
Improving the efficiency of bakery ovens

Case study



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Acknowledgements

The Carbon Trust would like to thank Campden BRI, Spooner Industries and the Regional Growth Fund for their work and support for this project.



The Carbon Trust's mission is to accelerate the move to a sustainable, low carbon economy. It is a world leading expert on carbon reduction and clean technology. As a not-for-dividend group, it advises governments and leading companies around the world, reinvesting profits into its low carbon mission.

The UK Government's Regional Growth Fund (RGF) financed this report. The Regional Growth Fund supports eligible projects and programmes that are raising private sector investment to create economic growth and lasting employment. Since its launch in 2010 it has invested £2.85 billion to help local businesses grow and take on more staff across England.

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The Carbon Trust's Industrial Energy Efficiency Accelerator identified bakery ovens as a priority area for innovation to reduce industry carbon emissions. Gas flow through ovens is currently not optimised for efficiency, and to test the potential for improvement, the Carbon Trust conducted two trials with Campden BRI and Spooner Industries.

The trials measured gas volumes produced during baking, both from combustion and from the product itself, and the effect on oven efficiency of improved management of flue gas. Analysis shows that dynamically matching exhaust fans to the volume of gases produced within the oven could provide savings of 4.7%. This could save £14,000 per site per year, with payback times varying from one to five years depending on the condition of the existing oven.

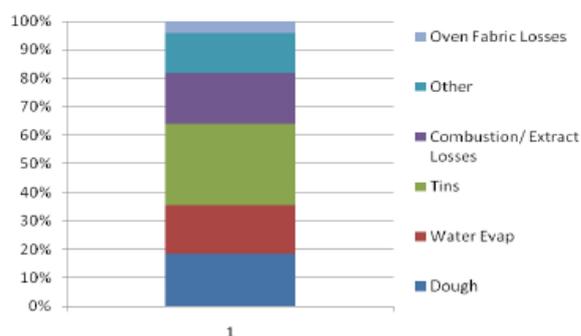
1 Background

Bread production in the UK is dominated by high volume plant bakeries, which are responsible for about 80% of bread consumed in the UK.

Energy savings available within bakeries can be significant due to the high energy consumption of baking itself, which costs an average bakery £335k per year.

Ovens are responsible for 35-45%¹ of total site carbon emissions. *Figure 1* shows the breakdown of oven energy use for a typical direct-fired gas oven, where hot air exiting the flues is responsible for around 20% of gas use. This makes no contribution to heating bread dough and is a direct loss.

Figure 1 - Breakdown of oven energy use for a direct-fired gas oven



High speed bread bakery lines can run at 8-10,000 units per hour, and the highest volume product in the UK is the 800g lidded loaf. Baking times for 800g tinned bread vary from 18 to 24 minutes in continuous or

travelling ovens depending on oven type and whether the bread is lidded or unlidded.

Most oven bakeries are fitted with three to six flues of equal diameter and with the same fan specification for each flue. These ovens are lengthy pieces of equipment with flues along their length. Each flue has a fixed speed fan together with a physical restriction plate, often known as a damper, which allows flue outlet size to be adjusted.

Fixed speed fans do not allow for fine tuning of the exhaust air flow which is required to optimise the oven balance during operation. If this cannot be closely controlled together with the oven combustion air, which results in reduced combustion efficiency caused by sub-optimal fuel to air ratios.

This project investigated gas production from bakery products during the baking process, how gas flow rates in flues affects oven efficiency and whether there is potential to improve oven efficiency by controlling flue gas flow rates with variable speed drives (VSDs).

It is part of a package of projects funded by the Regional Growth Fund (RGF), which aims to promote a step change in the energy efficiency of industrial processes.

The project was undertaken by Campden BRI and Spooner Industries, with support from the Carbon Trust.

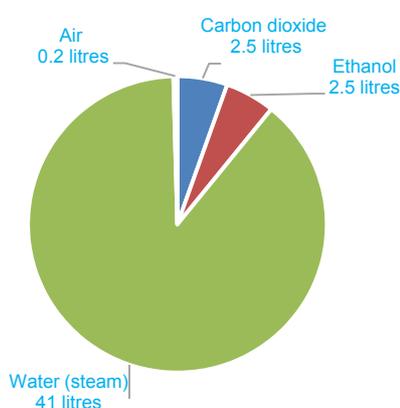
¹ Industrial Energy Efficiency Accelerator: Guide to the industrial bakery sector

2 Measuring gases produced within the oven

Methodology

Estimates from existing research shows that a 400g loaf of bread produces 46.2 litres of gas during baking, which consists of water vapour, air, ethanol and carbon dioxide (*Figure 2*²).

Figure 2 - Estimated volumes of gases generated or expanded during the baking process for a 400 g loaf (scaled at 453 g)



However, these estimates are inferences – direct measurement of the volume of gases released from baked products during the oven process has not been studied

extensively, and the technologies for directly measuring gas volume or flow rate at flue gas temperatures of 180-200°C do not exist. This required the use of novel approaches in measuring gas volumes produced.

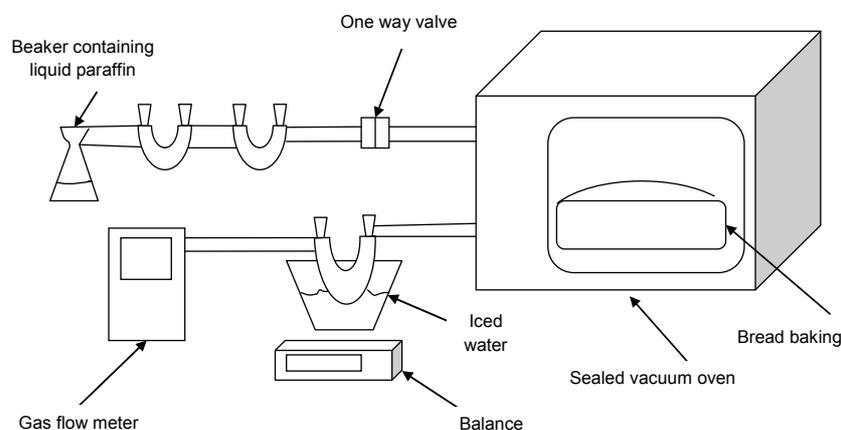
The approach used by Campden BRI measured a combination of condensable and non-condensable gases using a laboratory vacuum oven. This oven had excellent door seals together with an entry port that could be sealed off and exit port for measuring gas.

The volume of gas produced from various products was measured by baking at 200°C in the vacuum oven. A one way valve was fitted to the inlet port and a thermal dispersion mass flow meter to the outlet (*Figure 3*).

Water vapour and ethanol from the products were condensed by directing the gas to flow through a U-tube chilled with ice water. Hence gases responsible for the flow rate changes were mostly carbon dioxide and air.

Flow rates of gases from each test in the vacuum oven were recorded manually from flow meter readings every minute during baking.

Figure 3 - Schematic diagram of setup used by Campden BRI to measure the volume of gas produced during baking



² Campden BRI research combined with literature review

Products studied included yeast leavened bread, and various chemically leavened cakes, muffins and scones. The reason for studying different leavening systems was to determine if the flow rate change with baking time followed a different relationship.

As the flow rate work progressed, it was apparent that carbon dioxide and air contributed less than 10% of the total gas flow rate. If the assumption of equal volumes of carbon dioxide and ethanol is approximately correct during the dominant anaerobic fermentation phase, steam contributes around 95% of gas volume released from bread during baking. This is a substantial amount and sufficiently large that engineering calculations on gas flow optimisation can ignore the contribution of all gases other than steam.

On this basis a baking trial was set up to measure weight loss during baking and to generate a plot of gas volume against baking time. These data were calculated by removing 400 g loaves at two minute intervals during baking.

A larger oven was required than the laboratory vacuum oven, and a direct gas-fired reel oven with six shelves was chosen, using a standard baking time for 400 g loaves of 24 minutes at 240°C.

This type of oven has a major advantage over almost all other oven types for removing samples before the baking is completed because the door opening is small compared with the oven size, which results in minimal heat loss from the oven during sample removal. Loaves in their tins were weighed immediately on removal from the oven to determine the weight loss as the bake progressed.

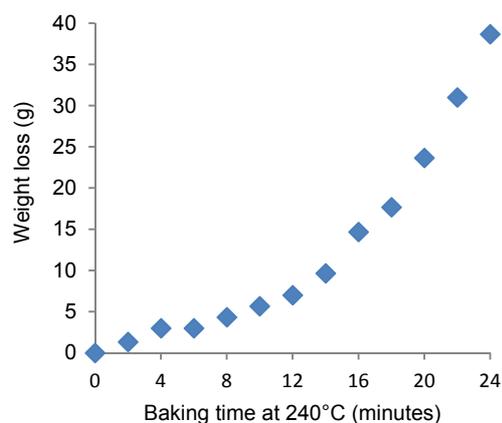
Conversion of weight loss to gas volume assumed all weight loss was water, which again was a fair engineering assumption, and that steam behaved as an ideal gas.

Results

Water, which is converted to steam during baking, has the greatest impact on total or cumulative gas volumes released from the products. This project sought to optimise flue gas control, therefore changes in steam volume production rate as bread changed from a 36-38°C dough to a 96-100°C baked loaf was measured.

Measurements of loaf weight every two minutes of baking at 240°C in a direct gas-fired oven were taken. *Figure 4* presents the cumulative weight loss for each loaf removed.

Figure 4 - Water (steam) contribution to flue gas volume, by measurements of weight loss during baking of a 400g open top loaf

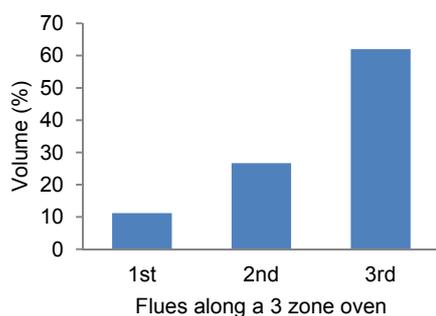


Of interest to improved flue gas control is the relative volumetric rate of gas released from the bread compared with that from the combustion products, so this weight loss can be converted to volumetric gas production.

These calculations assumed a typical industrial bread oven operating at 8,000 units per hour, with three burner zones and each of these zones has a separate flue. *Figure 5* presents the relative gas volumes that exit the flues (as percentages of the total volume) as the bread moves from the oven inlet to the outlet.

Figure 2 previously showed the breakdown of gas volumes produced by the bread during baking – 46.2 litres per 400 g loaf. As expected from the weight changes in Figure 4 the increase in flue gas volumes is exponential, as shown in Figure 5.

Figure 5 - Estimated percentage of flue gas volume from measurements of weight loss during baking of a 400g open top loaf



A range of UK bakery ovens were previously surveyed by the Carbon Trust to calculate carbon dioxide emissions from bakery combustion gases. This survey provides data that allows total combustion gas volumes to be estimated.

This calculation (Table 1) shows that 43.44 litres of gas are produced from combustion for every 400 g loaf. It is clear from this that the overall gas volumes from product and combustion are similar in magnitude, though different in terms of when they are released in the baking process, so optimisation of gas flows in ovens should consider both sources.

Table 1 - Gas volumes calculated from combustion products to bake a 400 g loaf

Baked loaf weight	400 g
Energy to bake loaf	0.0884 kWh
CO ₂ released from combustion gases per loaf	14.48 litres at 200°C
H ₂ O released per loaf	28.96 litres at 200°C
Total combustion gases to bake 400g loaf	43.44 litres at 200°C

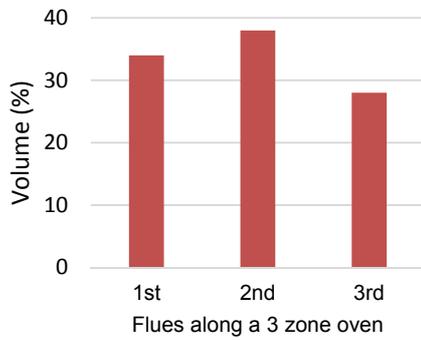
Assumptions

- > Oven energy consumption is 221 kWh / t product with direct gas ovens, mean figure for large bakery.
- > Carbon dioxide released per kWh is 0.000186 t CO₂

Although gas from baking bread and burning combustion fuel are similar (46.2 litres and 43.4 litres respectively), the gases are released at different points throughout the oven, which will affect how gas flows should be optimised.

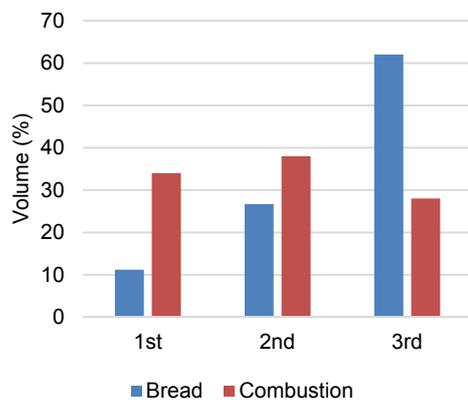
How gas flow from combustion changes across the oven can be calculated using data on burner rates for a typical three-zone bread oven obtained from Spooner Industries, and is shown in Figure 6.

Figure 6 - Estimated percentage of flue gas volume from combustion products exiting the flues of a 3-zone oven, calculated from burner fire rate data provided by Spooner for a commercial 3-zone bread oven



Gas volumes from bread and from combustion are shown side by side in *Figure 7*. It is clear that the gas volumes are not evenly distributed from the bread, but they are reasonably even from the combustion products.

Figure 7 - Estimated percentage of flue gas volume released from bread and combustion products for a 3-zone bread oven



Gas production from bread may seem unexpected because the evaporation rate of water increases almost exponentially towards the oven exit as the bread temperatures rise towards 100°C in the outer regions of the bread – evaporation involves a phase change that is high in its energy demand.

The first zone of a bread oven must heat relatively cold tins and dough from 36-38°C, which also demands a high amount of energy. The middle zone of the oven also delivers high rates of energy into the part-heated tins and bread, as well as starting the water evaporation process.

Temperatures in the middle zone are usually higher than in the first or last zones, which requires a higher rate of burner fire to achieve.

3 Testing the potential for exhaust control

Typical exhaust systems feature a range of sophistication depending on age and level of previous investment. Old systems are likely to have high exhaust flow as there may be no dampers to reduce flow, or dampers may no longer reduce flow effectively. These systems have been largely phased out in modern commercial bakeries.

Newer systems with properly set up exhausts and burners may still not be optimised to regulate air flow over the full range of burner fire rates, resulting in exhaust flow rates that are too high during operation.

Methodology

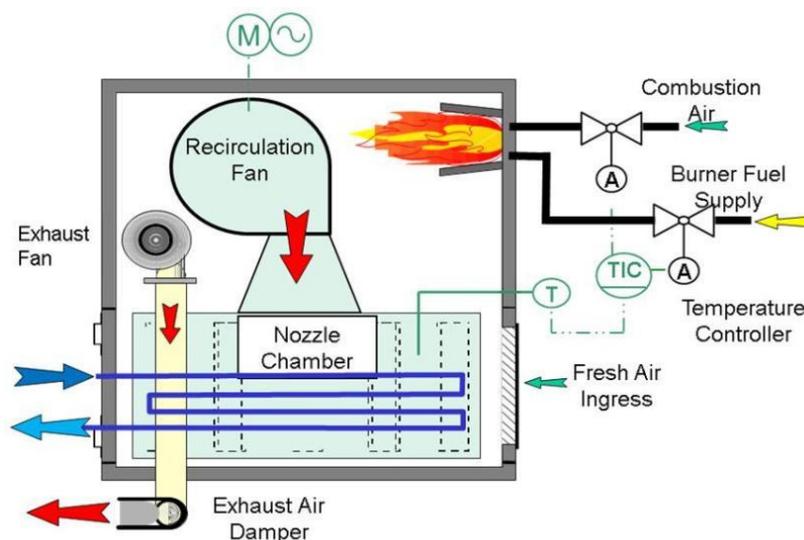
To measure the impact of improved exhaust control on efficiency, tests were carried out by Spooner Industries. This involved a single chamber test oven (shown in *Figure 8*), configured to simulate three oven types.

The aim of this part of the project was to understand the benefit that could be achieved by improving the oven balance – reducing the amount of exhaust air to match the burner air - using sensors, a ratio controller and variable speed fan.

- > **High exhaust flow with no purge damper.** While not common in modern commercial bakeries, this setup may still be found in small craft bakeries
- > **Exhaust reduced to simulate 'fixed speed' system.** This setup is more representative of a modern commercial bakery oven under current operation
- > **Excess air minimised and exhaust set to balance oven.** This would simulate a modern commercial bakery oven with gas flows optimised to improve efficiency.

The test was run at three different baking temperatures: 250°C, 200°C and 150°C using each oven configuration.

Figure 8 - Single chamber test oven at Spooner Industries used to measure gas use for three different oven set-ups



Results

The results, shown in *Figure 9*, show the relative energy consumption at each temperature in each oven configuration, normalised to the 'fixed speed' system, which is considered to be representative of a modern commercial bakery oven.

It is clear that the extent of exhaust flow has a significant impact on energy consumption of the oven. The first test with high exhaust flow and no damper (not considered representative of a commercial bakery oven) consumed approximately 30% more energy than the fixed speed system.

The third case, with excess air minimised and with exhaust set to balance oven gases, showed a 42% energy saving over the fixed speed setup on the single chamber test oven, indicating that significant savings could be achieved by balancing oven gases.

These findings are based on measurements from a single chamber test oven, as opposed to a more common three-zone oven that would be found in a modern commercial bakery.

Calculations were made by Spooner Industries to scale-up this work to industrial ovens that operate with lower heat losses and for longer periods with the same heat load, shown in *Table 2*.

Analysis showed that this technology could provide gas savings of 4.7% if applied to a commercial oven, saving £14,000 per year in gas.

Conclusions on savings and payback from the calculations were:

- > A modern commercial oven with a suitable burner and existing ratio controller will require minimal investment, which will pay back in one year.
- > Many industrial bakery ovens are more than 5 years old and do not have suitable burners or controllers. Further interventions are likely to be required on a case by case basis, depending on existing equipment .
- > Additional gas savings may be available by adding heat recovery technology. Estimated total cost savings of around 7.2% are possible.

Table 2 - Burner gas savings achievable against a representative bakery oven

Production oven 3-section	Load of representative commercial bakery oven (kW)	Load with exhaust control to match fresh air for burner fire rate to balance oven (kW)
Burner load (Gas)	1700	1620
Exhaust load (Electric)	230	152
		4.7% gas saving
		£14,400 per year

Figure 9 - Comparison of Energy Consumption as a % of "Standard" setup

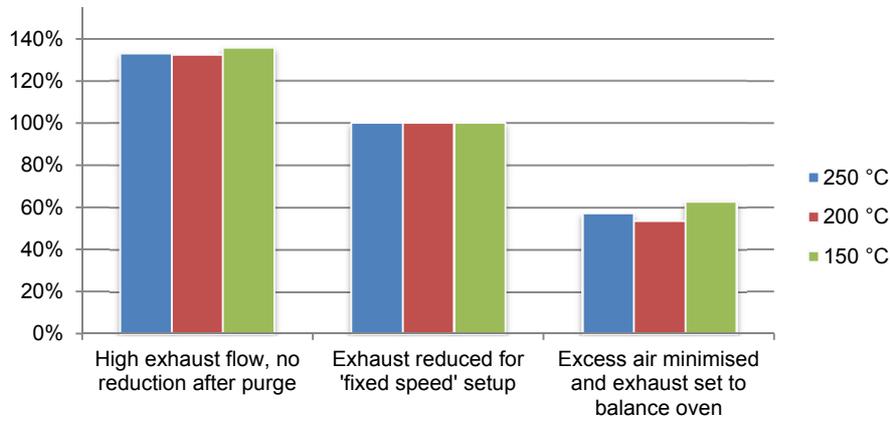


Table 3 summarises possible interventions based on existing oven characteristics.

If an oven has suitable burners and an existing ratio controller then only minimal interventions are needed, and the system should pay back within 1 year.

If the burners are suitable but there is no ratio controller than additional installation needs will increase payback time to 2.5 years.

In an extreme case, where burners are unsuitable, all new equipment plus new burners would be required, leading to a 5 year payback period. This would likely only be considered if burners were to be replaced anyway through routine upgrades. In all cases the ongoing savings would be 4.7%.

Table 3 - Requirements, payback time and achievable savings from a range of oven interventions

Intervention	Requirements	Payback (years)	Ongoing savings (%)
Suitable burner with existing ratio controller	<ul style="list-style-type: none"> Survey Instruments Gas meter Commissioning 	1	4.7
Suitable burner without ratio controller	<i>All above, plus:</i> <ul style="list-style-type: none"> Ratio controller Gas train Valves, Installation 	2.5	
Burner redundant or not suitable for upgrade	<i>All above, plus:</i> <ul style="list-style-type: none"> New burners 	5	
Heat recovery installation	<ul style="list-style-type: none"> Space available Suitable burner 	<4	7.2

4 Conclusions and recommendations for further work

A fixed speed flue gas fan will draw the same quantity of gas through each flue despite products and combustion gases producing different volumes at different stages.

Data on flow meter readings for non-condensable gases from bread baking showed that steam constitutes 95% of product gases.

A lab scale trial established that product gases released more at the later stage of the baking process, while gases produced by combustion were more evenly distributed across the oven zones. Tests on a single chamber test oven further indicated that

42% of energy saving is possible by optimising flue gas.

The production modelling trial condition illustrate that savings of 4.7% are possible by linking variable speed drives with combustion control. These savings can be significant when the costs for operating an industrial bread oven are calculated.

A typical oven will cost over £300,000 in gas to operate each year, so 4.7% represents £14,000 in annual savings.

Further work could be the scaling up of pilot trials to production ovens to verify the energy savings and feasibility of the system.

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Published in the UK: April 2015.

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