Design and Experimental Performance Evaluation of Heat Exchanger Installed to Recover Exhaust Heat from Chimney to Supply Dry and Hot Air Required in a Bread/Biscuit Production Processes.

Ashish J. Chaudhari*, Vinay D. Patel*, Ravindra D. Jilte*

*(Assistant Professor, Department of Mechanical Engineering,
Vidyavardhini's College of Engineering and Technology, Mumbai University, Vasai-401202,(M.S.).
Email: chaudhari.aj@gmail.com, vinay.d.patel@gmail.com, rdjilte@gmail.com)

ABSTRACT

The head loss to the surrounding from exhaust gases of oven of bakery while producing work cannot be recovered which is also called as waste heat energy. Hence the overall efficiency of the bakery gets reduced. If some part of it can be recovered then the overall efficiency of the bakery can be increased.

There is need of a socio-economic project intended to recover heat from chimney to heat air as required in process of bread /biscuit production. In a conventional way, bread/biscuit process requires hot and dry air, supplied with heater which consumes electrical energy. No attempt has been to utilize exhaust energy leaving through chimney of Bread/Biscuit production factory. There are several heat exchangers as promising candidates for heat recovery. Since fresh air and exhaust gas should not get mixed while transferring energy, we will design heat pipe heat exchanger, which does not require any external energy for its operation. The main inputs for the project are bakery oven, heat exchanger, thermal insulation and preheating chamber.

The outcome of the project includes recovering the heat from exhaust gases of the oven to preheat the food in bakery. With this , it will help save energy in terms of fuel consumed by bakery and improving the plant efficiency.

Keywords – *Bakery oven, Counter flow heat exchanger, Effectiveness, Overall efficiency, Waste heat recovery*

NOMENCLATURE

m_f	Mass of flue gases, kg
m_a	Mass of air, kg
C_c	Specific heat capacity of fresh air (cool fluid), KJ/kg
C_h	Specific heat of flue gases(hot fluid), KJ/kg
k	Thermal conductivity of material, KJ/kg^0K
D_o	Outer diameter of pipe, m
D_i	Inner diameter of pipe, m
Q	Heat generated , W
T_1	Temperature in food main chamber, ^0C
T_2	Temperature of flue gas leaving main chamber, ^0C
T_3	Temperature of ambient air from blower, ^0C
T_4	Temperature of fresh air after heat exchanging, ^0C
T_5	Temperature of flue gas leaving heat exchanger, ^0C
T_6	Temperature of fresh air leaving precombustion chamber, ^0C
Cp_f	Specific heat of flue gas, KJ/kg^0K
Cp_a	Specific heat of fresh air, KJ/kg^0K

I. INTRODUCTION

1.1 Flue Gas:

Flue gas is a gas that exits to the atmosphere via a flue, which is a pipe or a channel called chimney for conveying exhaust gases from a fireplace, oven, furnace, boiler or steam generator etc Its composition depends on what is being burned, but it will usually consist of mostly nitrogen (typically more than two-third) derived from the combustion air, carbon dioxide(CO_2) and water vapour as well as excess oxygen(also derived from combustion air). It further contains a small percentage of pollutants such as particulate matter, carbon monoxide, nitrogen oxides and sulphur oxide.[7]

1.2 Waste Heat Recovery:

Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction and then dumped into the environment even though it could still be reused for some useful and economical purpose. The essential quality of heat is not the amount but rather its value. The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved.

Large quantity of hot flue gases is generated from boilers, Kilns, Ovens, and furnaces. If some of this waste heat is could be recovered, a considerable amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. [1]

1.3 Task to be performed:

There is need of a socio-economic project intended to recover heat from chimney to heat air as required in process of bread /biscuit production. In a conventional way, bread/biscuit process requires hot and dry air, supplied with heater which consumes electrical energy. No attempt has been to utilize exhaust energy leaving through chimney of Bread/Biscuit production factory. There are several heat exchangers as promising candidates for heat recovery. Since fresh air and exhaust gas should not get mixed while transferring energy, we will design heat pipe heat exchanger, which does not require any external energy for its operation. The main inputs for the project are bakery oven, heat exchanger, thermal insulation and preheating chamber. Thus fuel required for baking of food is reduced. The thermal efficiency and overall efficiency of system increases thereby reducing the overall cost of production.

II. LITERATURE REVIEW

2.1 Heat exchangers[3]

2.2.1. Recuperators: In a recuperators heat exchange takes place between flue gases and air through metallic or ceramic walls. Ducts or tubes carry the air for combustion to be preheated; the other side contains the waste heat stream.

2.2.2. Regenerator: The regeneration which is preferable for large capacities has been very widely used in glass and steel melting furnaces. In a regenerator, time between reversals is an important aspect. Long period means higher thermal storage and hence higher cost. Also long period of reversal result in lower average temperature of preheat and consequently reduce fuel economy.

2.2.3. Heat Pipe: A heat pipe can transfer up to 100 times more thermal energy than copper, the best known conductor. It has no moving parts and hence require minimum maintenance. Heat pipe consist of three main elements- a sealed container, a capillary wick structure and a working fluid. A heat pipe heat exchanger is a lightweight compact heat recovery system. It doesn't need input power for its operation and is free from cooling water and lubrication system. These systems are capable of operating at 315^0C with 60% to 80% heat recovery capability.

2.2.4 Economizer: In case of boiler system, economizer can be provided to utilize the flue gas heat for preheating the boiler feed water. For every 220C reduction in flue gas temperature by passing through economizer or air preheated, there is 1% saving of fuel in boiler.

2.2.5 Shell and tube heat exchanger: When the medium containing waste heat is a liquid or a vapor which heats another liquid, this heat exchanger is used. The shell contains the tube bundle, and usually internal baffles to direct the fluid in the shell over the tubes in multiple passes. The shell is inherently weaker than the tubes so that higher temperature fluid is circulated in the tubes while the lower pressure fluid flows through the shell.

2.2.6 Plate heat exchanger: The cost of heat exchange surfaces is a major cost factor when the temperature differences are not large. One way of meeting this problem is the plate type heat exchanger, which consist of a series of separate parallel plates forming thin flow pass. Each plate is separated from the next by the gasket and hot stream passes in parallel alternative plates through alternative plates whilst the liquid to be heated passes in parallel between the hot plates.

2.2 Heat Recovery[2]

2.2.1 High temperature heat recovery:

Table 1
Typical Waste heat temperature at high temperature range.

Type of device	Temperature, ^0C
Nickel Refining furnace	1370-1650
Aluminum Refining	650-760
Zinc Refining furnace	760-1100
Steel heating furnace	925-1050
Glass melting furnace	1000-1550

2.2.2 Medium temperature heat recovery

Table 2
Typical Waste heat temperature at medium temperature range

Type of device	Temperature, ^0C
Steam boiler exhaust	230-480
Gas turbine exhaust	370-540
Reciprocating engine	315-600
Heat treating furnace	425-650
Drying and baking ovens	230-600

2.2.3 Low temperature heat recovery

Table 3
Typical Waste heat temperature at low temperature range.

Type of device	Temperature, ^0C
Bearing	32-88
Welded machines	32-88
Annealing furnace	66-230
Air compressor	27-50
Pumps	27-88
Internal combustion engines	66-120
Air conditioning and refrigeration condensers	32-43

2.3 Benefits of waste heat recovery[4]

2.3.1. Direct Benefits: Recovery of waste heat has a direct effect on efficiency of the process. This is reflected by reduction in the utility consumption and costs and process cost.

2.3.2 Indirect Benefits:

a. **Reduction in pollution:** A number of toxic combustible waste such as carbon monoxide gas, sour gas, carbon black off gases, oil sludge, Acrylonitrile and other plastic chemicals etc releasing to atmosphere if/when burnt. Heat recovery reduces the temperature of exhaust gas pollution also.
b. **Reduction in equipment size:** Waste heat recovery reduces fuel consumption which leads to reduction in flue gas production. This results in reduction in equipment sizes
c. **Reduction in auxiliary energy consumption:** Reduction in equipment sizes gives additional benefits in the form of reduction in auxiliary energy consumption like electricy of fans, pumps etc.

III. CONCEPT AND MECHANISM

3.1 Concept:[5]

The overall efficiency of any bakery (wood fired) is in the range of 35 to 40%. Since it has a temperature range of 200 to 600 ^0C. For continuous combustion it is necessary to supply fuel to the system at regular intervals. However, the heat produced from it is not being completely utilized and major portion of it is lost to the atmosphere. By using waste heat recovery system, the heat energy is recovered. This heat energy is utilized to preheat the food product such as bread or biscuit so that they will partially bake. Finally the partly baked food is baked in the oven with less heat.

3.2 Mechanism:

The mechanism consist of

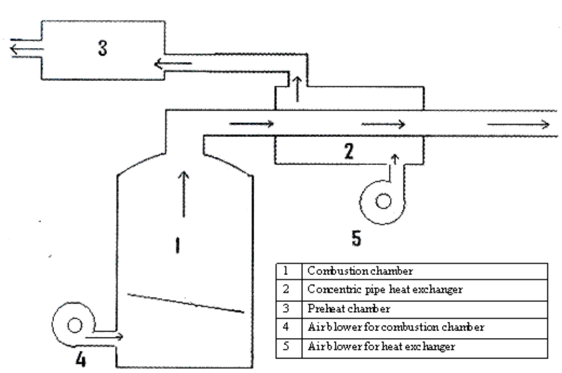

Figure 1 Line diagram of Assembly of waste heat recovery system

IV. THEORETICAL EVALUATION

4.1 Flue Gas Analysis [6]

For 1 kg of dry wood
Composition by weight:
C=48.5%, H_2=6%, O_2=43%,N_2=0.5%
Incombustible ash = 1.5%
Gross calorific value = 10500 KJ/kg
Assuming complete combustion
Flue gas formed per kg of dry wood= 6.788 kg.
Assuming Cp_f =1.046 KJ/kg ^{0}K

Heat carried away by dry flue gas= 784.24 KJ/kg of dry wood

So Per cent loss= $\frac{784.24}{10500}$ = 7.46%

But in actual case combustion is not complete
Excess of oxygen required for complete combustion. Therefore loss tends to increase.

4.2 Oven Design:

Assumptions:

- Heat lost considered only by conduction.
- m_f =0.5 kg/hr

-Heat generated on combustion $Q = \frac{m_f \times CV}{3600}$ (1)

- Thickness of combustion chamber

Assuming temperature in combustion chamber is 150^{0}C and ambient temp. 30^{0}C

$$- \frac{Q}{A} = \frac{(t_i - t_o)}{\left(\frac{L_1}{K_1} + \frac{L_2}{K_2}\right)} \quad (2)$$

Dimensions of oven = 2 ft × 2 ft= 0.37 m^2
K_1-Thermal conductivity of steel= 40$W/m^2\,{}^0K$
K_2-Thermal conductivity of asbestos= 0.166$W/m^2\,{}^0K$
-thickness of oven chamber =5.5 mm

4.3 Blower Selection:

-Since we require 5.187 kg of air / kg of fuel(wood) for complete combustion. We take 3 kg of air for 0.5 kg of fuel.
- The velocity of fresh air at inlet = 3.11 m/sec.
-selecting the appropriate blower from the standards available.

4.4 Concentric tube type heat exchanger

-Assumptions
-Ideal cases are considered
-Losses to the surrounding is not considered
- No radiation heat loss
- Steady state heat transfer condition
- m_f = 11×10^{-3} kg/hr
- m_a = 12.5×10^{-3} kg/hr
- CP_f = 1.045 KJ/kg^{0}K
- CP_a = 1.005 KJ/kg^{0}K
- $C_c = m_a \times CP_a$ (3)
- $C_h = m_f \times CP_f$ (4)
- designing the heat exchanger by NTU Method, the outlet temperature of fresh air coming from heat exchanger =61.51^{0}C

V. EXPERIMENTAL EVALUATION

Figure 2 Experimental Set up

5.1 Procedure to perform experiment:

i. The fuel was supplied in the combustion chamber at rate of 1 kg/hr.
ii. 1 kg dry wood was burned inside combustion chamber with no food in either main or preheat chamber.
iii. Temperature at various points were observed and noted down. The readings were taken at interval of 5 min. This is to find the effectiveness of heat exchanger.
iv. Now bread yeast was kept only in the main food chamber and time required for baking in main chamber is noted.
v. Now the bread yeast first kept in preheat chamber for some time and then shifted to main chamber for complete baking, the total time required for baking is noted.
vi. Results and tabulated.

5.2 Observation Table:

5.2.1 Without food item

-Type of fuel = Dry wood
-Mass of fuel = 1 kg/hr
-Calorific value of dry wood= 10500 KJ/kg

Table 4 Observations of oven with out food and pre heater

Sr No	Time min	Temperature ^{0}C					
		T1	T2	T3	T4	T5	T6
1	5	320	215	37	50	199	46
2	10	319	218	37	49	203	42
3	15	317	198	37	48	190	42
4	20	317	214	37	47	185	41
5	25	315	220	38	49	202	41
Mean		319.6	213	37.2	48.6	195.8	42

5.2.2 With food item

-Weight of food = 100 gm
-Mass of fuel = 1 kg/hr
- Food yeast= bread yeast

Table 5 Observations of oven with food in main chamber

Sr No	Time min	Temperature ^{0}C					
		T1	T2	T3	T4	T5	T6
1	2	192	147	42	57	134	43
2	4	196	146	43	57	133	43
3	6	197	148	42	57	135	44
4	8	203	150	42	56	137	46
5	10	215	154	42	57	141	41
Mean		200.6	149	42.2	56.8	136	44.4

- Time taken for baking = 10 mins.

5.2.3 Preheated food shifted to main combustion chamber

Table 6 Observations of oven with preheated food from preheater in main chamber

Sr No	Time min	Temperature ^{0}C					
		T1	T2	T3	T4	T5	T6
1	2	195	164	40	50	152	44
2	4	195	164	41	52	153	43
3	6	196	164	41	52	153	44
Mean		195.33	164	40.66	51.3	152.6	43.6

- Time taken for baking = 6.47 mins
- Savings in time = 3.53 mins

-Effectiveness of heat exchanger

$$\varepsilon = \frac{1-\exp(-NTU(1-R))}{1-R\exp(-NTU(1-R))} \quad (5)$$

- Thermal efficiency without preheat chamber

$$\eta_{th1} = \frac{Q_{utilized}}{Q_{\sup plied}} \quad (6)$$

- Thermal efficiency without preheat chamber

$$\eta_{th2} = \frac{Q_{utilized}}{Q_{\sup plied}} \quad (7)$$

VI. RESULTS

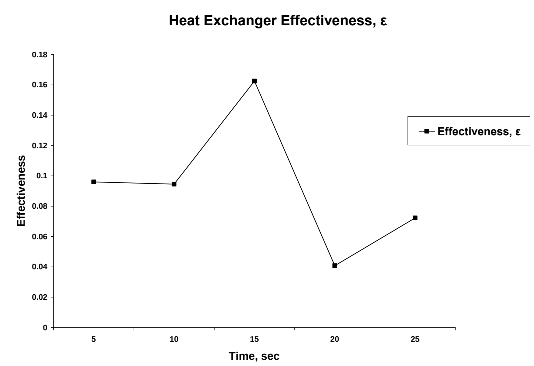

Figure 3 Heat exchanger effectiveness Vs Time

- The effectiveness of heat exchanger is calculated at different time interval which is plotted above. It is found that avg .10% effectiveness is achieved.

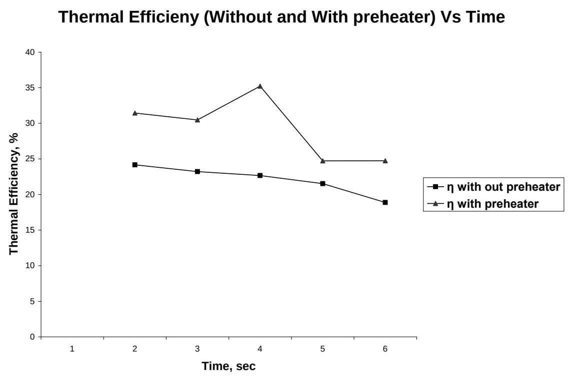

Figure 4 Thermal Efficiency (without preheater and with preheater) Vs Time

- Thermal efficiency results are shown with the time interval without preheated food and with preheated food. The results show that the thermal efficiency is improved with preheated food process.

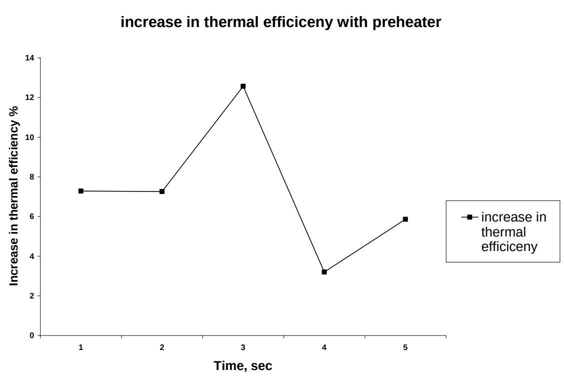

Figure 5 Increases in Thermal Efficiency (with preheater) Vs Time

- Increase in thermal efficiency of system by average of 4.61% observed.
- Also there is saving of fuel of 3.46 kg of wood per day

VII. CONCLUSION

From the above experimentation it is found that

- The design of heat exchanger will be done with maximum variables taking into account so that effectiveness can be improved which is approximately 10% in this paper. The selection of material for heat exchanger will improve the heat exchanger efficiency
- The method is very useful for the food products which are been the daily eatables for humans because the cost of the product will decrease with this waste heat recovery.
- By this experimentation the waste heat recovery system for bakery is really useful.

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