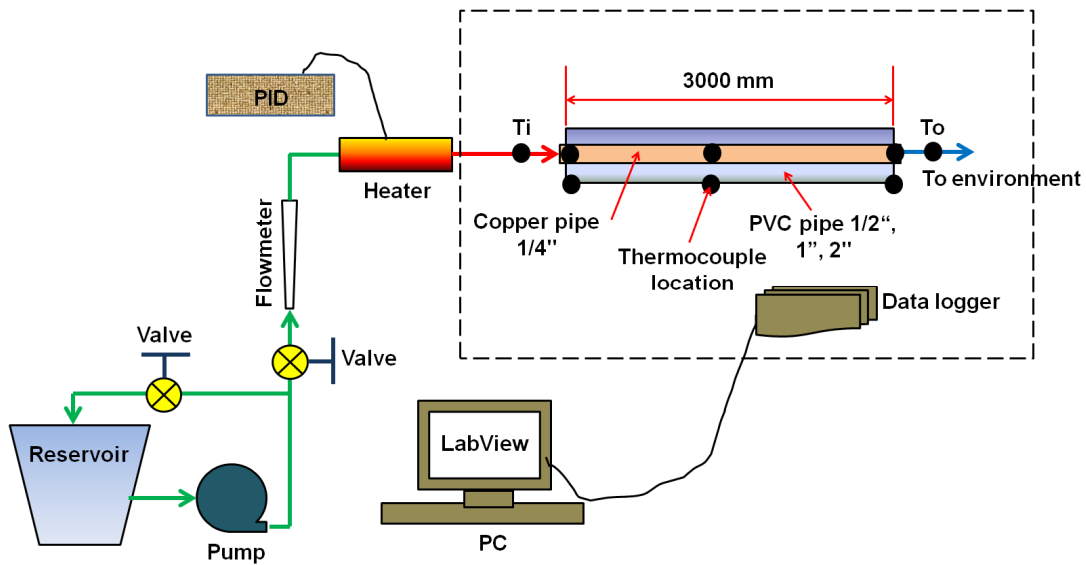


Figure 1. Schematic diagram of the test rig

Hence there is an energy balance that can be estimated as written in Holman (1997):

$$q_i = q_{loss} \quad (1)$$

$$q_i = \dot{m}c_p(T_i - T_o) \quad (2)$$

$$q_{loss} = h_o A(T_w - T_a) \quad (3)$$

where q_i represents the heat input (W), q_{loss} is the heat loss from the fluid (water) to the environment (W), \dot{m} is the mass flow rate (kg/s), c_p is the specific heat (J/kg°C), T_i and T_o are the inlet and outlet temperatures (°C). A represents the heat transfer area (m²), while T_w and T_a are the wall and ambient temperatures (°C). In this study, T_i , T_o , T_w , and T_a are measured directly, hence q_i can be obtained. For the Case B, C, and D, T_w is located on the outer wall of the PVC tube. Equation (2) was also used by previous researchers, e.g. Ljubenko et al. [2]. If there is no heat loss to other directions, then Equation (2) is the same as Equation (3) and h_o can be determined. h_o resulted from those two equations is the experimental free heat transfer coefficient, which is expressed as, Holman (1997):

$$h_o = \frac{\dot{m}c_p(T_i - T_o)}{A(T_w - T_a)} \quad (4)$$

Table 2. Dimension of the tubes and Cases, $L = 3000$ mm

Case	Single/Double	Nominal diameter (mm)	
		Copper	PVC
A	Single	6.35	
B	Double	6.35	12.7
C	Double	6.35	25.4
D	Double	6.35	50.8

RESULTS AND DISCUSSION

Experiments were performed at an inlet temperature of around 75°C measured at the entrance of the test section. The results are presented in the form of graphs. Before presenting the heat loss, temperature differences $\Delta T = (T_i - T_o)$ need to be existed for all cases, see Figure 2. The temperature differences are used to estimate the heat loss and all temperatures are recorded for about 3000 seconds. From Figure 2, it can be seen that Case A results in higher temperature differences, however, the temperature difference fluctuates with a big margin. This is due to the environment and random error effects.

When a PVC pipe is existed to cover the copper pipe, the difference temperatures decrease and their fluctuation margins are lesser. This means that the PVC pipe can reduce the heat loss and even the fluctuation of the temperature difference. Increasing the diameter of the PVC pipe decreases the temperature differences.

Consequently, the heat loss decreases with an increase in the PVC pipe diameter, see Figure 3. Nevertheless, the study of this subject is still very limited, or even there is no investigation on the use of air enclosed using a PVC pipe as isolation. Note: in Figure 3, when the temperature differences are indicating close to zero degree, the heaters are not on yet.

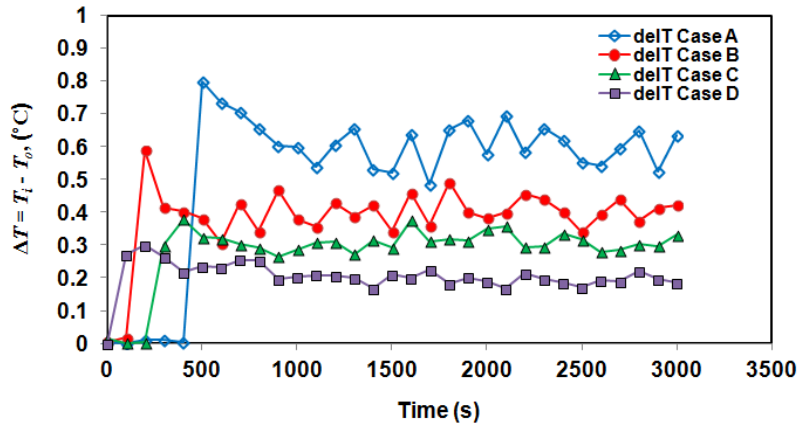


Figure 2. Temperature difference, $\Delta T = T_i - T_o$ for all cases at the same inlet temperature of 75°C and mass flow rate of 12 g/s. $\text{del}T = \Delta T$

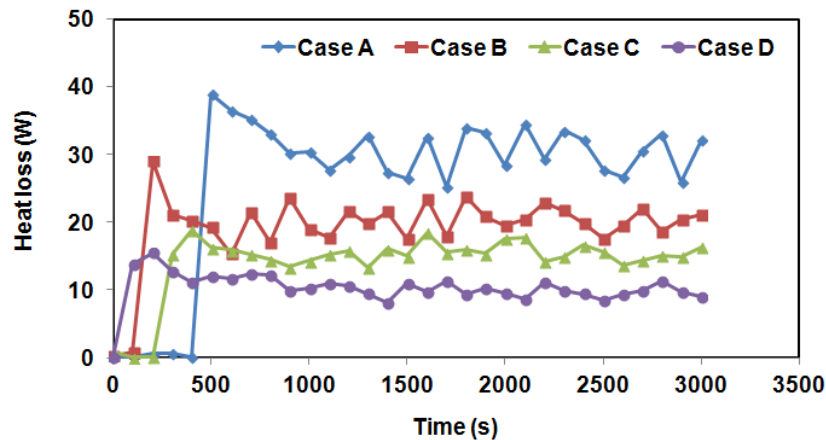


Figure 3. Heat losses to the environment for all cases at the same inlet temperature of 75°C and mass flow rate of 12 g/s

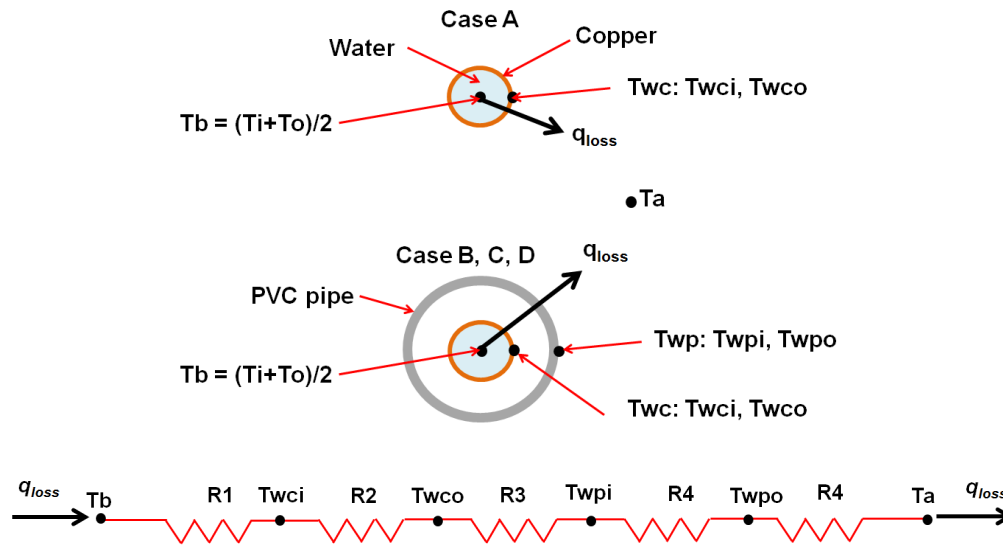


Figure 4. Schematic diagram of heat flows from the water to the environment through pipe walls and thermal circuit

However, according to the Engineering tool box, the heat loss from copper pipes with a nominal diameter of 1/2", is approximately 40 W/m. Increasing the diameter of the copper pipe raises the heat loss. Meanwhile, the experimental heat loss from a copper pipe with a diameter of 1/4" is around 10 W/m. So following the Engineering Tool

heat loss from a copper pipe with a diameter 1/2" or more.

To determine experimental free heat transfer coefficients, an illustration of heat flow is described as follows, see Figure 4. Due to measurements of T_{wco} and T_{wpo} , heat loss, can be estimated and given by equation (5) and (6). Equation (5) for the

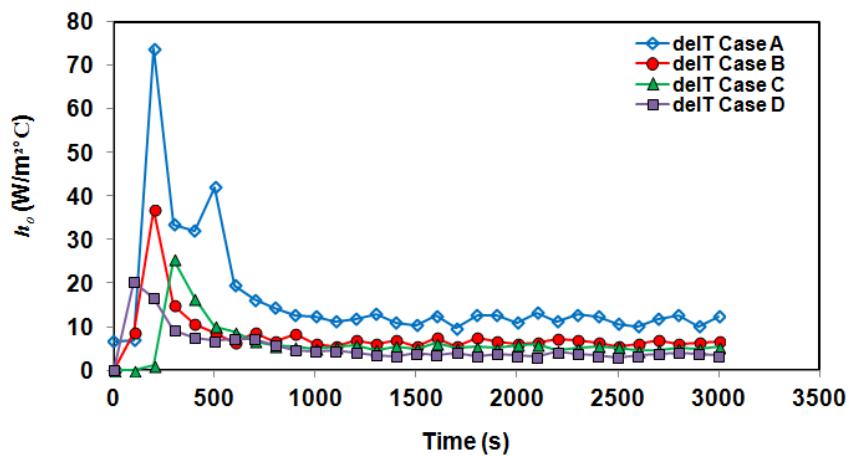


Figure 5. Experimental free heat transfer coefficients for all cases at the same inlet temperature of 75°C and mass flow rate of 12 g/s

Box, the heat loss obtained in this study is on the right track, because the heat loss is lower than the

Case A, and equation (6) for the Case B, C and D, can be estimated, Holman (1997):

$$q_{loss} = h_o A(T_{wco} - T_a) \quad (5)$$

$$q_{loss} = h_o A(T_{wpo} - T_a) \quad (6)$$

$$r_c = \frac{k}{h_o} \quad (7)$$

However, q_{loss} is the same as q_i if the heat

where r_c is the critical radius (m). When the outer

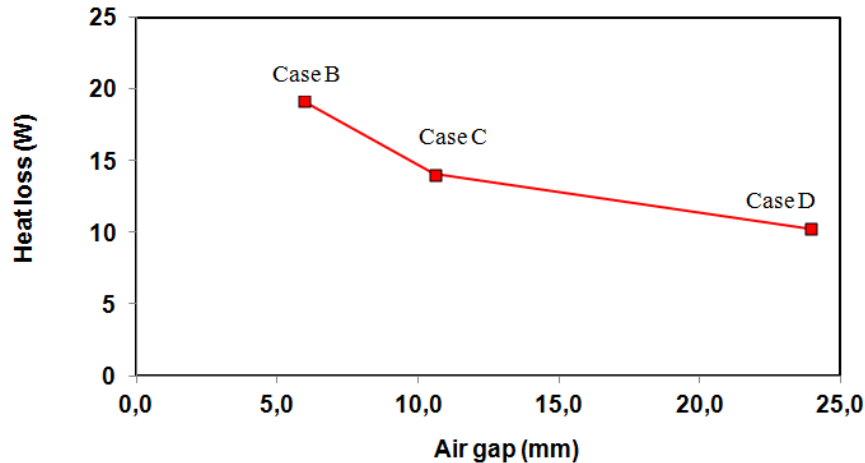


Figure 6. Effect of air gap on the heat loss for cases B, C and D at the same inlet temperature of 75°C and mass flow rate of 12 g/s

loss to the ends of the pipe is neglected. Therefore, using Equation (4), h_o can be calculated and the results of the calculation are given in Figure 5.

In Figure 5, from the time 0 to around 500 s, the heat transfer coefficient fluctuates with a big margin, then after 500 s, it starts to be constant. This is because of the increased inlet temperature before the flow or the temperatures reach the steady condition. At the 0 to 500 s, the inlet temperature is increasing because the heaters are presently turned on. At this time period, the condition is still transient. However, this finding is still in the range of the free heat transfer coefficient obtained by previous researchers; see Lee, et al. (2013). They found that their experimental free heat transfer coefficients were ranging from 2 to 10 W/m²°C. This was also found by Mirmanto dkk (2016a, 2016b, 2016c), Mirmanto dkk (2017).

The relationship between the air gap and the heat loss is presented here, see Figure 6. As the gap increases, the heat loss decreases. It means, in these experimental conditions, the thicker insulation is the better. The trend of q_{loss} with the air gap should be checked using a critical radius. The critical radius can be obtained in Holman (1997) and is expressed as:

radius of the insulation is less than the critical radius, increasing the insulation thickness gives the increased heat loss. Let us choose Case D with the biggest outer radius. The thermal conductivity of the PVC is approximately 0.0455 W/m°C, while the free convection heat transfer coefficient of the air determined from the experiments is around 5.2 W/m²°C, hence the critical radius is 0.011 m. Meanwhile, the outer radius of the PVC pipe is 0.03 m; therefore, the outer radius is bigger than the critical radius. Following the critical radius theory, see equation (5), increasing the insulation thickness decreases the heat loss. It means that the trend of heat loss in Figure 6 is right.

CONCLUSION

Experiments to investigate the heat loss from hot water flowing in a copper pipe have been performed. Hot water was used as the working fluid. The mass flow rate of the water used was around 12 g/s and the inlet temperature of 75°C was kept constant at the entrance of the test section. From the experimental data and analysis, some conclusions may be drawn as follows:

1. The biggest heat loss occurs in the bare copper pipe.
2. As the diameter of the PVC pipe increases the heat loss decreases.

- The trend of the heat loss with the increase in air gap agrees with the insulation critical diameter theory.
- The air gap can be used as a good insulation material.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Mechanical Engineering Department for the facility.

NOMENCLATURE

A	Heat transfer area (m^2)
c_p	Specific heat ($J/kg^\circ C$)
ΔT	Delta T
HVAC	Heating ventilating and air conditioning
h_o	Free convection heat transfer coefficient ($W/m^2^\circ C$)
k	Thermal conductivity ($W/m^\circ C$)
L	Length of the test section (m)
\dot{m}	Mass flow rate (kg/s)
PVC	Polyvinyl chloride
q_{loss}	Heat loss (W)
R	Thermal resistance ($^\circ C/W$)
r_c	Critical radius (m)
T	Temperature ($^\circ C$)
T_a	Ambient temperature ($^\circ C$)
T_b	Bulk temperature, $T_b = (T_i + T_o) / 2$, ($^\circ C$)
T_{wc}	Copper wall temperature ($^\circ C$)
T_{wp}	PVC pipe wall temperature ($^\circ C$)
ΔT	Temperature difference ($^\circ C$)

Subscript:

i	Inlet, inner
o	Outlet, outer

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