Heat Recovery from Industrial Baking Oven

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Dr Sanjay Mukherjee, Dr Abhishek Asthana, Dr Martin Howarth, Ryan McNeill

1st International Conference on Sustainable Energy and Resources Use in Food Chains
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- National Centre Of Excellence For Food Engineering (NCEFE)
- Hallam Energy
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- Research Project - Waste Heat Recovery from Baking Ovens
National Centre of Excellence for Food Engineering

Engage. Engineer. Enable
National Centre of Excellence for Food Engineering


Objectives and core activities
To deliver world class capability and competitiveness of the UK's largest manufacturing sector through:

• Educating and developing outstanding engineers, ensuring a supply of highly qualified, sector trained professionals entering and growing the industry.

• Development and delivery of world class innovative engineering solutions to drive continued growth of the sector.
National Centre of Excellence for Food Engineering

National and International food manufacturers
Arla; Coca Cola Enterprises; Kellogg's; Mars; McCains; Nestle; Tate & Lyle; Pepsico, Premier Foods; Warburtons;

National industry bodies
Food and Drink Federation
National Skills Academy

Equipment and systems providers
Endress & Hauser; FESTO; Invensys; Rockwell Automation; Siemens;

Funding sources
Higher Education Funding Council for England (HEFCE) £6.9m
ERDF (ESIF) £2.8m
UK Commission for Education & Skills (UKCES) £250k
Innovate UK £4.4M

30 companies offering 40 industrial training places
23 companies pledging £1m of finance, equipment and other support for the centre
Current NCEFE Projects

Waste Heat Recovery From Wafer Ovens

Waste Heat Recovery from baking ovens

Effective milk processing with variable composition

Optimising food composition: reducing salt and fat

Reduce and re-using waste from rice Milling
Hallam Energy

- Established in 2009 as an industrial research group offering research, KT and consultancy services
- Delivered 50+ projects, Income > £2.6 Million
- Clients: start-ups and SMEs to MNCs and Government bodies in UK and abroad
- Core Areas:
  - Power generation
  - Thermal management
  - Energy recovery
  - Energy in buildings
  - Biofuels
- 8 staff + PhD students

<table>
<thead>
<tr>
<th>Value (£)</th>
<th>Project Type</th>
<th>Funding Sources</th>
<th>Number of Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,430,000</td>
<td>Research</td>
<td>Innovate UK, Government of India, Malaysia</td>
<td>3</td>
</tr>
<tr>
<td>300,000</td>
<td>Consultancy</td>
<td>EU and UK Industry, local authorities, Innovate UK</td>
<td>38</td>
</tr>
<tr>
<td>600,000</td>
<td>Knowledge Transfer</td>
<td>Innovate UK</td>
<td>5</td>
</tr>
<tr>
<td>250,000</td>
<td>Sponsored PhD students</td>
<td>Governments of Nigeria, Iraq and Libya</td>
<td>5</td>
</tr>
</tbody>
</table>

Director
Dr Abhishek Asthana
a.asthana@shu.ac.uk
Examples of

- 32 MW<sub>e</sub> WTE plant in New Delhi
- 4,000 tons per day
- £68 million (INR 6 billion)
Doctoral Training Alliance in Energy

Alliance universities
- Coventry University
- Kingston University
- Liverpool John Moores University
- Manchester Metropolitan University
- Nottingham Trent University
- Oxford Brookes University
- Plymouth University
- Sheffield Hallam University
- Teesside University
- The Open University
- University of Brighton
- University of Central Lancashire
- University of Greenwich
- University of Hertfordshire
- University of Huddersfield
- University of Lincoln
- University of Portsmouth
- University of Salford
- University of South Wales
- University of the West of England

Knowledge Transfer Network (KTN)
- Launched 2016
- 15 Universities
- 30 PhD students/year
- 90 PhD students by 2018
- 180 Academic supervisors
- Independent Advisory Group
- Industrial Placements
- Australian Technology Network (ATN)
- Conferences
- Joint research proposals
- Equipment sharing

Dr Abhishek Asthana
Deputy Director

http://www.unialliance.ac.uk/
WASTE HEAT IN FOOD INDUSTRY
Waste Heat

A heat stream that is generated in boilers, kilns, ovens, furnaces, and been dumped into the environment even though it could still be reused for some economic purpose.

Heat losses in industrial process heating equipment include flue, wall, opening and conveyor losses as well as stored heat.
Heat in Food Manufacturing

Drying

Frying

Boiling

Food manufacturing Process

Pasteurisation

Grilling

Roasting

Baking
65% energy lost in the stack

165 °C or more

WASTE HEAT IN BAKING
Waste Heat In Food Industry

- The UK food industry accounts for 12% of the total energy consumption by the UK’s industrial sector.

- It produces circa 2.8 TWh of recoverable heat into the environment via waste streams annually, accounting for 4-7% of total factory energy use.

- Emits approximately 7 million tonnes of CO₂ per annum.

- Without intervention this figure will double in line with an increase in food demand by 2050.

Reduce carbon footprint of food
**Emission Targets - Food Industry**

- **Nestle** – 40% GHG emission reduction by 2020.

- **PepsiCo** - Make our UK operations and manufacturing fossil fuel free by 2023.

- **Coca-Cola Enterprises, Inc** - commits to reduce absolute GHG emissions from their core business operations 50% by 2020.

- **Kellogg Company** - commits to a 15% reduction in emissions intensity (tonne of CO₂ per tonne of food produced) by 2020.
RESEARCH PROJECT

WASTE HEAT RECOVERY FROM BAKING OVENS
65% energy lost in the stack

165 °C or more
Project opportunities

- The energy efficiency of wafer baking is circa 35%, this clearly presents an opportunity.
- Develop scientific knowledge that can be used to underpin future development work on energy efficient baking technology.

Project Cost – £ 858,000

Primary objectives

- Optimisation of wafer baking ovens for combustion and air circulation
- Deliver 15% reduction in thermal energy consumption.
- Provide a scalable solution – cross category
- Ensure ‘Zero’ negative impact on product quality
Baking Oven

- Extractor fan
- Primary air supply pipe
- Fuel air mixing unit
- Damper controller
- Secondary air
- Exhaust duct
- Batter deposition section
- Glass door
HEAT RECOVERY TECHNOLOGY

1. Using heat exchanger

1.1 Pre-heat combustion air

1.2 Produce hot water

2. Re-circulation of exhaust gases

Concerns
- Check humidity levels
- Risk of excessive moisture in wafer
HEAT RECOVERY - CHALLENGES

1. Low temperature
   - low heat transfer rate
   - Large, heavy size heat exchanger - increases cost

2. Acid formation
   - \( H_2O, SO_2 \) → Sulphuric Acid → Rusting

3. Corrosion and fouling
   - Accumulation of unwanted material
     - Greasy and Sticky material
     - Reduce heat transfer rate and heat recovery

4. Contamination of food and beverage products
   - Corrosion can cause leakage
   - Stack debri contaminating food
EXPERIMENTS AND DATA COLLECTION

- Conducted experiments to measure gas and air flowrates, temperatures, gas composition, pressures, particulate matter concentration and wafer quality
- Developed a thermodynamic model of heat recovery
The current wafer baking ovens are based on very old technology and there is scope of optimising the operating conditions of the ovens.

Secondray air supply is more than required.

The operational optimisation was be done by:
- Changing air flowrates
  - by varying extractor fan speed to reduce excess secondary air flow.
  - by changing the position of damper controllers to reduce air flow through individual ducts.
- The key criteria is to maintain the wafer quality while making operational changes.
- The optimisation could not only provide direct fuel savings but also a high temperature or high grade exhaust stream, which means higher heat recovery efficiency.
EXPERIMENTS - PILOT OVEN OPERATIONAL OPTIMISATION

- Pilot oven
- Scaled down version of main factory ovens
- Runs at same baseline operating conditions as main ovens in the factory
Fan speed reduced from 40 to 30 Hz.

Door Temp (4-4, 4-8) remained close to ambient.

At lower fan speeds temperature variation reduced.

Plate temp remained stable at 162°C.
- Closing dampers reduced fuel consumption by 2.5%.
- 25% reduction in fan power further reduced fuel consumption by 6%.
EXPERIMENTS - COMBUSTION AIR PREHEATING

Combustion air preheating unit installed for trials

Supply filter for gas mixer removed

25 kW electric heater installed on Supply duct

Bespoke control system installed to control operating temperature, provide upper limit cut out and safe limits for Differential pressure sensing
Check flame quality while changing mixing air temperatures

- The flame should be bluish and only yellow at the tip
- Only yellow: too much gas in the mixture
- Only blue: too much air in the mixture

No Impact on flame quality
- Combustion air inlet temperature was raised from 30°C to 105°C.
- A 75°C increase in combustion air temperature can save 4% fuel consumption.
- More savings expected with higher mixing air temperatures.
- Maximum temperature achievable is 153°C. limited by the exhaust temperature
The exhaust gas temperatures in the intermediate ducts increased by 14-18°C.

The overall (combined) exhaust temperature raised by 8°C.

The increase in exhaust temperature gives higher heat transfer rates.

The exhaust temperature levels were below the upper operating temperature limits of the extraction unit and therefore do not possess any safety issue for the baking process.
Baseline wafer mapping completed under standard conditions.
Wafer mapping completed after fan speed adjustments and combustion air preheating.
Operational optimisation and combustion air preheating had no negative impact on product quality.

Table: Wafer quality measurements before and after trials.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Baseline Measurement</th>
<th>Measurements after Preheating Primary Air</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Moisture (mass %)</strong></td>
<td>Maximum allowed</td>
<td>2.08</td>
</tr>
<tr>
<td></td>
<td>Minimum allowed</td>
<td>1.73</td>
</tr>
<tr>
<td></td>
<td>Average observed value</td>
<td>1.87</td>
</tr>
<tr>
<td><strong>Weight (%)</strong></td>
<td>Maximum deviation from required weight</td>
<td>3.86</td>
</tr>
<tr>
<td></td>
<td>Minimum deviation from required weight</td>
<td>3.39</td>
</tr>
<tr>
<td></td>
<td>Average deviation</td>
<td>3.61</td>
</tr>
<tr>
<td><strong>Thickness (%)</strong></td>
<td>Maximum deviation from required thickness</td>
<td>2.25</td>
</tr>
<tr>
<td></td>
<td>Minimum deviation from required thickness</td>
<td>2.13</td>
</tr>
<tr>
<td></td>
<td>Average deviation</td>
<td>2.20</td>
</tr>
</tbody>
</table>
**Experiments - Exhaust Recirculation**

Are heat exchangers the only solution?
- Recirculation of hot air (165°C) inside the oven
- Humidity and product quality?

<table>
<thead>
<tr>
<th>Properties of exhaust gases coming out of the oven currently</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature, °C</strong></td>
</tr>
<tr>
<td><strong>Absolute humidity, ω</strong></td>
</tr>
<tr>
<td><strong>Saturation vapour pressure, p_g, kPa</strong></td>
</tr>
<tr>
<td><strong>Actual Vapour pressure, p_v, kPa</strong></td>
</tr>
<tr>
<td><strong>Relative humidity, φ, %</strong></td>
</tr>
</tbody>
</table>
EXPERIMENTS - HOT WATER PRODUCTION

An "Energy Audit" was done to identify the potential "Heat Sinks" or "Hot Water Demand" in the factory for the heat recovery.

Key heat sink selection parameters:

- Size of heat sink must be known across full 12 months
- Variability of heat sink is key
- Delta T of primary flow must be assured
- Visibility of performance should be clear but simple
- Insight of future expansion/changes to system on performance
A **heat pipe** is a metal tube, sealed at both ends with a vacuum inside, filled with a small quantity of fluid.

The lower end of the heat pipe is installed in a hot stream and the top end is fitted into a colder stream; sealed and separated by a separation plate.

- Higher heat transfer rates
- Long service life and robust construction
- Lightweight and compact
- Prevents fouling
- Easy Maintenance
HEAT RECOVERY MODEL

The information obtained from experiments were gathered and analysed to develop a thermodynamic model of the heat recovery system. The combustion air pre-heating model was compared with various other heat recovery options.

### Input parameters for the model

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline fuel consumption per oven</td>
<td>Nm³/hr</td>
<td>75</td>
</tr>
<tr>
<td>Per unit gas cost</td>
<td>£/KWh</td>
<td>0.018</td>
</tr>
<tr>
<td>Operating hours per oven per year</td>
<td>h/yr</td>
<td>7,500</td>
</tr>
<tr>
<td>Damper closed</td>
<td></td>
<td>TRUE</td>
</tr>
<tr>
<td>Extractor fan speed</td>
<td>Hz</td>
<td>30</td>
</tr>
<tr>
<td>Baseline exhaust flow per oven</td>
<td>m³/s</td>
<td>3.72</td>
</tr>
<tr>
<td>Exhaust temperature at HE Inlet</td>
<td>°C</td>
<td>178</td>
</tr>
<tr>
<td>Minimum limit of exhaust temperature at HE outlet</td>
<td>°C</td>
<td>110</td>
</tr>
<tr>
<td>Ovens used for heat recovery</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Heat exchanger effectiveness</td>
<td>%</td>
<td>45</td>
</tr>
<tr>
<td>Ovens used for pre-heating primary air</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Ovens used for optimisation</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Baseline primary air flow rate</td>
<td>m³/s</td>
<td>0.19</td>
</tr>
<tr>
<td>Primary air inlet temperature to HE</td>
<td>°C</td>
<td>10</td>
</tr>
<tr>
<td>Water produced per hour</td>
<td>kg/hr</td>
<td>275</td>
</tr>
<tr>
<td>Gas saved by pre-heating primary air - single oven</td>
<td>%</td>
<td>4</td>
</tr>
<tr>
<td>Capital investment</td>
<td>10⁶£</td>
<td>100</td>
</tr>
</tbody>
</table>

### Output parameters for the model

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline energy consumption per oven</td>
<td>kWh</td>
<td>829</td>
</tr>
<tr>
<td>Baseline running gas cost per oven per year</td>
<td>£/year</td>
<td>15</td>
</tr>
<tr>
<td>Exhaust flowrate per oven at corresponding fan speed (normalised)</td>
<td>Nm³/s</td>
<td>1.59</td>
</tr>
<tr>
<td>Exhaust mass flowrate per oven at corresponding fan speed</td>
<td>kg/hr</td>
<td>2</td>
</tr>
<tr>
<td>Primary air temperature after HX</td>
<td>°C</td>
<td>86</td>
</tr>
<tr>
<td>Exhaust temperature after HX</td>
<td>°C</td>
<td>145</td>
</tr>
<tr>
<td>Actual heat transfer</td>
<td>kW</td>
<td>65</td>
</tr>
<tr>
<td>Overall fuel and running cost savings by optimisation</td>
<td>Changed Fan Speed!</td>
<td>Dumpers closed!</td>
</tr>
<tr>
<td>Total gas saved per year by optimisation</td>
<td>Kg/yr</td>
<td>126,735</td>
</tr>
<tr>
<td>Total energy saved per year by optimisation</td>
<td>kWh/yr</td>
<td>1,973,425</td>
</tr>
<tr>
<td>Overall savings in running cost per year by optimisation</td>
<td>£/yr</td>
<td>35,622</td>
</tr>
<tr>
<td>Total gas saved per year by pre-heating primary air</td>
<td>Kg/yr</td>
<td>59,640</td>
</tr>
<tr>
<td>Total energy saved per year by pre-heating primary air</td>
<td>kWh/yr</td>
<td>928,470</td>
</tr>
<tr>
<td>Overall savings in running cost per year by pre-heating primary air</td>
<td>£/yr</td>
<td>16,716</td>
</tr>
<tr>
<td>Return on Investment (ROI)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total savings in running cost per year</td>
<td>£/yr</td>
<td>52,238</td>
</tr>
<tr>
<td>Payback period</td>
<td>yr</td>
<td>1.9</td>
</tr>
<tr>
<td>Environmental Benefits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction in CO₂ emissions per annum</td>
<td>tonnes/yr</td>
<td>536.89</td>
</tr>
</tbody>
</table>

### Graphs

- Gas cost per year (1000 £)
- Heat recovery potential (kW)
- Capital cost (1000 £)
- Pay back period (years)
Selection of Heat Recovery Technology

- Condensing  
  - Risk of acid formation

- Non-condensing  
  - (Exhaust temperatures above condensing point)

Non-condensing

- Hot water
  - Heat sink far from heat source
  - Large insulated piping required
  - High capital cost

- Exhaust Recirculation
  - Require major oven retrofit

- Pre-heating combustion air
  - Simple solution preferred
There are four industrial scale wafer baking ovens in the factory.

The heat recovery system is designed to preheat the combustion air of all four ovens using the heat available from the exhaust of a single oven.

Diagram:

- Hot Combustion air out
- Oven 1
- Oven 2
- Oven 3
- Oven 4
- Heat Exchanger
- Hot Exhaust In
- Cold Exhaust Out
- Fuel Air Mixture
- Fuel
- Air
- Fuel-Air mixture
- Baking Oven
RESULTS AND CONCLUSIONS

- 2.5% savings in fuel consumption of when all dampers were closed.
- 6% savings in fuel consumption by reducing fan speed by 25%.
- 4% savings in fuel consumption from raising combustion air temperature by 75°C.
- Oven efficiency increased from 35% to 47.5%.
- Stack losses reduced from 65% to 53% for single oven.
- Total natural gas saved by the factory per annum: 186,375 kg
- Total energy saved by the factory per annum: 2,902 MWh
- Total CO₂ saved per annum by the factory: 537 tonnes.
- Total savings in running cost per annum for the factory: £52,238
- Payback period: under two years
**Summary And Baseline Comparison**

<table>
<thead>
<tr>
<th>Key parameters (per oven)</th>
<th>Baseline</th>
<th>After recovery and optimisation</th>
<th>Difference</th>
<th>Change %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual fuel cost per oven £/yr</td>
<td>104,475</td>
<td>91,415</td>
<td>13,060</td>
<td>12.5</td>
</tr>
<tr>
<td>Energy used per kg of wafer kWh/kg</td>
<td>3.02</td>
<td>2.64</td>
<td>0.38</td>
<td>12.5</td>
</tr>
<tr>
<td>Annual CO₂ emissions per oven ton/yr</td>
<td>1,074</td>
<td>940</td>
<td>134</td>
<td>12.5</td>
</tr>
</tbody>
</table>

Wafer quality ✓

Fuel savings are *underestimated* due to limitations on pilot oven for testing conditions.
Thank You!

Dr Abhishek Asthana
a.asthana@shu.ac.uk