American Journal of Environmental Science 9 (3): 231-239, 2013
ISSN: 1553-345X

doi:10.3844/ajessp.2013.231.239 Published Online 9 (3) 2013 (http://www.thescipub.com/ajes.toc)

Waste Heat Recovery from Boiler of Large-Scale Textile Industry

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Received 2013-05-24, Revised 2013-06-20; Accepted 2013-06-21

ABSTRACT

Many industrial heating processes generate waste energy in textile industry; especially exhaust gas from the boiler at the same time reducing global warming. Therefore, this article will present a study the way to recovery heat waste from boiler exhaust gas by mean of shell and tube heat exchanger. Exhaust gas from boiler dyeing process, which carries a large amount of heat, energy consumptions could be decrease by using of waste-heat recovery systems. In this study, using ANASYS simulation performs a thermodynamics analysis. An energy-based approach is performed for optimizing the effective working condition for waste-heat recovery with exhaust gas to air shell and tube heat exchanger. The variations of parameters, which affect the system performance such as, exhaust gas and air temperature, velocity and mass flow rate and moisture content is examined respectively. From this study, it was found that heat exchanger could be reduced temperature of exhaust gases and emission to atmosphere and the time payback is the fastest. The payback period was determined about 6 months for investigated ANSYS. The air is circulated in four passes from the top to the bottom of the test section, in overall counter-flow with exhaust gas. The front area is 1720×1720 mm, the flow length 7500 mm, the inner and outer diameter of exhaust gas is 800 mm, the tube assembly consist of 196 tubes, the tube diameter is 76.2 mm, the tube thickness is 2.6 mm, the tube length is 4500 mm, the tube length of air inner and outer is 500 mm. The result show that, the boiler for superheated type there are exhaust gas temperature is 190°C, 24% the moisture content of fuel and there are palm kernel shell 70 tons day^{-1} which there are the high temperature after the heat exchanger, 150°C. It was occurred acid rain. The hot air from heat exchanger process can be reduced the moisture of palm kernel shell fuel to 15%.The fuel consumption is reduced by about 2.05% (322.72 kJ kg^{-1}), while the shell and tube heat exchanger outlet exhaust gas temperature decreases from 190 to 150°C.

Keywords: Waste Heat Recovery, Shell and Tube Heat Exchanger, Boiler, Palm Shell and Exhaust (Flue) Gas

1. INTRODUCTION

The Textile Industry (TI) is one of the most complicated manufacturing industries and the oldest industrial sectors in Thailand. Because it is a fragmented and heterogeneous sector dominated by Small and Medium Enterprises (SMEs). Characterizing the textile manufacturing industry is complex because of the variety of substrates, processes, machinery and components used and finishing steps undertaken (Hasanbeigi and Price, 2012). Cotton is the primary raw material followed by synthetic yarns (rayon and nylon). The production of

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cotton yarns and fabrics involved the following general processes: Spinning (twisting/texturing), weaving (knitting/tufting/nonwoven) and wet processing which includes scouring, de-sizing, washing, mercerizing, bleaching, dyeing, printing and finishing of yarns and fabrics as shows in **Fig. 1**. The main products are yarns and finished fabric (Zabaniotou and Andreou, 2010).

The Textile Industry (TI) uses large quantities of both electricity and thermal (such as in boilers, motor systems, distribution). The fuels used for the production of thermal energy in general in Thailand are Diesel oil, Heavy Fuel Oil, LPG, coal, natural gas and Solid fuels (such as palm oil shell). Electricity is the major type of energy used in spinning plants, especially in cotton spinning systems. If the spinning plant just produces raw yarn in a cotton spinning system and does not dye of fix the produced yarn, the fuel may just be used to provide steam for the humidification system in the cold seasons for preheating the fibers before spinning them together (Hasanbeigi and Price, 2012).

The total amount and types of wastes have increased due to rapid industrial development in recent years. A focus on environmental problems caused by industrial wastes, especially those containing waste heat in textile industry. Considering the environmental protection and also in the context of great uncertainty over future supplies, attention is concentrated on the utilization of sustainable energy sources and the energy conservation methodologies (Pandiyarajan *et al*., 2011). High capacity biomass (such as palm oil shell) is one of the most widely used boiler units for Dyeing process. Nearly one-third of input energy is wasted through exhaust gas of these boilers. Decreasing energy losses and recovering the lost energy are of great importance. This waste energy in form of heat can be removed and used for other applications for environment protecting and the energy saving purpose.

In each production process of the Textile Industry (TI), the heating and cooling of gases and liquids are frequently required. This is done through heat exchange between different fluids and in order to avoid contamination or chemical reaction due to their direct contact, heat exchangers are used to carry out indirect heating and cooling. It is important to use the right heat exchanger for the intended purpose. Boiler flue gases contain substantial heat energy. This energy can be utilized to preheat the boiler feed water through economizer (Chaojun *et al.*, 2012). It is well known that the utilization of waste heat of flue gases is of the best possibilities for reduction of the green house gases emissions. Different types of heat exchenger represents primary importance in heat recovery systems design. It is necessary to perform the design is such a way so that there were utilize conventional types of heat exchnagers with maximum degree of compactness in relation to process parameters like temperature, composition of process fluids, proximity to fouling and potential problems. The possibility to use ceramic materials which have been subject to intense development in the last 40 years and they exhibit good properties at high temperatures (up to 1400°C). However, generally, these ceramic materials, if they are application for temperatures around 1000°C, are too expensive. There were use for lower temperatures in flue gas (off-gas) application is technically possible but is economically too expensive. Therefore, most requirements for common high temperature flue gas industrial applications (up to 1000°C) use metallic mateerials (Stehlik, 2011).

Pandiyarajan *et al*. (2011) have performed experiments on heat recovery from diesel engine exhaust using finned shell and tube exchanger and thermal storage system. Depending on the temperature level of exhaust stream and the proposed application, different heat exchange devices, heat pipes and combustion equipment's can be employed to facilitate the use of the recovered heat. The shell and tube heat exchanger is the most widely used type industrial heat transfer equipment. Initially, only plain tubes were used in shell and tube heat exchangers. The heat transfer coefficient (h) for gases is generally several times lower than that for water, oil and other liquids. In order to minimize size and weight of a gas to liquid heat exchanger, the thermal conductance (hA) on both sides of the exchanger should be approximately the same. Therefore, the heat transfer surface on the gas side needs to have a much larger area and be more compact than can be realized practically with the circular tubes commonly used in shell and tube exchangers.

The thermal design of the condensing boiler aims to estimate adequate surface area of the heat exchanger to handle the required thermal duty. Therefore, heat transfer coefficients need to be evaluated before the size of the condensing boiler can be calculated. The heat transfer coefficient (h) can be written as.

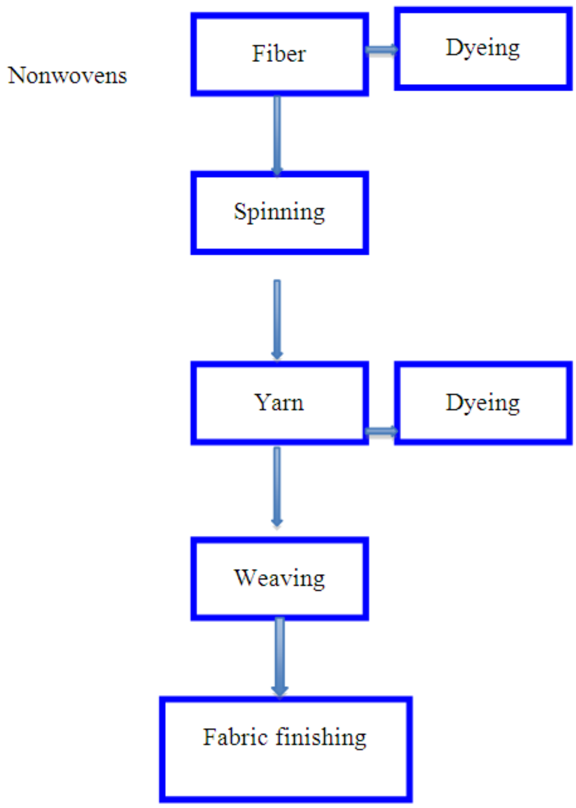


Fig. 1. The textile process

1.1. Tube-Side Heat Transfer Coefficient

The correlation (Nusselt number) obtained under fully developed turbulent flow in smooth tubes can be to calculate the tube-side heat transfer coefficient Equation 1 (Chen *et al*., 2012):

$$\mathrm{Nu}_t = \frac{h_t d_i}{\lambda_t} = \frac{\left(\frac{f}{2}\right)(\mathrm{Re}-1000)\,\mathrm{Pr}}{1+12.7\left(\frac{f}{2}\right)^{\frac{1}{2}}\left(\mathrm{Pr}\frac{2}{3-1}\right)} \tag{1}$$

Where:
λ_t = The thermal conductivity of the water on the tube-side
d_i = The inner diameter of the tubes
h_t = The tube-side heat transfer coefficient
P_r = The Prandtl number and f can be expressed as Equation 2:

$$f = (1.58\ln\mathrm{Re} - 3.28)^{-2} \tag{2}$$

For flow in a pipe or tube, the Reynolds number is generally defined as Equation 3 (Chen *et al*., 2012):

$$\mathrm{Re} = \frac{\rho v D_H}{\mu} = \frac{v D_H}{\nu} = \frac{Q D_H}{\nu A} \tag{3}$$

Where:
D_H = The hydraulic diameter of the pipe; its characteristic travelled length, L (m)
Q = The volumetric flow rate (m^3/s)
A = The pipe cross-sectional area (m^2)
Vis = The mean velocity of the fluid (SI units: m/s)
μis = The dynamic viscosity of the fluid (Pa·s or N·s/m^2 or kg/(m·s))
vis = The kinematic viscosity ($v = \mu/p$) (m^2/s)
pis = The density of the fluid (kg/m^3)

1.2. Shell-Side Heat Transfer Coefficient

The heat resistances in the shell-side consist of those of the condensate film and the cooling of the sensible heat of the flue gases. For the heat transfer coefficient of gas stream (h_g) in the shell-side, the following correlation can be used Equation 4 (Chen *et al*., 2012):

$$\mathrm{Nu}_{s.g} = \frac{h_g D_e}{\lambda_g} = 0.27\,\mathrm{Re}_{De}^{0.63}\,\mathrm{Pr}_g^{0.34} \tag{4}$$

Where:
λ_g = The thermal conductivity of gas mixture
D_e = The equivalent diameter calculated along (instead of across) the long axes of the shell

The compositions of exhaust gas from combined cycle are non-condensable and the steam concentration is small. Thus, the heat transfer process in the shell and tube heat exchanger for flue gas is forced convective heat transfer with partial water vapour condensation. The condensation-convection heat transfer coefficient and sensible heat transfer coefficient is of the same order. As the flue gas flows downward in the channel, when the wall temperature T_w is lower than the saturation temperature T_s of the vapour, the temperature of flue gas next to wall is below T_s and then condensation will take place on the wall surface and a condensate film forms (Shi *et al*., 2011). The local overall heat transfer coefficient (U) from the shell-side to the tube-side can be show as Equation 5 (Chen *et al*., 2012):

$$1/U = 1/h_t + R + 1/h_{s,ef} \tag{5}$$

Where:

R = The thermal resistance due to the tube wall and fouling
h_{sef} = An effective shell-side heat transfer coefficient

The condensation occurs, this effective coefficient is obtained by Equation 6:

$$1/h_{s,ef} = 1/h_{m,N} + q_g/q/h_g \quad (6)$$

Where:
Q = The total heat flux from the shell-side to the tube-side
Q_g = The sensible heat flux from the non-condensable gas components

Fouling and thermal resistance of tube wall are certain that fouling may occur inside and/or outside the tubes in the condensing boiler. Although fouling is time dependent, only a fixed value can be assumed during the design stage. Inside the tubes, the feed water to the bolier should be chemically treated. However, outside the tubes, the flue gas contains ultrafine particles and trace acid gases. Therefore the condensate on the shell-side may contain some amounts of solid and liquid contaminants. Consequently, the fouling resistances inside and outside the tubes ($R_{f,I}$ and $R_{f,o}$) were chosen as 0.000176 m^2K/W and 0.00176 m^2K/W. The thermal resistance of the stainless steel wall is 6.55×10^{-5} m^2K/W whereas for the carbon steel tubes coated with polypropylene, the thermal resistance is approximately 9.23×10^{-4} due to the low thermal conductivity of polypropylene.

Many possibilities' of energy saving systems in textile finishing are as follows: (i) waste water heat recovery; (ii) condensing stack economizer; (iii) wood gasification; (iv) conventional or wood gasification cogeneration of electricity and steam; (v) wood gas for coater frame incineration; (vi) air to air heat recovery; and (vii) electrical saving. All seven areas apply to dyehouses in the category, which is spending up to 750,000 annually on boiler fuel (Pulat *et al*., 2009).

This research focuses on the utilization of waste heat boiler to heat exchanger for preheat palm oil shell which the utilization of waste heat of flue gases is one of the beat possibilities for reduction of the green house gases emissions. This study aims to achieving the following: (i) calculation of the shell and tube heat exchanger for waste heat boiler in dyeing process, (ii) analysis of model solution heat exchanger is performed by ANSYS, (iii) economic evaluation of heat exchanger.

2. MATERIALS AND METHODS

2.1. Materials

Gas to gas waste-heat recovery exchangers may be categorized as plate-fin and primary surface exchangers, heat pipe exchangers, rotary regenerators, radiation and convection recuperator and runaround coils. Metallic radiation recuperators consist of two concentric metal tubes with the hot exhaust (flue) gas flowing through the central duct and the air to be preheated flowing in the outer annulus (Pulat *et al*., 2009), using as exhaust gas from boiler in textile industry (Y.R.C. Textile. Co, LTD.,Thailand).

2.2. Experimental investigation

The design of these heat exchangers is usually carried out with the aid of ANSYS using either commercial software packages available at the market or in house software products. Modeling unambiguously belongs to methods for an improved or even optimum design of heat exchangers. In this research are following areas: (i) simulation based on energy and mass balance which is thermal and hydraulic calculation of heat exchangers and (ii) economics evaluation.

Simulation based on energy and mass balance is the first step in calculations is necessary for evaluation of all process parameters for further calculation of heat exchangers (values of process fluids temperature, flow rates and properties of exhaust gas and air. For simulation several well-known commercial software packages are used like e.g., ASPEN PLUS, ChemCAD, Pro II, HYSYS (Stehlik, 2011), however, for some special areas like thermal processing of waste including energy utilization a creation of own software packages proved itself to be good solution. There are using specific software ANSYS which is suitable to gas-to-gas waste-heat recovery exchangers.

Values of process: the temperatures of exhaust gas and air inlet are average 190 and 34°C, respectively as shown in **Fig. 2 and 3**.

The flow rate of exhaust gas from boiler and air are average about 6.2 and 2.84 kg sec^{-1}, respectively as shown in **Fig. 4 and 5**.

The chemical composition of exhaust gas consisted of the following percentage by weight; N_2, 69.712%; O_2, 4.274%; CO_2, 13.629%; SO_2, 0.02%; H_2O, 12.382%. The moisture content of air is average about 0.2 kg vapor/kg dry air.

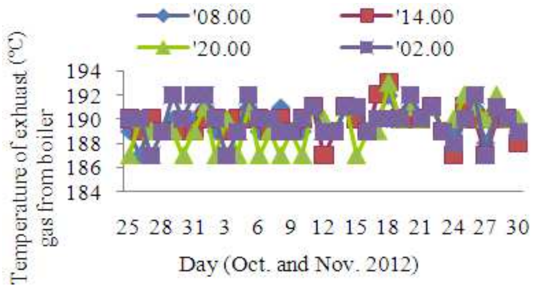


Fig. 2. The measure of exhaust gas temperature from boiler between 25 Oct to 30 Nov 2012 on 8.00, 14.00, 20.00 and 02.00 am

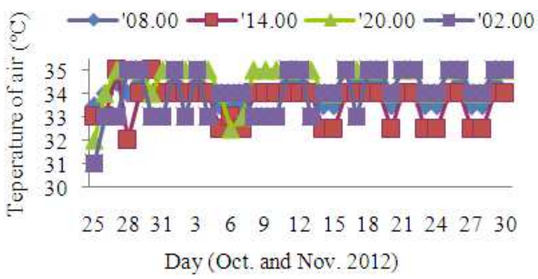


Fig. 3. The measure of air temperature between 25 Oct. to 30 Nov. 2012 on 8.00, 14.00, 20.00 and 02.00 am

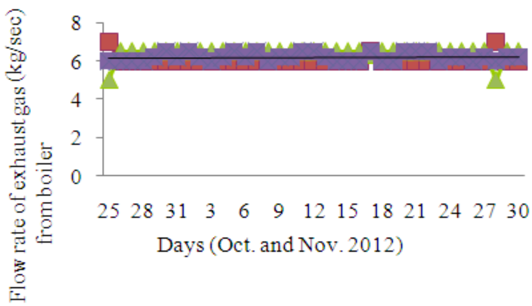


Fig. 4. The flow rate of exhaust gas from boiler between 25 Oct. to 30 Nov. 2012 on 8.00, 14.00, 20.00 and 02.00 am

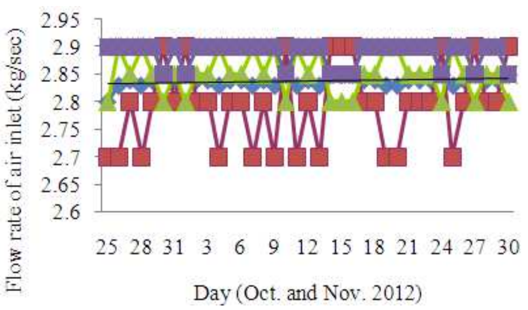


Fig. 5. The flow rate of air between 25 Oct. to 30 Nov. 2012 on 8.00, 14.00, 20.00 and 02.00 am

Economic evaluation is computation of Payback Period (PBP). The Payback Period (PBP) is the length of time that it takes for a project to recoup its initial cost out of the cash receipts that it generates. This period is sometimes referred to as" the time that it takes for an investment to pay for itself". The basic premise of the payback method is that the more quickly the cost of an investment can be recovered, the more desirable is the investment. The payback period is expressed in years. When the net annual cash inflow is the same every year, the following formula can be used to calculate the payback period:

PBP = Investment cost/Net annual cash inflow

3. RESULTS

3.1. Selection of Heat Exchanger

In the present work s shell and tube heat exchanger is selected to extract heat from the exhaust gas to air, in general the surface convective heat transfer surface on the gas side needs to have a much larger area for better heat transfer. Hence a separate heat exchanger is designed with tubes in which the exhaust gas is allowed to pass through the shell side to achieve higher surface area on the gas side. The major criterion in the design of waste heat recovery system is the proper selection of heat exchanger with optimum conditions. In the present investigation, the initial data are consist of palm shell consumption 70 ton day^{-1} (feed to boiler 0.8102 kg sec^{-1}), 24% of initial moisture content of palm shell, 0.1944 kg H_2O/s of initial moisture flow rate in palm shell, 0.6157 kg sec^{-1} of born dry palm shell mass, 15 % palm shell moisture content requirement, 0.7244 kg sec^{-1} of outlet palm shell weight, 0.1087 kg H_2O/s of outlet moisture flow rate in palm shell and 0.0858 kg H_2O/s of drying load.

The results of input and output data for shell and tube heat exchanger by using ANSYS software are reported in **Fig. 6 and Table 1**. The air is used to simulate the exhaust gas from boiler. The heat exchanger used for experiments is a shell and tube construction in a staggered arrangement as shown in **Fig. 6**. The tubes are mechanically expanded for the purposes of assembling with shell. The heat exchanger is in cross-counter flow. The air is circulated in four passes from the top to the bottom of the test section, in overall counter-flow with exhaust gas.

The front area is 1720×1720 mm, the flow length 7500 mm, the inner and outer diameter of exhaust gas is 800 mm, the tube assembly consist of 196 tubes, the tube diameter is 76.2 mm, the tube thickness is 2.6 mm, the tube length is 4500 mm and the tube length of air inner and air outer is 500 mm as shown in (**Fig. 7**).

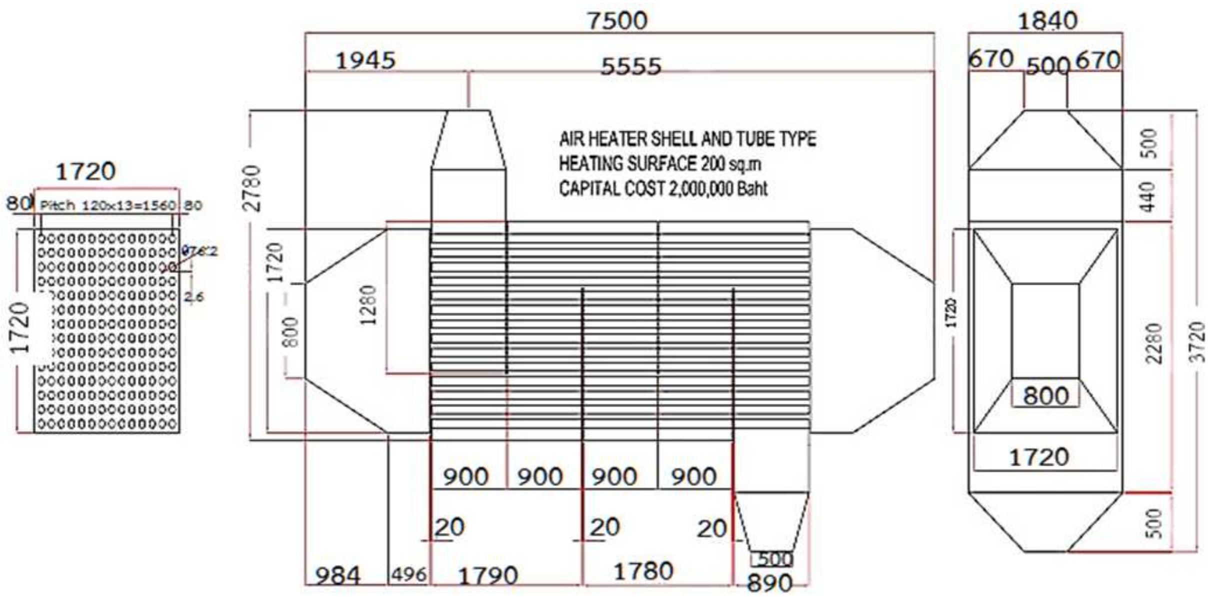


Fig. 6. The flow rate of air between 25 Oct. to 30 Nov. 2012 on 8.00, 14.00, 20.00 and 02.00 am

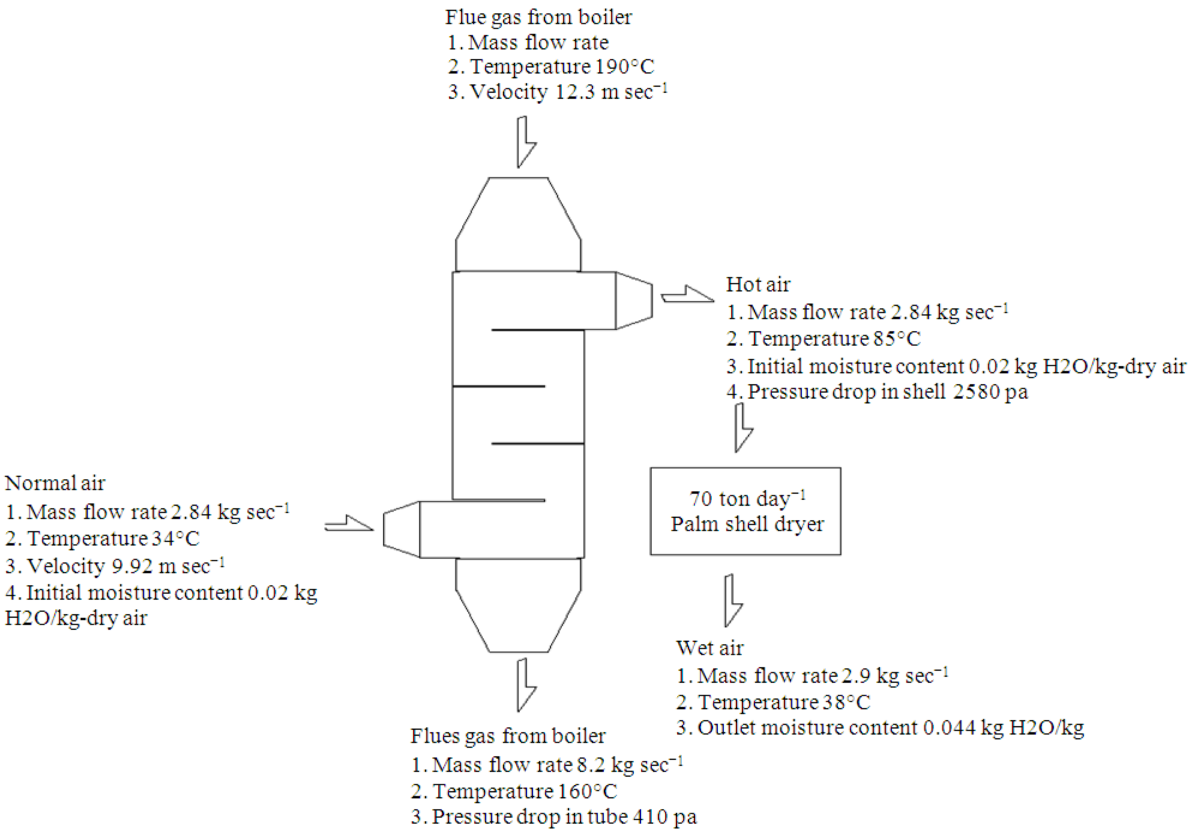
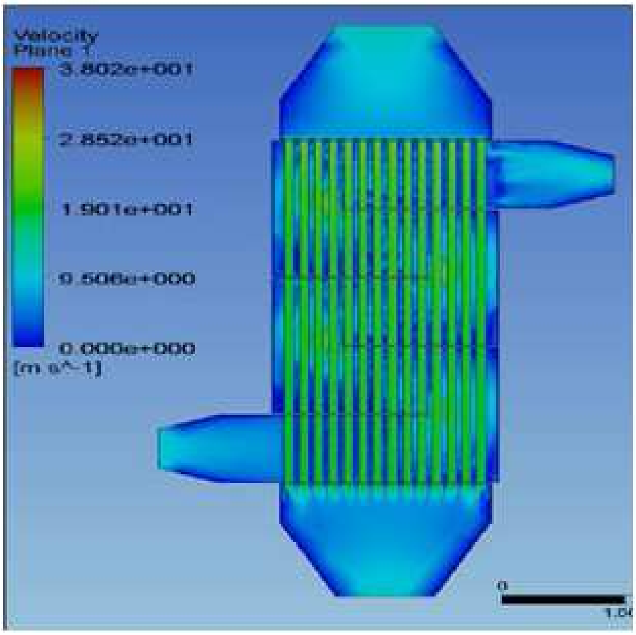
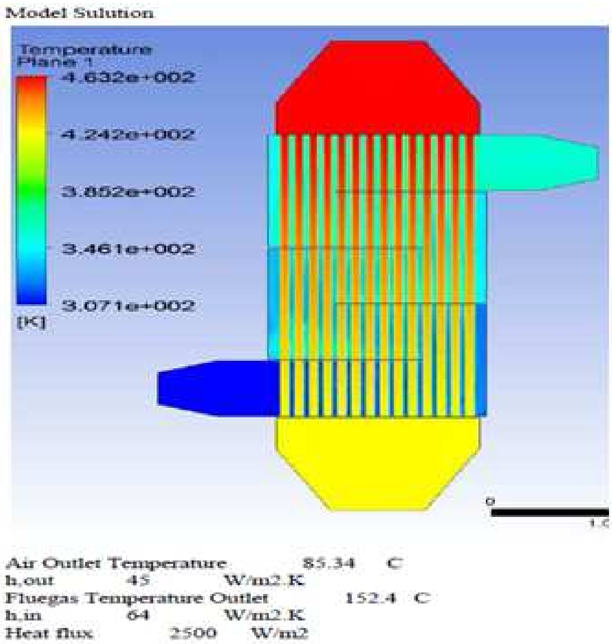


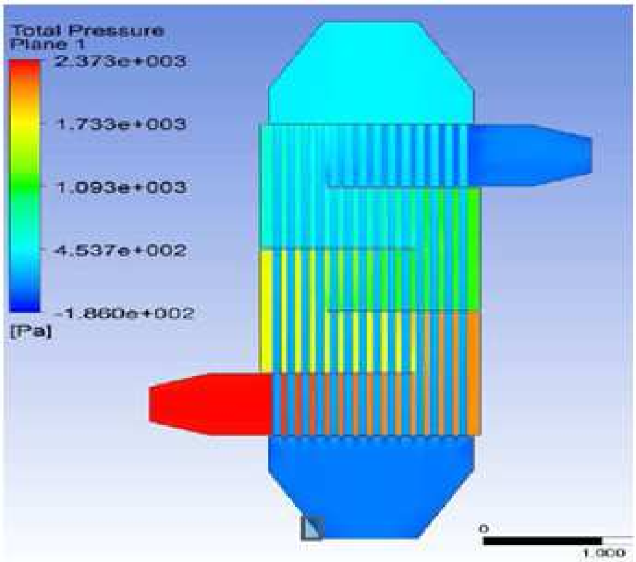
Fig. 7. Geometric dimensions of the shell and tube heat exchanger



(a)



(b)



(c)

Fig. 8. (a) Geometry of velocity with heat exchanger, (b) Geometry of temperature with heat exchanger and (c) Geometry of total pressure with heat exchanger

The results of simulation from ANSYS are shown reported in **Table 1**. The flow rate inlet and outlet is measured using a V-cone flow meter. The air inlet and outlet temperature are measured using two T-type thermocouple meshes placed upstream and downstream of test section. The core pressure drop across the heat exchanger is measured using eight pressure taps (four upstream and four down stream). The test conditions are as follows: Facing air velocity at the inlet and outlet of test section is 9.506 m sec^{-1} (**Fig. 8a**).

Table 1. The parameter input and output of heat exchanger design

	Parameter Input and output	
Input data	Calculation formula	Calculation result
Number unit	Description	Number unit
2920 kg h^{-1}	Q: Fuel consumption	2920 kg hr^{-1}
0.35	F: Heat transfer factor	0.35
211.14 m^2	Hs: Heating surface	211.14 m^2
0.0762 m	d: Tube air heater diameter	0.0762 m
4.5 m	L: Tube air heater length	4.5 m
196pcs.	Q'tyL: Tube air heater number	196 pcs.
0.0026 m	Ts: Thickness of tube wall	0.0026 m
1	F: Tube air heating factor surface	1
190°C	Tg1: Flue gas temperature after hot oil boiler	190°C
166.05°C	Tg2: Flue gas temperature after air heater	166.05°C
34°C	Ta1: Open air temperature	34°C
89.4°C	Ta2: Hot air temperature	89.4°C
120 mm	Pitch: Tube air heater pitch	120 mm
0.31815 m^2	Pa: Pass area in minimum section	0.31815

Table 2. First investment for shell and tube heat exchanger

Investment item	Cost (THB)
Land and building	
Machine/equipment	200,000
2,356,530.50	
Total first investment	2,556,530.50

Table 3. Operating cost for shell and tube heat exchanger

Operating cost	(THB/year)
Labors (3 workers/shifts)	97,200
Maintenance (15% of machine cost)	50,000
Electricity	792,824
Operated cost	550,581.20
Total	1,490,605.2

The inlet temperature of exhaust gas is 190°C, which is the exhaust gas outlet temperature is 152.2°C. While the inlet temperature of air is 34°C, which is the outlet temperature is 85.34°C (**Fig. 8b**).

The total pressure of exhaust gas at the inlet is 0.4537 kPa, which is the outlet about 0.186 kPa. The total pressure of air at the inlet is 2.373 kPa, which is the outlet about 0.186 kPa (**Fig. 8c**).

3.2. Economic Evaluation

In economic analysis for investment is shell and tube heat exchanger with capacity 70 tons/day, using palm shell to boiler from the case study. It is assumed that, the fifteen years of project life, working time at 8 hours a day, 360 days a year, direct labor cost per day is 300 THB/worker, the interest rate of 6.5%, electricity cost of 2.97 THB/kWh, the palm shell is 3,000 THB/tonne and maintenance cost is 15% of the machines' prices. The first investment is 2.907 million THB. Income from this case is the save energy cost to boiler about 6.6 million THB/year. Amount of electricity used for fan is 30 kW/hours. The approximated first investment and operating cost are shown in **Table 2 and 3**.

Results from the analysis show that, payback period of the heat exchanger are approximate 6 mouths; the Internal Rate of Return (IRR) is 182%.

4. DISCUSSION

The principal reason for attempting to recover waste heat is economic. All waste heat that is successfully recovered directly substitutes for purchased energy and therefore reduces the consumption of and the cost of that energy. A second potential benefit is realized when waste-heat substitution results in smaller capacity requirements for energy conversion equipment. Therefore, the use of waste-heat recovery can reduce the requirement for space-heating energy. This permits a reduction in the capacity of furnaces or boilers used for heating the plant. In every case of waste-heat recovery, a gratuitous benefit is derived: That of reducing thermal pollution of the environment by an amount exactly equal to the energy recovered, at no direct cost to the recover (Pulat *et al*., 2009).

Experimental results indicate the suitability of the shell and tube heat exchanger in textile industry, especially on boiler in dyeing process. Energy and environmental studied show that in increase of process efficiency simultaneously with a decrease of thermal pollution. In this study, system parameters such as heat capacity, recuperator energy saving potential were calculated. If feed air is heated with flue gases, the fuel consumption is reduced by about 2.05% (322.72 Kj kg^{-1}), while the shell and tube heat exchanger outlet flue gases temperature decreases from 190 to 150°C.

5. CONCLUSION

The present investigation has demonstrated that waste heat recovery exhaust flue gas from boiler to shell and tube heat exchanger for drying palm shell before input to boiler and ANSYS program of 70 tons/day were design. The second law of thermodynamic is powerful tool for design, optimization and performance evaluation of thermals systems. Base on the present analysis, the following results were concluded: (i) The heat exchanger is in cross-counter flow. The air is circulated in four passes from the top to the bottom of the test section, in overall counter-flow with exhaust gas. The front area is 1720×1720 mm, the flow length 7500 mm, the inner and outer diameter of exhaust gas is 800 mm, the tube assembly consist of 196 tubes, the tube diameter is 76.2 mm, the tube thickness is 2.6 mm, the tube length is 4500 mm and the tube length of air inner and air outer is 500 mm. (ii) The maximum heat extracted using the heat exchanger at full load condition is around 2920 kg h^{-1}. By decreasing the exhaust gas temperature about 150°C. it is possible to recover the heat, which is liberated from fuel along with the air. (iii) The result show that, the boiler for superheated type there are exhaust gas temperature is 190° C, 24% the moisture content of fuel and there are palm shell 70 tons/day which there are the high temperature after the heat exchanger, 150°C. It was occurred acid rain. The hot air from heat exchanger process can be reduced the moisture of palm shell fuel to 15%. (iv) The results of the thermo-economical analysis were given for both academic and industrial users. Also optimum parameters presented here are simple and have wide applicability. The payback period was determined about 6 months for investigated ANSYS.

Therefore, it can be concluded that waste-heat recovery techniques, which are environmental friendly and have technical and economical advantageous, should be evaluated in order to contribute to energy economy studies in Thailand.

6. ACKNOWLEDGMENTS

The researchers thank Y.R.C. Textile. Co, LTD., Thailand, for providing the ANSYS simulation and Rattanakosin College for Sustainable Energy and Environmemt, Rajamangala University of Technology Rattanakosin96 moo 3 Puthanomthon Sai 5, Salaya, Puthamonthon Nakhon Pathom, 73170 Thailand, for the help rendered during manuscript preparation.

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