Adding Value by Culinary Smoking

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Introduction

A quick tour of any local supermarket will reveal a great variety of smoked food products. While clear they sell at a premium, it is not easy, without extensive market research, to find out how many are exported from New Zealand. This is because smoked products are not generally differentiated in import-export statistics; they are usually lumped with salted, brined and dried products. The value to the producer is also unclear, because smoking adds processing cost and the margin needs to be worth the effort.

Scope of research

Food smoking is an art that currently requires a trial and error approach based on experience to generate the 'perfect' smoke, prepare the food to accept the smoke, and to define the temperature-time-exposure conditions between the smoke and the food. The first of these is critical as the quality of the smoke itself affects the consistency of colour, aroma and flavour profile of the finished food product.

At Massey University (MU) and the University of Otago (UO), a small team are working on smoke generation and food safety for smoked foods. Their programme includes science and engineering. In science, they aim to understand smoke generation chemistry and kinetics. One of their focuses is to define what it is that is unique about New Zealand wood smokes: manuka, pohutukawa, rewa rewa, tawa and NZ silver beech, compared to other northern hemisphere smokes such as oak and hickory.

Concurrently, in engineering, they are developing smoke generation devices and control systems that take advantage of these distinctive aromas, to better control the aroma profile in a predictable fashion. This understanding will enable better batch-to-batch consistency and result in producers being able to pinpoint and reproduce their desired flavour and colour signature. All of these factors confer potential market advantage.

At the same time, MU and UO aim to minimise the production of the undesirable polycyclic aromatic hydrocarbons (PAH's), implicated as carcinogenic compounds. The EU introduced regulations with maximum PAH limits on imported smoked food products in September 2014. However, no other jurisdictions have concentration limits to our knowledge. New Zealand and Australia currently have no limits in place, although the Ministry for Primary Industries does have a watching brief on this matter.

The art of food smoking

Food smoking is a traditional preservation method that extends the shelf life of perishable food, particularly meats that are available only in a short season, e.g., salmon. In New Zealand, smoking as a food preservation technique was brought here by European immigrants. It was not practised by Maori, who were formerly a tropical people. Without the trees of the northern hemisphere, New Zealand found its own wood smokes, with manuka being the best known internationally. Interestingly, New Zealand uses only a small amount of northern hemisphere woods, such as oak and hickory, mainly for exported products rather than domestic consumption.

Smoking involves two unit operations, the smoke generator and the smoke house, where the smoke contacts the food. Prior to smoking the food goes through a brining/curing step to assist the smoking process and extend the resulting product shelf life. Once the food is placed in the smokehouse, or prior, it is air-dried for a period of time to allow the surface proteins to become tacky, to form what is called a pellicle that allows the food to better accept the smoke, providing good colour without over-drying during smoking.

The first modern smoking system, called the Torry kiln, was developed in 1939 in Scotland. It separates the smoke generation from the smokehouse chambers, into which trolleys are wheeled, containing the food on trays or racks. Newer technologies have improved smoke generation, and the smoke chambers are controlled to ramp through various stages of temperature and humidity, to achieve phases of drying, smoking, and cooling. The flows of air and smoke are carefully controlled so that all food samples receive equal amounts of smoke. Between cycles, or daily, the systems are automatically cleaned.

Smoke is generated in a number of ways.

The simplest method is to use a tray containing smouldering wood chips placed in the bottom of a smokehouse with the products to be smoked hanging above. It is not uncommon to see this system used by artisanal butchers. These systems have no control once the smoke house door is closed.

The next simplest system is a fire box with a raised stool grate. It requires periodic addition of wood chips and/or sawdust with combustion controlled by damping the primary air inflow. The secondary air inflow is used to cool and entrain the smoke into the duct leading to the smokehouse. This sort of system sits outside the smokehouse and is the method employed by small auxiliary units which attach to hobby smokehouses. They generally include a forced draft of air across the smouldering chip. This type of unit is also seen in the kitchen (e.g., on Masterchef), where a thimble-sized basket of chips is ignited and a fan is used to maintain the smouldering, while also blowing the smoke down a tube into the enclosed food container.

Smoke generation

Larger industrial systems become increasingly sophisticated, where smoke generation is driven by a heat source. A typical setup uses a heated element or hot plate, where wood chips are continuously fed from a hopper with a sealed lid to prevent air ingress. Wood chips pass through the hot zone or over the hot plate. Once charred, they drop through a grate below to the ash box. The smoke escapes through the bed and is then drawn up through a vertical pipe where water and heavy tars condense and drain into a liquid trap. Oil-containing aerosols and volatile compounds are entrained into a recirculating system, and passed repeatedly through the smoke house.

Alternately, the heat source can be superheated air or steam. Superheated air produces a localised zone of combustion which quickly consumes the oxygen introduced with the air, providing localised heat for the smouldering of nearby wood chips. Superheated steam does not carry oxygen and all the heat for pyrolysis is carried by the steam. In both cases the forced draft of superheated air or steam assists by driving the smoke out of the packed bed.

Most patents in the last 15 years have been for friction smoking where planks of wood are pressed against a spinning friction wheel. The heat generated liquefies and volatilises the wood by pyrolysis. The smoke is then drawn into the duct to the smokehouse. Friction systems are easy to start, are less susceptible to environmental changes, and are relatively predictable in their performance. However, they are known to struggle to produce large volumes of smoke required for large production systems.

An alternative method is atomisation of liquid smoke. Liquid smoke is produced by generating smoke separately and collecting a liquid following a condenser, then post processed, mainly by filtering to remove particulates and heavy, insoluble tars. Smokehouses then purchase the liquid smoke and pump it to an atomiser before blowing it into the smokehouse. Alternatively, liquid smoke is simply sprayed or basted onto food, or mixed into a food preparation (e.g., in canned fish), as a flavouring addition. This approach does not use a smokehouse and is used when a smoky flavour is desired and suits low cost production systems where the additional cost of batch treatment in smoke houses is uneconomic. However, it lacks the traditional and artisanal perception that certain consumers may wish for.

There are several challenges in smoke generation. The first is the PAH production which due to carcinogen concerns has led to the European Commission Regulation to impose limits of PAHs in food products. The limits for selected smoked goods, effective from September 2014, are shown in the table below. It must be noted that PAHs form whenever food is grilled, fried, barbecued or roasted.

EU Limits on PAHs	Limits 1PAH µg/kg	 4PAH µg/kg
Smoked meat and smoked meat product	2	12
Muscle meat from smoked fish and smoked fishery product	2	12
Smoked bivalve molluscs	6	35

COMMISSION REGULATION (EU) No 835/2011

1PAH: Benzo(a)pyrene
4PAH: Benzo(a)pyrene + Chrysene + Benz(a)anthracene + benzo(b)fluoranthene

Table 1. Values of allowable PAH content in smoked products permitted in Europe. European Union Commission Regulation No 835/2011

Factors in smoke variability

A second challenge is the variability of smoke generation. The thermal decomposition of wood is affected by many factors, which are notoriously difficult to control. While the purpose of the heat source is to drive the decomposition, the wood chips themselves experience a great range of temperatures. It is typical to see some wood chips that have charred and others with little charring at all. Friction smokers are also beset by this problem; they generally operate in cycles of pushing the wood plank against the friction wheel then releasing it. In this way, the temperature profile sawtooths between low and high values. Also of profound importance is the amount of oxygen that is present. When there is no air present the decomposition is described as torrefaction at temperatures below about 250°C and pyrolysis when they are above this. Here, both are generically referred to as pyrolysis. When oxygen is present, combustion occurs, which produces far simpler combustion products than pyrolysis, but is exothermic. In contrast, pyrolysis is endothermic at the lower end of its range (~280°C) and mildly exothermic at the higher end (~450°C). In many systems, air is drawn or forced through the bed of wood chips in order to use partial combustion to provide the heat to maintain smouldering. Thus, some wood chips are combusting and become glowing embers, while others receive no oxygen and instead pyrolyse at a range of temperatures depending on their proximity to the heat source. Added to this is the effect of moisture content, both of the wood chips and also the humidity of air drawn into the smoker. Another wood-specific factor is the ash content of the wood: the ash catalyses the decomposition reactions forming different decomposition products. The composition of the wood is also important, as essential oil components may vary. This variability has implications on smoke quality in that not only will the smoke aroma profile and composition be difficult to control, but when temperatures are high, carcinogenic polycyclic aromatic hydrocarbons are more likely to be produced.

Elucidating the science

The science of food smoke generation is not well understood. Heating of wood breaks the chemical bonds of hemicellulose, cellulose and lignin, producing gases, liquid and solid char. It is the liquid phase that condenses to an aerosol and is carried into the smoke house. Heavy tars with a high boiling point generally either do not volatilise or condense in the pipework between the smoke generator and the smoke house. When heavy tar end up on the food this is known as spotting and is undesirable. Some solid char particulates can also carry over, and often the PAHs form on the char phase.

During decomposition, hemicellulose, cellulose and lignin each form gas, liquid and char at a specific rate, which depends on the temperature, but also the amount of oxygen, moisture, and ash content of the wood. Some of these reactions are called primary reactions as they are single step decomposition of the wood components. Others are termed secondary reactions, where primary products interact to produce secondary products. The extent to which secondary reactions occur depends on the interplay between heat and mass transfer, the heating rate and residence time. More secondary products are formed when the distance molecules have to travel through the bed is long, and when their residence time is long. Heating rate is an operating parameter that needs to be considered during smoke generation as it affects the ratio of primary and secondary reaction products.

Despite the complexity, certain woods are favoured because they deliver a pleasant smoke aroma that results in the desired sensory properties of the smoked product. Traditionally, smoking was also part of food preservation because the deposited smoke acted as a bactericide. Today, however, with many other food preservation techniques available to manufacturers, smoking is more focused on delivering a unique taste to foods.

Identifying the compounds that are desirable and non-desirable is a non-trivial task as wood smoke is a complex mixture containing over 400 compounds of various compound classes such as acids, alcohols and phenols. The literature provides a general understanding of their effects on culinary smoking. For example phenol derivatives like guaiacol and methylguaiacol impart a smoky flavour, whereas phenol at certain concentrations creates an unpleasant flavour. Compounds can also affect the colour, and have medicinal and preservative properties. Sensory perception of the flavour profile results from the interactions between the aroma compounds present. For example, furans soften the heavy or strong smoky flavour of the phenolic compound class. Therefore, to characterise an aroma profile, a broad understanding of the compounds involved is required, encompassing their quantity and odour thresholds, chemical interactions, aroma properties, synergistic

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effects and stability in the presence of oxygen. It is clear, however, that there is a range of conditions where the aroma is most desirable.

The laboratory work done so far at Massey and Otago indicates that careful control of the smoking conditions can deliver smoke consistently within a ‘sweet spot’ of the aroma profile, and with the ability to modify it one way or the other according to product flavour requirements.

The class of compounds that need to be avoided are polycyclic aromatic hydrocarbons (PAHs), which are known to be carcinogenic, mutagenic and bioaccumulative. PAHs form increasingly in conditions above 700°C, which is well above the typical thermal degradation temperature for food smoking (<500°C), but it is typical of the temperature of glowing embers, where air ingress allows oxidative combustion to occur. Therefore, careful smoke generator design is needed to avoid PAH formation. It is entirely feasible that well controlled food smoking conditions can minimise, if not eliminate, the formation of PAHs and their transfer to the food products. It is important to also note that smoked products are not unique in containing PAHs; they are also present in baked, fried and grilled food products.

It is the aim of the team at Massey and Otago to enable New Zealand producers of smoking woods, smoke generators and smoked products to take advantage of the unique New Zealand woods, but also to manufacture smoked foods with better quality flavour and with more consistency.

This work is one project within the MBIE funded FIET research programme (Food Industry Enabling Technologies). Research is technology driven to enable a wide range of sectors within the food economy to grow export returns.