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HEAT PIPE HEAT EXCHANGERS FOR WASTE HEAT RECOVERY

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About 90% of the total energy required for tea manufacture is thermal energy and a major portion of it (50 – 75%) goes as waste through flue gas of the stoves and exhaust air from the dryers. In the present study, heat pipe heat exchanger was successfully used to recover and reuse 42% of the waste heat from the flue gas of the stoves resulting in an overall saving of 21%.

Energy is one of the critial inputs in tea manufacture and about 90% of the total energy required is only thermal energy mostly to remove water from the leaves during withering and drying (Ramakrishna *et al.*, 1991; Ramakrishna *et. al.*, 1993) Different types of furnaces and fuels are used to produce thermal energy required for generating hot air for drying tea. The overall thermal efficiency depends upon the method of manufacture and type of furnace, fuel and dryer. However, a major portion of thermal energy (50 – 75%) generated is wasted mainly through the flue gas of the stove and exhaust air from the dryer.

Earlier efforts by the authors to recover energy from the flue gas through indirect conventional heat exchangers were found to be not viable due to poor heat transfer coefficients. Recycling of exhaust air from the dryer through the stove was also not very successful due to the back pressure in the filters and presence of fine fluff or dust in the air leaving the bag filter for recycling.

Heat pipe heat exchangers (HPHE) (Anon, 1989) is one of the most advanced type of heat exchangers with versatile applications. Due to the use of hyperconducting hollow pipe, the equivalent thermal conductivity of heat pipes is about one thousand times more than any known metal (e.g. silver or copper). Similarly, its heat absorbing capacity is also several hundred times more than even copper. Thus the heat pipe is a thermal energy absorbing and transferring system, which can carry about one thousand times more heat energy than an equivalent size of copper rod for the same temperature gradient.

Tata Tea Ltd, Munnar and Messrs Auracon Energy Machine Pvt. Ltd, Coimbatore pioneered the idea of using heat pipe heat exchangers for waste heat recovery in tea manufacture. Accordingly one heat pipe heat exchanger was successfully designed and commissioned to recover waste heat from the flue gas of the furnace in one of the factories of Tata Tea Limited at Munnar. The results and the scope of heat pipe heat exchangers in tea manufacture are discussed in this paper.

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Principle of heat pipe

Heat pipe is a thin metal tube with a capillary mechanism along the inner periphery. A small quantity of working fluid is introduced in the pipe and the system is evacuated and sealed. Thus the three basic components of a heat pipe are the working fluid, the wick or capillary structure and the metal tube or container as shown in Fig. 1 (a). In the longitudinal direction, the heat pipe is made up of an evaporator section and a condenser section. The adiabatic section separates the evaporator and condenser sections. The cross section of the heat pipe, shown in Fig. 1 (b) consists of the container wall, the wick structure and the vapour space. Heat pipes are normally installed vertical along with their height. One end of the tube (evaporator) is heated causing the working fluid to evaporate and the vapour moves to the cold end of the tube (condenser) where it is condensed. The condensate is returned to the hot end (evaporator) by capillary forces. Since the latent heat of evaporation is large, considerable quantities of heat can be transferred with a very small temperature difference from end to end. The performance of a heat pipe is often expressed in terms of 'Equivalent Thermal Conductivity'.

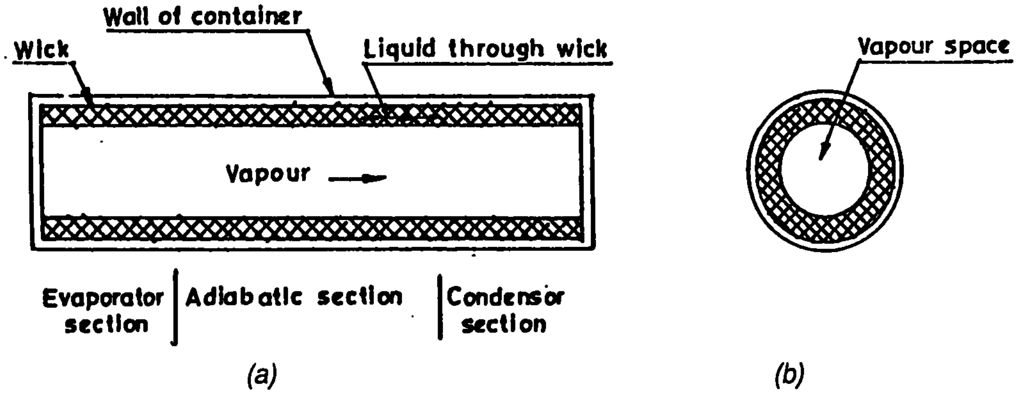

Fig. 1 – The main regions of the heat pipe

Working fluids and the material of construction depend mainly on the operating temperatures. Aluminium, copper or stainless steel are some of the common materials of construction. Acetone, methanol or molten lithium or even water are some of the working fluids mentioned in literature. The wick in the heat pipe is made up of a fine metallic or ceramic mesh.

EXPERIMENTAL

The studies were conducted at the Tea Factory in Madupatty Estate of Tata Tea Ltd located in the High Ranges at Munnar 685 612, Kerala, India. The factory has a capacity to process about 60,000 kg of green leaf per day. It consists of three different processing lines or CTC batteries. The fermented leaf is dried in three different Vibro Fluid Bed Dryers (Model Minor) supplied by M/s Kilburn Engineering Ltd. Each dryer is connected to a 16 cm firewood stove (Model Mar II) supplied by Messrs Pandian Engineering, Kotagiri, India.

The Heat Pipe Heat Exchanger was designed and supplied by M/s. Auracon Energy Machines Pvt. Ltd., Coimbatore. The layout of the unit is shown in Fig. 2.

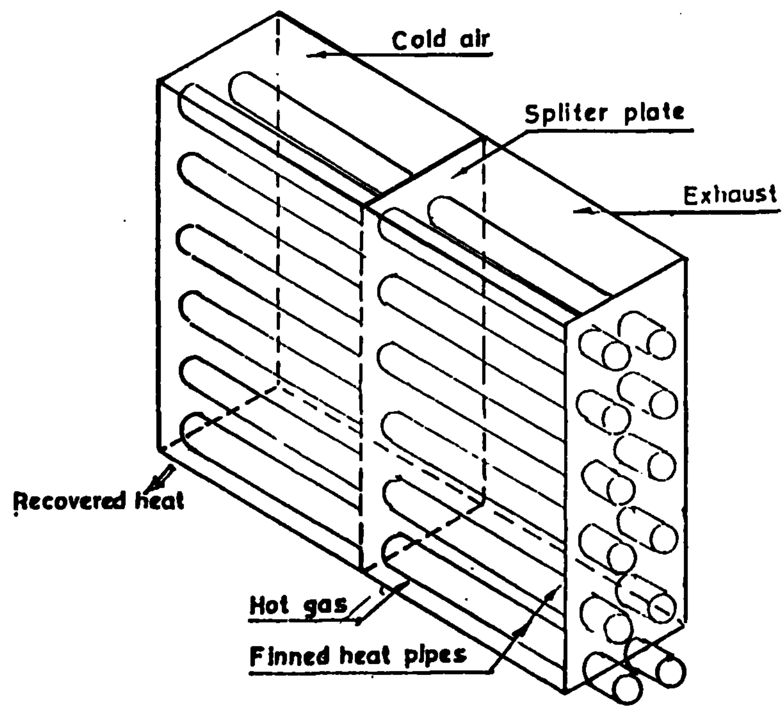

Fig. 2 – Layout of a heat pipe heat exchanger

Some important technical details of the heat pipe heat exchanger are as follows:

Material of construction	:	Aluminium
Diameter of the pipe	:	12 mm
Length of the pipe	:	2 m
No. of rows	:	14
No. of pipes in each row	:	10
No. of pipes	:	140

Overall dimensions

Height	:	2.06 m
Width	:	0.80 m
Depth	:	0.62 m

Specifications of the fan

Nominal capacity	:	3000 CFM
HP of motor	:	3

The nominal capacity of the hot air fan of each dryer is 18000 CFM. However, based on design considerations of HPHE, only part of this air is pre-heated in HPHE. Flue gas is passed through the evaporating section of HPHE with an ID fan at its outlet. Ambient air is fed through the condenser section of the HPHE through a FD fan of 3000 CFM (the acual flow rates of air from different fans could not be measured due to various reasons). In order to get heated further to the required temperature the pre-heated ambient air is mixed with the fresh amibent air in the heater (Fig. 3). The HPHE can be by-passed if required for repairs/maintenance through the by pass air duct provided for the purpose at the bottom.

Eucalyptus grandis is one of the common firewood species used in tea manufacture in the factories of Tata Tea and the same was used for this study as well. The amount of firewood consumed daily both by the experimental heater (with HPHE) and two other heaters (without HPHE) were measured along with the amount of tea produced by the respective dryers connected to these stoves. The same firewood was used in all the dryers on any given day or batch. Data was collected continuously for 25 working days during Sept./Oct. 1993.

The terminal temperatures of the ambient air and flue gas across the heat exchanger were measured using an RTD sensor and a portable display unit.

Soot on the HPHE exchanger on the flue gas side was cleaned once a week with the help of nylon brushes provided by the suppliers along with the equipment.

RESULTS AND DISCUSSION

The data on firewood consumption by heater with and without HPHE are given in Table 1. Specific fuel consumption by the stoves without HPHE was 1.24 kg of firewood per kg of dryer mouth tea (DMT). However, the consumption of the heater connected to HPHE was 0.94 kg only leading to a saving of 0.26 kg of firewood per kg of dryer mouth tea. This has contributed to an overall saving of 21% in firewood consumption. However, savings may vary depending upon the heater, HPHE, firewood and operating conditions. Average flue gas temperatures at the inlet and outlet of the HPHE, at different ambient temperatures of air are given in Table 2. The data show that 42% of the heat in the flue gas was recovered using the HPHE in the present study. The design of HPHE and heat recovery depend mainly on the heat content of the flue gas and temperature of the flue gas.

TABLE 1 – *Data on fuel consumption*

	Dryer 1 & 2 Control	*Dryer 3 with HPHE*
Dryer Mouth Tea (kg)	299396	153758
Firewood (kg)	369893	150983
Kg firewood/kg of DMT	1.24	0.98

Savings = 0.26 kg/kg of dmt
= 20.97%

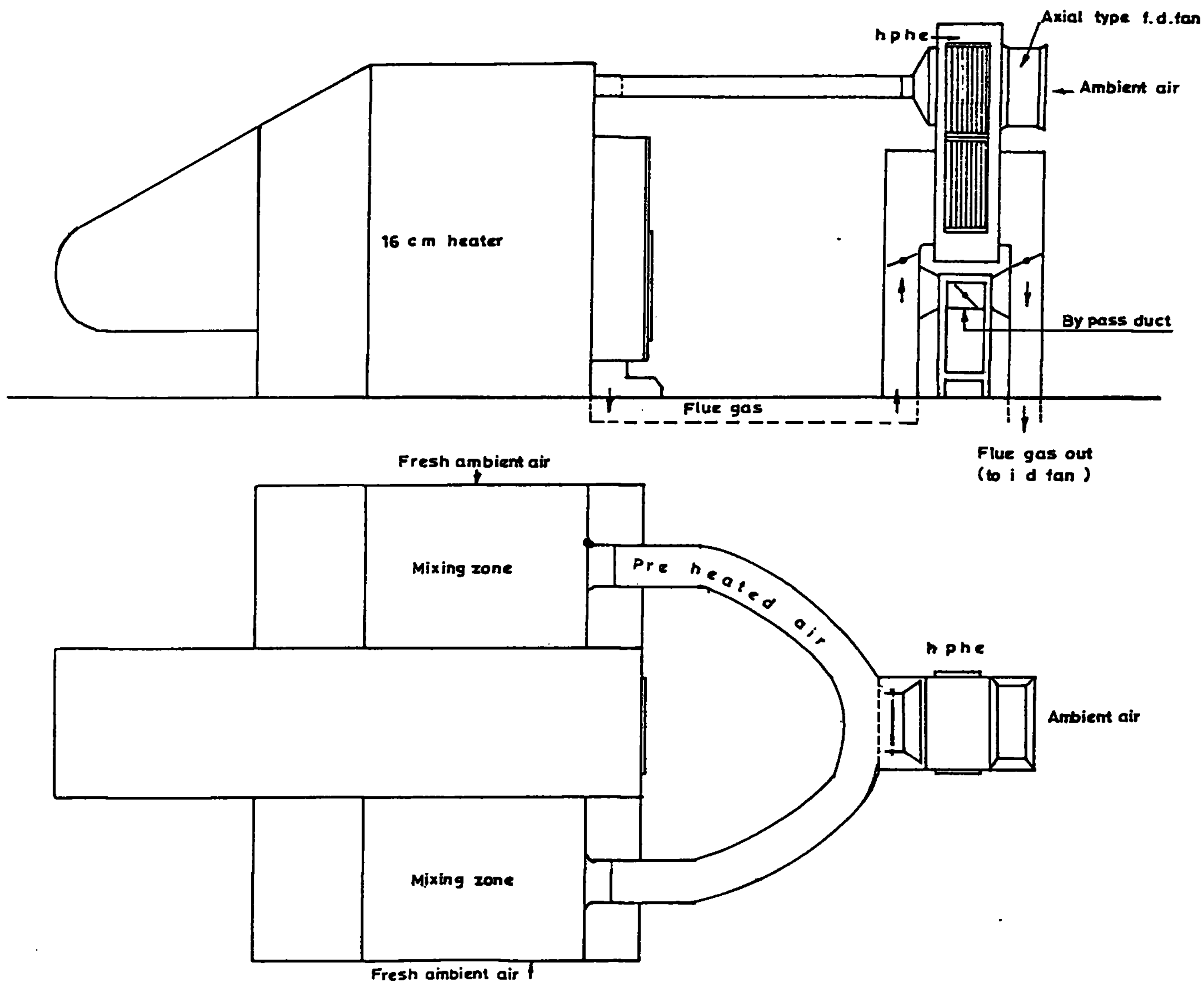

Fig. 3 – *Layout of heat pipe heat exchanger with stove*

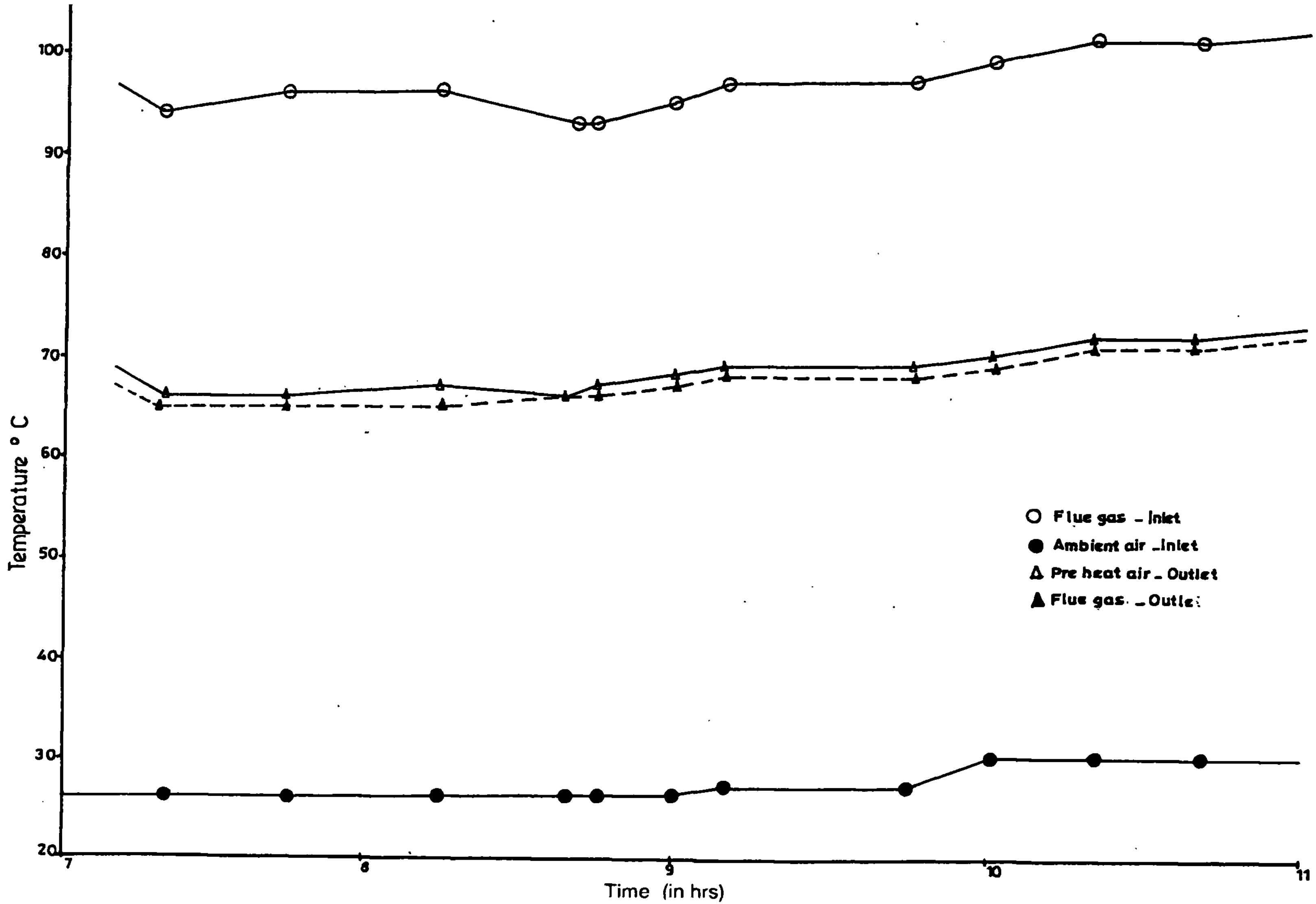

Fig. 4 – *Terminal temperature of HPHE*

TABLE 2 – *Data on heat recovery*

Ambient temperature (°C)	*Flue Gas HPHE* Inlet	*Temp (°C) HPHE* Outlet	*% Recovery*
26	95	65	42.03
27	97	68	41.43
30	101	71	42.25
	Average		42.00

Temperature of the air and flue gas obtained at the inlet and outlet of HPHE respectively in one typical batch between 0700 and 1100 hours are given in Fig. 4. Temperature of the pre-heated air and outlet temperature of the flue gas are almost equal confirming that heat pipe heat exchangers work on isothermal conditions.

CONCLUSION

HPHE can be used successfully to recover waste heat from flue gas of the stove in tea manufacture. In the present study, 42% of the heat available in the flue gas was recovered. The overall saving in firewood was found to be around 21%. The pay back period would be 1 to 2 years depending on the various cost factors and savings achieved.

Considerable amount of heat is also wasted from the exhaust air of the dryer from FBDs depending upon the temperature maintained in them. However, it may not be viable if the exhaust temperature is below 110°C.

The thermal efficiencies are generally higher with the heaters using fluid fuels. Tea factories using steam boilers for generating hot air already have an in-built heat recovery unit giving high thermal efficiencies. In such cases HPHE may have limited scope, depending upon the thermal efficiencies and operating conditions.

Many tea factories in South India have since installed HPHE units to recover heat from fuel of the stove successfully. Some factories are using them to recover heat from the exhaust of the dryer as well.

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