Energy Conservation Analysis in Biscuit Industry

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Abstract
The paper is mainly based on energy audit of heat energy undertaken on a biscuit factory. The exhaust flue gases carrying significant amount of waste thermal energy is detected from independent exhaust stacks. There is a substantial amount of waste energy available, which can be harnessed easily and be equalized to purchase energy. The existing system is required to be modified in a cost effective way to conserve significant amount of precious conventional fuel (High Speed Diesel). The proposal recommended is feasible with a very short pay back period. The saved money can be utilised in improvement of the product quality, expansion of the plant, efficiency improvement of the plant as a whole etc. At the same time reduction in energy consumption will reduce the pollution level to some extent. Identification and quantisation (in selected cases) of these energy saving opportunities have been achieved through the present study.

Key Words: Audit, Stack, Thermal, Mass flow rate, Pay-back, Energy, Enthalpy

1. Introduction
The name of the industry Nezone Biscuit Private Limited, located in Tezpur in the state of Assam, where intensive research work conducted. 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. The Indian power sector is facing a big energy crisis. There is a good potential of defending the present energy crisis through energy conservation and efficiency improvement at the end use stage. Reductions in energy cost can therefore, improve profit level in the industries. Saving money on energy bills is attractive to business, industries, and individuals alike. Customers, whose energy bills use up a large part of their income, and especially those customers whose energy bills represent a substantial fraction of their company’s operating costs, have a strong motivation to initiate and continue an ongoing energy cost control program. The potential of recoverable waste heat is estimated and modifications are suggested 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.

2. Recovery of Waste Heat Energy
Waste heat which is at a temperature high enough above the ambient temperature to permit the economic recovery of some fraction of that energy for useful purposes. 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 expressed in terms of the enthalpy flow of the waste heat, or

\[ H^\square = m^\square h \]  

where, \( H^\square \) = total enthalpy flow rate of waste stream, kW,
\( m^\square \) = mass flow rate of stream, kg/s,
\( h \) = Specific enthalpy of waste steam, kW/kg

The mass flow rate, \( m^\square \), is given by the expression,

\[ m^\square = \ell Q \]  

where, \( \ell \) = density of material, kg/m\(^3\), \( Q \) = volumetric flow rate, m\(^3\)/s

3. Methods of Calculation of Different Data
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 °C. But the temperatures in the exhaust flue gas and exhaust moisture at exit of the flue gas chimney and moisture chimneys respectively are higher than 100 °C (Ref. energy management by Paul O’ Callaghan, page no.395). However it is assumed that these relations hold good for the present cases too. (For different temperatures refer Table no. 3.14)

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Specific heat of flue gas, (J/kg °K)
\[ C_{pg} = 1003.74 + 0.036T + 0.000223T^2 + 0.0000003T^3 \]  
(3)

Specific heat of moisture, (J/kg °K)
\[ C_{pm} = 1853.7 + 0.6119T + 0.0008929T^2 + 0.0001042T^3 \]  
(4)

Specific heat of air in the exhaust moisture, (J/kg °K)
\[ C_{pa} = 1003.74 + 0.036T + 0.000223T^2 + 0.0000003T^3 \]  
(5)

Specific heat of water in the exhaust moisture, (J/kg °K)
\[ C_{pw} = 4216.5 - 2.398T + 0.04238T^2 - 0.000194T^3 \]  
(6)

Density of moisture, (kg/m^2)
\[ \rho_m = 0.0235518 - 0.003303T + 0.000088312T^2 \]  
(7)

Density of flue gas, (kg/m^2)
\[ \rho_g = \frac{P}{RT} \]  
(8)

Where,
- \( P \) = Pressure of gas in N/m^2 = 10^5 N/m^2
- \( R \) = Characteristic gas constant = 287 J/kg K
- \( T \) = Absolute temperature of gas in K

<table>
<thead>
<tr>
<th>Chimney Nos.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flue Gas Head in m of K* Oil</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.001</td>
</tr>
<tr>
<td>Moisture Head in m of ‘K’ Oil</td>
<td>0.001</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.001</td>
</tr>
</tbody>
</table>

* Kerosene

**Calculation of Fluid Mass Flow Rate of Flue Gas**

We know that,
\[ \rho_g h_g = \rho_k h_k \]  
(By equating the pressure heads)  
(9)

Where,
- \( \rho_g \) = 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
- \( \rho_k \) = Density of ‘K’ oil at normal temperature, kg/m^3
- \( h_k \) = Pressure head of ‘K’ oil in manometer tube, m

\[ H_g = \rho_k h_k \]
\[ \frac{\rho_g}{\rho_k} = \frac{800 \times 0.002}{0.592} = 2.703 \text{ m} \]  
(10)

We know that,
\[ V_g = \sqrt{2gh} \]  
(11)

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

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\[ V_g = \sqrt{\frac{2 \times 9.81 \times 2.703}{9.81}} \]

\[ = 7.282 \text{ m/s} \] (12)

Mass flow rate of flue gas = \( a \times V_g \) (13)

Where,

\[ a = \text{Area of the chimney, m}^2 \]

\[ = \pi/4 \times d^2 \]

\[ (d = 0.166 \text{ m, diameter of the chimney and is same for all the chimneys, m}) \]

\[ = 3.14/4 \times (0.166)^2 \] (14)

\[ = 0.0216 \text{ m}^2 \] (This area of the chimney is same for all the chimneys because the diameter of all the chimneys are same)

Therefore,

\[ \text{Mass flow rate} = 0.216 \times 7.282 \] (15)

\[ = 0.157 \text{ m}^3/\text{s} \]

\[ = 0.157 \times 0.592 \text{ (Density of flue gas)} \]

Mass flow rate = 0.0931 kg/s

In the same way, we can calculate the mass flow rate of flue gas and moisture for all other flue gas chimneys and moisture chimneys respectively.

**Calculation of Mass Flow Rate of Air**

We know that,

\[ \text{Mass flow rate of moisture} (Q_m) = \text{Mass flow rate of air} (Q_a) + \text{Mass flow rate of water} (Q_w) \]

\[ (Q_m) = (Q_a) + (Q_w) \] (16)

Therefore,

\[ \text{Mass flow rate of air} (Q_a) = (Q_m) - (Q_w) \] (17)

**Table 2: Calculated Data of Oven Performance**

<table>
<thead>
<tr>
<th>Particular</th>
<th>Chamber numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Average exhaust flue gas temperature, K</td>
<td>589</td>
</tr>
<tr>
<td>Exhaust flue gas head in m of 'K' oil column</td>
<td>0.002</td>
</tr>
<tr>
<td>Exhaust flue gas density, kg/m³</td>
<td>0.592</td>
</tr>
<tr>
<td>Exhaust flue gas flow rate, kg/s</td>
<td>0.0931</td>
</tr>
<tr>
<td>Specific heat of flue gas, kJ/kg K</td>
<td>1.047</td>
</tr>
<tr>
<td>Average exhaust moisture temperature, K</td>
<td>363</td>
</tr>
<tr>
<td>Moisture head in m of 'K' oil column</td>
<td>0.001</td>
</tr>
<tr>
<td>Exhaust moisture density, kg/m³</td>
<td>0.442</td>
</tr>
<tr>
<td>Exhaust moisture flow rate, kg/s</td>
<td>0.057</td>
</tr>
<tr>
<td>Specific heat of moisture, kJ/kg K</td>
<td>3.0</td>
</tr>
<tr>
<td>Diesel Consumption, Ltr/hr.</td>
<td>7.5</td>
</tr>
</tbody>
</table>

**Table 3: Diesel Fuel Data:**

<table>
<thead>
<tr>
<th>Calorific value, kJ/kg</th>
<th>Density, kg/m³</th>
<th>Carbon Content, %</th>
<th>Hydrogen Content, %</th>
<th>Combustion Air, m³/kg</th>
<th>Air Req'd. for clean combn. (min.), m³/kg</th>
<th>CO₂ emission, (Max.), %</th>
<th>Mass of 1 ltr of diesel, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>42000</td>
<td>850</td>
<td>86.3</td>
<td>13.5</td>
<td>11.2</td>
<td>15</td>
<td>15.4</td>
<td>0.85</td>
</tr>
</tbody>
</table>
Table 4: Oven Temperature Data

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Oven Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chambers Temp. K</td>
<td>At inlet of oven, Chamber No. 1, Chamber No. 2, Chamber No. 3, Chamber No. 4, Chamber No. 5, At exit of oven</td>
</tr>
<tr>
<td>Biscuit Temp. K</td>
<td>463, 503, 528, 543, 448, 303, 329, 345, 363, 376, 382, 366</td>
</tr>
</tbody>
</table>

4. Biscuit Baking Profile & Oven Temperature Profile

Fig. 2 shows the biscuit baking profile. At inlet of the oven the raw biscuits are at atmospheric temperature. As the oven band (Biscuits supporter) moves further to chamber no. 5, temperature gradually increases. At outlet of the oven the temperature decreases. It attains maximum temperature at chamber no. 5 which is 382 K and the lowest temperature at chamber no. 1 which is 303 K. Total biscuit baking time is 4.15 minutes. Baking time can be varied to meet the desired quality of the biscuit.

Fig. 1 Oven Temperature Profile

Fig. 2 Biscuit Baking Temperature Profile

Fig. 1 shows the oven temperature profile. This graph is between oven temperatures in K and biscuits baking time in minutes. Oven temperature first increases gradually till chamber no. 4 and then decrease in chamber no.5, which is the lowest oven temperature.

Table 5: Enthalpy Distribution Table for Different Streams

<table>
<thead>
<tr>
<th>Stream No.</th>
<th>Type of stream</th>
<th>Stream Name</th>
<th>Supply Temp. K</th>
<th>Target Temp. K</th>
<th>∆T K</th>
<th>Specific Heat (C_p) kJ/kg K</th>
<th>Mass Flow Rate (m) kg/s</th>
<th>m x C_p kJ/s K</th>
<th>Total Enthalpy (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Utility</td>
<td>Feed -1 (Air)</td>
<td>303</td>
<td>619</td>
<td>316</td>
<td>1.005</td>
<td>0.0147</td>
<td>0.0148</td>
<td>4.668</td>
</tr>
<tr>
<td>2</td>
<td>Hot</td>
<td>Exhaust Flue Gas -1</td>
<td>589</td>
<td>303</td>
<td>289</td>
<td>1.047</td>
<td>0.0931</td>
<td>0.0975</td>
<td>27.878</td>
</tr>
<tr>
<td>3</td>
<td>Hot</td>
<td>Exhaust Moisture -1</td>
<td>363</td>
<td>303</td>
<td>60</td>
<td>1.376</td>
<td>0.018</td>
<td>0.0248</td>
<td>1.486</td>
</tr>
<tr>
<td>4</td>
<td>Cold</td>
<td>Biscuit -1</td>
<td>303</td>
<td>329</td>
<td>26</td>
<td>3.2</td>
<td>0.156</td>
<td>0.499</td>
<td>12.98</td>
</tr>
<tr>
<td>5</td>
<td>Utility</td>
<td>Feed - 2 (Air)</td>
<td>303</td>
<td>646</td>
<td>343</td>
<td>1.005</td>
<td>0.2202</td>
<td>0.2213</td>
<td>75.91</td>
</tr>
<tr>
<td>6</td>
<td>Hot</td>
<td>Exhaust Flue Gas - 2</td>
<td>616</td>
<td>303</td>
<td>313</td>
<td>1.054</td>
<td>0.09</td>
<td>0.0949</td>
<td>29.70</td>
</tr>
<tr>
<td>7</td>
<td>Hot</td>
<td>Exhaust Moisture - 2</td>
<td>489</td>
<td>303</td>
<td>186</td>
<td>1.06</td>
<td>0.224</td>
<td>0.237</td>
<td>44.164</td>
</tr>
</tbody>
</table>

**Assumptions:** Datum considered is at room temperature (303 K) and at atmospheric pressure.
Total fuel consumption = 50 ltrs/hr.
= 50 x 0.850 (Density of diesel = 850 kg/m³)
= 42.5 kg

Calorific value of diesel = 42000 kJ/kg
Total heat energy generated, kW = 42.5 x 42000
= 1785000 kJ/hr
= 496 kJ/Sec

Say, 500 kW

Total cold stream enthalpy = 39.47 kW
Total flue gas enthalpy = 127.81 kW
Total moisture enthalpy = 166.833 kW

5. Proposal for Energy Conservation
The present oven system needs modification since significant amount of useful thermal energy is wasted as exhaust flue gas and moisture, which can be recovered and effectively utilized.

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

![Diagram of oven system with modified heat recovery]
EC – Exhaust gas Chimney; MC – Moisture Chimney; HF – Heat fan; TF – Turbulence Fan
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.

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.

### 6. Utilization of Reused Waste Flue Gas Heat for Heating of Water

The reused exhaust flue gases from chimney nos. 1 & 5, after incorporation of the proposed modification, have been combined and then be utilized for water heating with the help of a heat exchanger. The heat extracted so shall be useful for making syrup, cleaning of utensils and also dough making etc. As such, the electrical energy presently used for syrup making can be saved substantially.

![Oven diagram](image_url)

**Fig 4: Oven diagram**

### 7. Cost Analysis

Present electricity consumption in water heating = 9 kW/hr
Electricity saving in terms of money per annum = 9 kW x 72 00 hrs per yr. x Rs. 5.65 per unit (commercial charges) = Rs. 366120.00

Proposed electricity/fuel consumption in water heating = Nil
Annual saving = Rs. 366120.00
Investment for heat exchanger = Rs. 1.5 lac (approx.)
Pay back period = 4.9 months
Say 5 months

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8. Conclusion

Present Indian power sector is facing a big energy crisis. There is a good potential of defending the present energy crisis through energy conservation and efficiency improvement at the end use stage. Reductions in energy cost can therefore, improve profit level in the industries. There is a substantial amount of waste energy available, which can be harnessed easily and be equalized to purchase energy. The saved money can be utilised in improvement of the product quality, expansion of the plant, efficiency improvement of the plant as a whole etc. At the same time reduction in energy consumption will reduce the pollution level to some extent. Identification and quantisation (in selected cases) of these energy saving opportunities have been achieved through the present study.

References

5. Wayne C. Turner, Energy Management Hand Book, School of Industrial Engineering & Management, Oklahoma state University, Published by The fairmart Press, Inc. 700 Indian Trail Lithur, and GA30247.