Heat Pipe Technology for Economiser and Air Preheater**

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INTRODUCTION

Heat recovery can take many different forms. In general terms, it can be classified as direct recovery, indirect recovery and secondary recovery. Direct recovery refers to the use of flue gas, which is a combination of carbon dioxide, nitrogen and oxygen generated by the combustion process in an incinerator or boiler, to preheat or dry products directly. Indirect recovery takes place when flue gas is used to preheat combustion air or fuel. Secondary recovery utilises the waste heat to preheat an external medium or to generate power.

Fuel savings is the most obvious benefit of waste heat recovery and this is the key motivating factor for the companies to invest in equipment to tap their waste energy. Other than that, a reduction in fuel usage also results in less emission of pollutants, which include carbon monoxide, hydrogen sulfide and sulfur dioxide, to the environment. Moreover, emission of carbon dioxide, which is a greenhouse gas, will also be reduced.

WASTE HEAT RECOVERY IN BOILER SYSTEMS

This simple concept of waste heat recovery could be illustrated by looking at boiler systems (Figure 1). Feed water enters the boiler to produce process steam. The energy for the steam production normally comes from the combustion of biomass, diesel or fuel oil, which produces an exhaust with a temperature of about 220°C to 270°C. For very old boilers, the temperature of the exhaust gas could even be higher. The exhaust flue gas, which still contains a substantial amount of waste heat, is discharged directly to the atmosphere through the chimney systems and as a result, precious energy is wasted.

The energy from the exhaust flue gas could be tapped through the use of heat exchangers, as shown in Figure 2 below.

In this case, the exhaust flue gas is used to preheat the feed water and the combustion air. Consequently, much less fuel is required to produce the same amount of steam. For example, an 8 t hr⁻¹ boiler in
which the flue gas flow rate is 9700 Nm$^3$ hr$^{-1}$ would result in approximately 22 000 litre savings per year in fuel oil or diesel consumption for every 10°C recovery of the exhaust gas temperature. This would be translated to more than USD 5000 in actual dollar savings annually.

The dew point of the flue gas is normally in the range 110°C to 140°C, depending on the sulfur content in the fuel used. Therefore, for most applications, the temperature of the exhaust fumes could theoretically be reduced by at least 70°C before low temperature corrosion occurs. This results in potential savings of more than USD 35 000 a year.

![Figure 1. Schematic diagram of a typical boiler without heat recovery system.](image1)

![Figure 2. Schematic diagram of a typical boiler with waste heat recovery system.](image2)

**PROBLEMS WITH CONVENTIONAL HEAT EXCHANGERS IN WASTE HEAT RECOVERY**

However, most industrial boilers that are smaller than 10 t hr$^{-1}$ are normally not equipped with heat exchangers to recover the waste heat. This is because there are many maintenance problems associated with low temperature corrosion if conventional heat exchangers are used for such applications.

Low temperature corrosion refers to the corrosion at the tube walls of the heat exchangers as the gas film temperature at the

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$^1$Assuming that the calorific value, density and price of the fuel is 43.6 MJ kg$^{-1}$, 970 kg m$^{-3}$ and USD 0.24 litre$^{-1}$ respectively.
The tube wall is below the dew point of the flue gas. This is because the gas side heat transfer coefficient is relatively low. This results in a huge temperature gradient between the tube wall and the flue gas. As a result, the flue gas temperature must always be maintained at around 200°C if conventional heat exchangers are used. Due to the above, it is not economically viable to install waste heat recovery systems for smaller boilers in the past. For larger boilers that use conventional heat exchangers for heat recovery, the amount of waste heat released to the environment is still significant (Figure 3).

HEAT PIPE HEAT EXCHANGERS

The corrosion and maintenance problems faced by conventional heat exchangers in heat recovery systems could be addressed using the heat pipe heat transfer technology. In terms of industrial applications, this is still a relatively novel technology. Early efforts were directed toward space applications; however, due to the high cost and the rapid rise in demand in energy, the commercialisation and application of heat pipe heat exchangers (Figure 4) in other industries have become more widespread in recent years. Figure 4 shows a schematic diagram of a heat pipe heat exchanger. Heat pipes are simply pipes that contain a working fluid. They are sealed at both ends after a vacuum is created above the working fluid.

The heat exchanger is divided into two ends: evaporating and condensing ends. The hot medium flows through the evaporating end and evaporates the working fluid. The vapor rises up the heat pipes, and condenses at the condensing end such that energy is transferred to the cool medium. As such, heat pipes operate at almost constant temperature.

The phase change heat transfer in heat pipes gives them very high thermal conductance. In fact, the conductivity of heat pipes is about 100 times higher than copper.
Moreover, the ratio of the heat transfer area between the evaporating and condensing ends of the heat exchanger could be easily manipulated by adjusting the height of, and adding fins to, the evaporating and condensing ends.

**ADVANTAGES OF HEAT PIPE HEAT EXCHANGERS**

Owing to the high thermal conductivity of heat pipes, their simple construction with no mechanical moving parts and the ease of manipulating the heat transfer area, heat pipe heat exchangers offer many advantages compared to conventional heat exchangers.

- Heat transfer up to 97%.
- Fuel saving.
- CO₂ reduction for climate change.
- Low flue gas temperature discharge to chimney.
- Boiler efficiency increase by 3%-15%.
- Small volume and light weight.
- Simple structure.
- Small pressure drops on gas side.
- More resistant to low temperature corrosion.
- Carry on running even when some of the pipes corrode over time.
- Simple installation.
- Maintenance free, except using MFO and Biomass as fuel.
- High investment return due to high energy recovery.
- Life spans between 4-10 years, depend on individual condition.

One key advantage is that the temperature gradient between the wall of a heat pipe and the flue gas is not drastic. Therefore, the heat exchanger is extremely tolerant to low temperature corrosion and the effluent flue gas temperature could be as low as 140°C. This makes this kind of heat exchangers extremely economically viable for waste heat recovery applications.

**HEAT PIPE HEAT EXCHANGER PROJECT IN MALAYSIA**

**Palm Oil Mill No. 1**

**Project 1**

Date of installation: April 2011

**Stage 1: Heat Pipe Heat Exchanger Economiser**

1. **Operating parameters (as provided by client)**
   - Capacity of boiler: 45 t hr⁻¹
   - Operating mode: 24 hr day⁻¹, 330 day yr⁻¹
   - Type of fuel: Fibre/EFB
   - Fuel consumption: 8430 kg hr⁻¹
   - Fuel price: Fibre RM 20 t⁻¹, Shell RM 120 t⁻¹
   - Flue gas inlet temperature: 330°C
   - Feed water inlet temperature: 30°C
   - Feed water outlet temperature: 70°C
   - Feed water flow rate: 39 000 kg hr⁻¹
   - Heat exchanger duty: 2170 kW

2. **Design specification (non-pressure vessel)**
   - Flue gas inlet temperature: 300°C
   - Flue gas outlet temperature: 210°C
   - Feed water inlet temperature: 30°C
   - Feed water outlet temperature: 70°C
   - Feed water flow rate: 39 000 kg hr⁻¹
Mill 1, Project 2
Date of Installation: May 2014

Heat Pipe Heat Exchanger Stage 1 - Economiser (Figure 5)

1. Operating parameters (as provided by client)
   - Capacity of boiler: 70 t hr\(^{-1}\)
   - Operating bode: 24 hr day\(^{-1}\), 330 day yr\(^{-1}\)
   - Type of fuel: 50% Fibre, 50% EFB
   - Fuel consumption: 25 920 kg hr\(^{-1}\)
   - Fuel price: RM 160 t\(^{-1}\)
   - Flue gas inlet temperature: 340°C
   - Feed water inlet temperature: 25°C
   - Feed water flow rate: 73 800 kg hr\(^{-1}\)

2. Design specification (non-pressure vessel)
   - Flue gas inlet temperature: 340°C
   - Flue gas outlet temperature: 266°C
   - Feed water inlet temperature: 25°C
   - Feed water outlet temperature: 70°C

Feed water flow rate: 73 800 kg hr\(^{-1}\)
Heat exchanger duty: 3926 kW
Heat Pipe Heat Exchanger Stage 2 - Air Pre-Heater

The photographs of layout diagram, Air Inlet and Heat pipe details are shown in Figures 7-10.

1. Operating parameters (as provided by client)
   Capacity of boiler : 70 t hr\(^{-1}\)
   Operating mode : 24 hr day\(^{-1}\), 330 day yr\(^{-1}\)
   Type of fuel : 50% Fibre, 50% EFB
   Fuel consumption : 25 920 kg hr\(^{-1}\)
   Fuel price : RM 160 t\(^{-1}\)
   Flue gas inlet temperature : 266°C
   Flue gas outlet temperature : 199°C
   Flue gas flow rate : 154 440 kg hr\(^{-1}\)

2. Design specification (non-pressure vessel)
   Combustion air inlet temperature : 30°C
   Combustion air outlet temperature : 150°C
   Combustion air flow rate : 75 730 Nm\(^3\) hr\(^{-1}\)
   Heat exchanger duty : 3364 kW

Heat Pipe Heat Exchanger Stage 1 - Air Pre-Heater (Figures 7-10)

1. Operating parameters (as provided by client)
   Capacity of boiler : 60 t hr\(^{-1}\)
   Operating mode : 24 hr day\(^{-1}\), 330 day yr\(^{-1}\)
   Type of fuel : Fibre/EFB
   Fuel consumption : 16 000 kg hr\(^{-1}\)
   Fuel price : Fibre RM 20 t\(^{-1}\), Shell RM 120 t\(^{-1}\)
   Flue gas inlet temperature : 263°C
   Feed water inlet temperature : 30°C
   Feed water flow rate : 54 000 kg hr\(^{-1}\)

2. Design specification (non-pressure vessel)
   Flue gas outlet temperature : 165°C
   Feed water outlet temperature : 75°C
   Feed water flow rate : 54 000 kg hr\(^{-1}\)
   Heat exchanger duty : 3018 kW

Palm Oil Mill No. 2

Date of Installation: November 2013

Heat Pipe Heat Exchanger Stage 2 - Economiser

1. Operating parameters (as provided by client)
   Capacity of boiler : 60 t hr\(^{-1}\)
   Operating mode : 24 hr day\(^{-1}\), 330 day yr\(^{-1}\)
   Type of fuel : Fibre/EFB
   Fuel consumption : 16 000 kg hr\(^{-1}\)
   Fuel price : Fibre RM 20 t\(^{-1}\), Shell RM 120 t\(^{-1}\)
   Flue gas inlet temperature : 263°C
   Feed water inlet temperature : 30°C
   Feed water outlet temperature : 75°C
   Feed water flow rate : 54 000 kg hr\(^{-1}\)
   Heat exchanger duty : 3018 kW

2. Design specification (non-pressure vessel)
   Flue gas inlet temperature : 263°C
   Feed water outlet temperature : 75°C
   Feed water flow rate : 54 000 kg hr\(^{-1}\)
   Heat exchanger duty : 3018 kW
Palm Oil Mill No. 3

Date of Installation: May 2014

Heat Pipe Heat Exchanger Stage 1 - Economiser

1. Operating parameters (as provided by client)
   - Capacity of boiler: 70 t hr$^{-1}$
   - Operating mode: 24 hr day$^{-1}$, 330 day yr$^{-1}$

2. Design specification (non-pressure vessel)
   - Type of fuel: 100% Fibre
   - Fuel consumption: 23 400 kg hr$^{-1}$
   - Fuel price: RM 160 t$^{-1}$
   - Flue gas inlet temperature: 340°C
   - Feed water inlet temperature: 25°C
   - Feed water outlet temperature: 73 800 kg hr$^{-1}$
   - Flue gas outlet temperature: 261°C
   - Feed water inlet temperature: 25°C
   - Feed water outlet temperature: 69°C
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Feed water flow: 73 800 kg hr\(^{-1}\)
Heat exchanger duty: 3826 kW

1. **Operating parameters (as provided by client)**
   - Capacity of boiler: 70 t hr\(^{-1}\)
   - Operating mode: 24 hr day\(^{-1}\), 330 day yr\(^{-1}\)
   - Type of fuel: 100% Fibre
   - Fuel consumption: 23 400 kg hr\(^{-1}\)
   - Fuel price: RM 160 t\(^{-1}\)
   - Flue gas inlet temperature: 261°C
   - Flue gas outlet temperature: 193°C
   - Flue gas flow rate: 141 840 kg hr\(^{-1}\)

2. **Design specification (non-pressure vessel)**
   - Combustion air inlet temperature: 30°C
   - Combustion air outlet temperature: 150°C
   - Combustion air flow rate: 70 162 Nm\(^3\) hr\(^{-1}\)
   - Heat exchanger duty: 2851 kW

   The tubes exposed to flue gases as also subjected to ultrasonic soot removal systems in order to maintain maximum heat transfer. The system is shown in Figures 13a-d.
CONCLUSION

The heat pipe heat exchanger offers many advantages compared to a conventional heat exchanger. It allows for large quantities of heat to be transported through a small cross-sectional area over a considerable distance with no additional power input to the system. Furthermore, design and manufacturing simplicity, small end-to-end temperature drops, and the ability to control and transport high heat rates at various temperature levels are unique features of heat pipes. These features make it extremely appropriate for waste heat recovery applications.

Waste heat recovery not only helps to protect the environment, but will also result in substantial cost savings for the company. Results from case studies have shown that the payback period for such investments using the heat pipe heat transfer technology is within two years.