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Oil Conservation in Biscuit Industry

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ABSTRACT
The paper is based on a thermal energy audit conducted in a medium scale biscuit industry. A significantly large amount of heat is detected in the exhausts from tunnel shaped oven used for baking biscuits. A cost effective waste heat recovery scheme is suggested to conserve precious oil. Since the fuel used is High Speed Diesel (HSD) oil and the saving potential is very large. The proposal claims a very short payback period.

***Key Words**: Tunnel Oven, Waste-Heat, Enthalpy, Mass flow rate*

1. INTRODUCTION
Commercial biscuit manufacturing involves a series of highly mechanized operation, which progressively convert the original ingredients into finished products. Large-scale biscuit baking is carried out in tunnel shaped ovens varying in length from 30 m to 150 m. The products travel through the oven on continuous baking supports. The paper is based on a work that has been an attempt to practically study the energy flow in detail in the oven system referred above, estimate the potential of recoverable waste heat and suggest modifications in the oven construction and/or operation with an objective to save the precious oil as much as possible in a cost effective way. The oven under study uses high-speed diesel (HSD) as fuel. Name of the industry is Nezone Biscuit Private Limited, located at Tezpur, in the State of Assam. The factory, well equipped with modern machineries, produces various varieties of biscuits. The annual consumption of diesel oil by two tunnel shaped ovens in the firm has an average value of 4, 70,000 liters.

2. WASTE-HEAT RECOVERY
Waste heat is that which is rejected from a process at a temperature high enough above the ambient temperature to permit the economic recovery of some fraction of that energy for useful purposes. A principal reason for attempting to recover waste heat is economic. All waste heat that is successfully recovered directly substitute for purchased energy and it therefore reduces the consumption and the cost of that energy. A potential benefit is realized when waste heat substitution results in smaller capacity requirement of energy conversion equipment. Thus the use of waste heat recovery can reduce capital cost in new installations. Reduction of thermal pollution of the environment by an amount exactly equal to the energy recovered at no direct cost is an added advantage. The quantity of waste heat available is ordinarily expressed in terms of the enthalpy flow of the waste stream, or

$$\dot{H} = \dot{m}h \qquad (1)$$

where, $\dot{H}$= total enthalpy flow rate of waste stream, kW, $\dot{m}$ = mass flow rate of stream, kg/s, h = Specific enthalpy of waste steam, kW/kg
The mass flow rate, $\dot{m}$, is given by the expression,

$$\dot{m} = \ell Q \qquad (2)$$

Where, ℓ= density of material, kg/m^3, Q = volumetric flow rate, m^3/s

3. THE TUNNEL OVEN
EC – Exhaust gas Chimney; MC – Moisture Chimney; HF – Heat fan; TF – Turbulence Fan
The tunnel oven is divided into five independent chambers, each comprising a combustion chamber with burner, circulating fan, turbulence fan, and the associated ductwork feeding the banks of radiator tubes. The flue gases and moisture are exhausted to the atmosphere through separate chimneys from each chamber as shown in the oven diagram in Fig 1.

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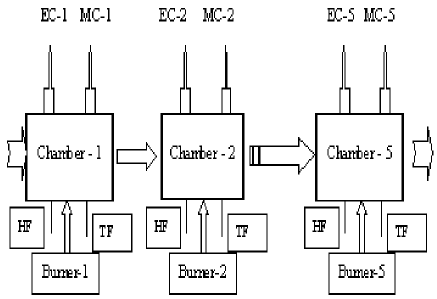

Fig 1: Oven diagram

4. MEASUREMENTS, ESTIMATION AND ANALYSIS

The following measurements/estimations have been carried out in order to obtain the complete performance data of the oven. Table-1 shows the measured data which are shown in Table – 2. Fig. 2 shows the biscuit baking profile obtained from the measured data.

(i) Measurement of temperature of exhaust flue gas and exhaust moisture for all chimneys and for several days
(ii) Measurement of temperature inside the five chambers of the tunnel oven
(iii) Measurement of temperature of biscuit sample inside different oven chambers
(iv) Measurement of pressure head in all five pairs of flue gas and moisture chimneys
(v) Estimation of moisture in biscuit samples
(vi) Estimation of mass flow rates of flue gas and moisture for all five pairs of chimneys
(vii) Diesel consumption rate of the five burners

Table-1: Measurement of Pressure Head in Flue Gas Chimney and Moisture Chimney

Chimney No.	1	2	3	4	5
Flue Gas Head in m of K* Oil	0.002	0.002	0.002	0.002	0.001
Moisture Head in m of ‘K' Oil	0.001	0.002	0.002	0.002	0.001

* Kerosene

Table - 2: Estimated Data of Oven Performance

	Chamber numbers				
Parameters	1	2	3	4	5
Chamber temperature (K)	463	503	528	543	448
Biscuit temperature (K)	329	345	363	376	382
Average exhaust flue gas temperature, K	589	616	581	579	525
Exhaust flue gas head (m of ‘K’oil column)	0.002	0.002	0.002	0.002	0.001
Exhaust flue gas density, (kg/m^3)	0.592	0.566	0.6	0.602	0.664
Exhaust flue gas flow rate, (kg/s)	0.0931	0.09	0.0937	0.0939	0.0697
Specific heat of flue gas, (kJ/kg K)	1.047	1.054	1.045	1.044	1.032
Average exhaust moisture temperature, (K)	363	489	501	502	424
Moisture head (m of ‘K’oil column)	0.001	0.002	0.002	0.002	0.001
Exhaust moisture density, (kg/m^3)	0.442	3.43	3.861	3.936	1.515
Exhaust moisture flow rate, (kg/s)	0.057	0.222	0.238	0.240	0.1043
Spec. heat of moisture, (kJ/kg K)	3.0	3.078	3.275	3.309	2.317
Diesel Consumption, (Ltr/hr.)	7.5	13.0	11.5	10.0	8.0

Fig. 2 shows the biscuit baking profile obtained from the measured data. Oven temperature gradually increases till chamber no.4 and then decreases. Biscuit baking temperature continue to increase till chamber no.5. This is to maintain the desired quality of the biscuit.

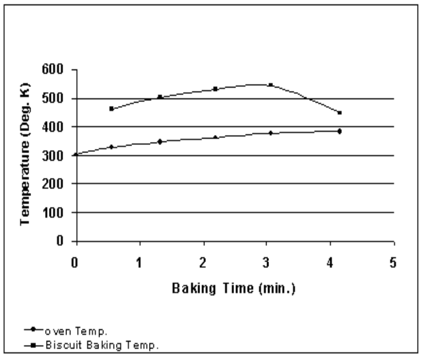

Fig. 2: Biscuit baking profile

5. ESTIMATION OF SPECIFIC HEAT

The following equations to estimate values of specific heat are applicable for atmospheric pressure (0.1013 MN/m^{-2}) in the temperature range of 0 to 100 ^{0}C. But the temperatures in the exhaust flue gas and exhaust moisture at the exit of the flue gas chimneys and moisture chimneys are higher than 100 ^{0}C [Callaghan, 1998]. However it is assumed that these relations hold good for the present cases too.

Specific heat of flue gas, (J/kg ^{0}K)

$$C_{pg} = 1003.74 + 0.036T + 0.000\,223T^2 + 0.000\,000\,3T^3 \quad (3)$$

Specific heat of moisture, (J/kg ^{0}K)

$$C_{pm} = 1853.7 + 0.6119T + 0.000\,892\,9T^2 + 0.000\,104\,2T^3 \quad (4)$$

Specific heat of air in the exhaust moisture, (J/kg ^{0}K)

$$C_{pa} = 1003.74 + 0.036T + 0.000223T^2 + 0.0000003T^3 \quad (5)$$

Specific heat of water in the exhaust moisture, (J/kg ^{0}K)

$$C_{pw} = 4216.5 – 2.398T + 0.04238T^2 - 0.000194T^3 \quad (6)$$

Density of moisture, (kg/m^2)

$$\rho_m = 0.0235518 – 0.003303T + 0.000088312T^2 \quad (7)$$

Density of flue gas, (kg/m^2)

$$\rho_g = \frac{P}{RT} \quad (8)$$

where,

P = Pressure of gas in $N/m^2 = 10^5\ N/m^2$

R = Characteristic gas constant = 287 J/kg ^{0}K

T = Absolute temperature of gas in ^{0}K

Diesel Fuel Data

Calorific value	= 42000 kJ/kg
Density	= 850 kg/m^3
Carbon content	= 86.3 %
Hydrogen content	=13.5 %
Combustion air (minimum)	= 11.2 m^3/kg
Combustion air required for clean combustion	= 15 m^3/kg
CO_2 emission (max.)	= 15.4 %
Mass of 1 litre of diesel	= 0.85 kg

Mass Flow Rate of Flue Gas

By equating the pressure heads,

$$\rho_g h_g = \rho_k h_k \quad (9)$$

where,

ρ_g = Density of flue gas in the chimney at flue gas temperature, kg/m^3

h_g = Pressure head of flue gas at the point of chimney, m of 'K'oil

ρ_k = Density of 'K'oil at normal temperature, kg/m^3,

= 800 kg/m^3 and is same for all the chimneys.

h_k = Pressure head of 'K'oil in manometer tube, m

Also,

$$V_g = \sqrt{2gh} \quad (10)$$

where,

V_g = Flow velocity of flue gas, m/s

g = Gravitational force, m/s^2

h = Pressure head of flue gas, m of 'K' oil

Mass flow rate of flue gas = $a \times V_g$ (11)

where, a = area of the chimney, m^2

Mass Flow Rate of Air

Mass flow rate of moisture, Q_m is the sum of mass flow rate of air, Q_a and mass flow rate of water, Q_w. Therefore,

$$Q_a = Q_m - Q_w \quad (12)$$

Mass Flow Rate of Water

Mass flow rate of water for the entire moisture chimney are calculated from the moisture data of biscuit. Estimation of moisture content in the biscuit is carried out in muffle furnace.

Enthalpy Distribution for Different Heat Streams

A total of 21 heat streams have been identified in one tunnel oven system for which the enthalpy calculations have been carried out with the datum considered as room temperature (303 ^{0}K) and atmospheric pressure. The results are presented in Table-3.

Table-3: Enthalpy Distribution

S. No.	Type of Stream	Stream Name	Supply Temp. ^{0}K	Target Temp. ^{0}K	ΔT ^{0}K	Total Enthalpy = $mC_P\Delta T$ kW
1	Utility	Feed -1 (Air)	303	619	316	04.67
2	Hot	Exhaust Flue Gas -1	589	303	289	27.88
3	Hot	Exhaust Moisture -1	363	303	060	01.49
4	Col	Biscuit -1	303	329	026	12.98
5	Utility	Feed - 2 (Air)	303	646	343	75.91
6	Hot	Exhaust Flue Gas - 2	616	303	313	29.70
7	Hot	Exhaust Moisture - 2	489	303	186	44.16
8	Utility	Biscuit - 2	329	345	016	08.00
9	Hot	Feed-3 (Air)	303	611	313	69.95
10	Hot	Exhaust Flue Gas - 3	581	303	278	27.22
11	Cold	Exhaust Moisture - 3	501	303	198	53.63
1	Util	Biscuit - 3	345	363	018	09.00
13	Hot	Feed - 4 (Air)	303	609	306	70.78
14	Hot	Exhaust Flue Gas- 4	579	303	276	27.05
15	Cold	Exhaust Moisture - 4	503	303	200	53.81
16	Utility	Biscuit – 4	363	376	013	06.49
17	Hot	Feed -5 (Air)	303	555	252	25.17
18	Hot	Exhaust Flue Gas -5	525	303	222	15.96
19	Hot	Exhaust Moisture -5	423	303	120	13.75
2	Col	Biscuit - 5	376	382	006	03.00
2	Hot	Biscuit - 6	382	303	079	39.44

Total fuel consumption = 42.5 kg
Total heat energy generated = 42.5 × 42000 = 496 kJ/Se Say, 500 kW
Total cold stream enthalpy = 39.47 kW
Total flue gas enthalpy = 127.81 kW
Total moisture enthalpy = 166.83 kW

6. ENERGY CONSERVATION PROPOSAL

The present oven system needs modification since a lot of useful heat is wasted as exhaust flue gas and moisture, which can be recovered and effectively utilized for

(i) baking biscuits in one or more oven chambers to yield fuel saving, or,
(ii) heating water used for preparation of syrup and dough in biscuit production, or,
(iii) Cleaning utensils used in biscuit production.

The modifications suggested are keeping the same process for baking biscuits and also the baking profile of the biscuits manufactured at the factory.

Considering only the first option of re-using the recovered waste heat in the existing oven chambers, the following modification in oven construction and operation has been suggested:

The exhaust flue gas temperature at the exit of the exhaust flue gas chimney EC-2 is 616 K and the corresponding value of enthalpy has been estimated as 29.7 kW, whereas the temperature and enthalpy required for biscuit baking in chamber-1 are 463 K and 13 kW respectively. So, the exhaust flue gas of chamber-2 can be utilised in chamber-1 replacing burner-1. The exhaust flue gas temperature of chimneys EC-3 and EC-4 are 581 K and 579 K respectively and their respective enthalpy values are 27.216 kW and 27.05 kW. If these are combined through extra piping, the average temperature and the average enthalpy will be 580 K and 27.11 kW respectively. The temperature and enthalpy requirements of chamber-5 are 448 K and 3.0 kW respectively. Therefore, the exhausts of chamber-3 and chamber-4 can be utilized in chamber-5 and burner-5 can be permanently removed.

Exhaust Flue Gas 252 ^{o}C

The suggested modification can save 15.5 liters of fuel (HSD) per hour (that is the combined fuel consumption of burners 1 and 2) as shown in Table-4. The exhausted flue gas can be fed to chambers 1 and 5 through insulated pipes of 4-inch diameter, so that the pressure and heat losses can be prevented. The proposed oven diagram is shown in Fig. 3.

Table-4: Comparison of Fuel Consumption Figures

Oven Chamber	Present Fuel Consumption Ltrs/hr	Proposed Fuel Consumption Ltrs/hr
1	7.5	-
2	13.0	13.0
3	11.5	11.5
4	10.0	10.0
5	8.0	-
Total	50.0	34.5
Total fuel saving = 50.0 – 34.5 = 15.5 ltrs/hr		

7. COST ANALYSIS

Net saving of fuel (diesel) = 15.5 ltrs/hr
Cost of diesel = Rs. 28.00 per litre.
Saving in terms of money = 15.5 ltrs/hr x 24 hrs x 300 days x Rs. 28.00 per litre = Rs. 31, 24, 800 per annum, Say, Rs 31 lakhs
Cost of modification work = Rs. 1,00,000

$$\text{Pay back period} = \frac{1 \times 12 \times 30}{31}$$

= 11.6 days, Say, 12 days

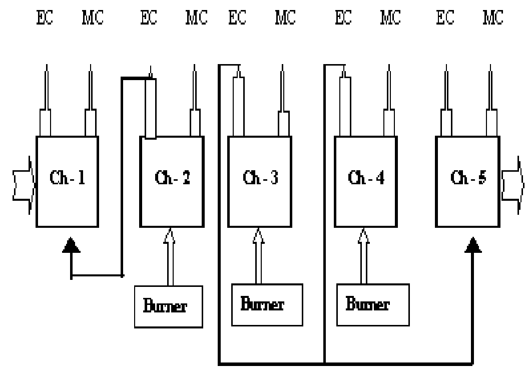

Fig. 3: Proposed oven diagram

8. CONCLUSION

The thermal energy audit conducted in a biscuit factory has revealed that a lot of heat energy is wasted; the amount of waste is significantly high even on hourly basis estimations and analyses show that cost effective waste heat recovery from the exhaust flue gas and exhaust moisture is not at all difficult. Even by a pessimistic benefit-cost estimate the payback period will be hardly two weeks.

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