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Surface decontamination by hot filling and post filling processes

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Summary

The objective of this project was to investigate the factors that influence the degree of pack surface pasteurisation, primarily for hot-filled foods. Most hot fill surface processes are thought to be excessive and it was the intention of this project to quantify by how much. This may enable companies to reduce the severity of the applied time-temperature regime or eliminate (or minimise) additional process steps such as post-filling pasteurisation tunnels.

The key approaches to address this issue were:

(1) Identification of contamination mechanisms and control measures for food pack contamination;
(2) Measurement and quantification of thermal process efficacy in industrial hot-fill operations, and
(3) Thermal process optimisation through modelling and better understanding of the heat transfer mechanisms on food packaging in hot-filling operations.

Three case studies surveys focusing on the existing levels of microbial contamination on pack surfaces and the surrounding factory environment showed similar trends. In all cases, the pack coming into the food factory (including plastic pots, lids and pouches, glass jars, paperboard packs and cardboard outers) had little microbiological contamination in the form of moulds, yeasts and other microorganisms. However, the processing environment and surfaces that the packs may come into contact with (e.g. conveyors, guiderails, filling heads) showed various degrees of higher level microbial contamination, which could be transferred onto the pack. This does stress the importance of maintaining good standards of hygiene within the process environment as a means of preventing food and pack contamination. Guidance on handling and storing of food packaging has been established based on these trials. It is recommended that a minimum heat process of 70°C for 2 minutes or equivalent should be delivered to the worst case position of the entire interior packaging surface to control vegetative pathogens. This is established based on reducing the level of *Listeria monocytogenes* by a factor of 10^6 in product (6 log reduction) (Gaze *et al*., 1989), and the risk that various varieties and degrees of vegetative pathogens and spoilage organisms can appear on the packaging surface.

Processing targets to control spoilage organisms on food packaging are still controversial. This is because the types and numbers of the organisms on the packaging vary significantly between different packaging materials and individual food manufacturers. Consequently, it is recommended that process targets for packaging to control spoilage organisms are developed on a case by case basis. A risk assessment approach is proposed as compared to a conservative approach. Processes

and controls that have been known by industry to have positive effects on reducing the level of the microbial contamination on packaging are also listed in this report.

To quantify the surface heat treatments during hot filling and post filling processes, several validation techniques are reviewed. It is recommended that flexible temperature probes connected to a datalogger are used as the default measurement tool where possible. The use of other methods such as time temperature Integrators (TTIs) and infra-red imaging can be applied where dataloggers cannot be used.

Experimental results found in an industrial setting showed that a significant temperature decrease could occur in certain packaging materials immediately following the hot-fill operation. Typically, the pack temperature compared with food temperature could be reduced as much as 20˚C on contact with a glass jar surface, about 5-10˚C reduction on contact with a plastic surface, and less than 3˚C reduction on contact with a thin film or pouch surface. This suggests that hot filling alone is not realistic even to deliver a minimum 70°C for 2 minutes equivalent process on the many non-preheated glass or plastic packs. It is possible that some plastic pack surfaces may be able to achieve a 70°C for 2 minutes equivalent process and it is likely that many pouches may be successfully decontaminated from hot filling.

It should be pointed out that the packages tested in this study are those without preheating treatment before hot filling. Proper preheating treatment on the glass jars for example, would raise the initial temperature on the pack and therefore minimising the temperature loss once product comes into contact with the pack surface. Changes in equipment parameters setting, e.g., steam capper, may also have impacts on the final results. It is likely that with significant energy input before hot filling process, glass jar may still be possible to achieve 70°C for 2 minutes equivalent after hot filling process, although a practical thermal validation will be required to confirm this possibility.

The significant temperature drop on pack surface during hot filling may be an important factor to consider during packaging selection in the initial product development stage. Some packaging materials, such as glass and some plastics, tend to require an additional pre filling or post filling heat treatment, which might increase the capital investment.

The slowest heating areas on the surface of rigid food packaging varied depending on the processes in use. Typically, headspace and bottom corners were found to be the worst cases. For non-steam capped processes, the pack lid or closure could be the worst case. For flexible packs, no consistent cold area on the packaging was found. This was because the flexible packaging allowed product to move around the entire internal surface of the packaging during processing. Doypack and Gualapack are exceptions, where the pack cold spot during hot fill was usually found at headspace wall or closure.

Several post filling options are reviewed in this report, e.g. pasteurisation tunnels, pack inversion and hold times after hot filling. Each method is capable of delivering a more uniform or higher level of heat treatment throughout the pack, but this post filling heat treatment requires validation to confirm its contribution. This could be challenging in some cases (e.g. viscous product inversion) where the product is forced to move to different areas within the pack during the process, while the product temperature decreases with time.

Optimising the thermal processes applied to packaging is possible through mathematical modelling. Understanding of the heat transfer mechanism and characteristics of the packaging material is crucial to the success of hot filling. From experimental time and temperature data obtained from the internal surface of packaging during a post-filling process, a model can be built to predict the pasteurisation value (P) changes as process parameters change. Such a modelling prediction could reflect which factors contribute most to the P value on the packaging surface and therefore help to understand the most cost effective way to deliver a desired P value. The optimal conditions for hot filling require practical validation to confirm the findings.

With better understanding of the factors that influence microbial contamination and the thermal processes that need to be applied in hot filling and post filling processes, it is now possible to dictate the level of pack surface pasteurisation to save energy and cost without compromising food safety.

Acknowledgements

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Contents

1. Introduction

In order to deliver safe and stable heat preserved food products, microorganisms that can contribute to problems with food safety or food spoilage should be eliminated or reduced to an acceptable level. This requires sufficient heat treatment to be delivered to the food product as well as any packaging surface in contact with the product. Pasteurisation requirements for many types of food products are clearly defined in many guidelines (e.g., Campden BRI Guideline 51). The degree of heat process required for an effective pasteurisation treatment will vary depending on the nature of the food, and the type and the number of microorganisms present. Pasteurisation is a process now widely used and is particularly well established in the prepared foods and ready meal manufacturing sectors. The pasteurisation treatment needs to be designed to work alongside other product parameters, such as pH, water activity or chilled temperatures, to deliver a safe and stable product. However, pasteurisation requirements for packaging surfaces that may come into contact with the product during hot fill operations are not widely available.

Pack surface decontamination can be achieved in several ways: for example, chemical methods such as hydrogen peroxide, radiation methods such as UVC and pulsed light, or combination methods that use a number of such methods. Campden BRI R&D Reports 281, 357 and 358 have reviewed these methods. Although such alternative surface decontamination methods are available, the most popular and effective method is still through heat treatment.

Pasteurisation treatments of food packaging surfaces can be delivered through 'in-pack' processes (packaging is heated by external heating source after sealing) or by 'hot filling' (packaging is heated by processed hot products in a filling process) (See **Figure 1.1**).

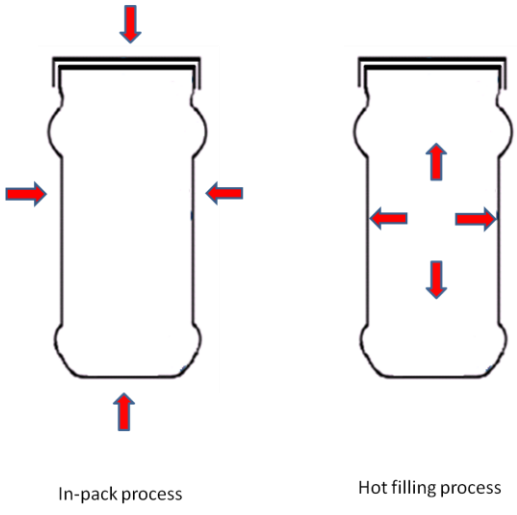


Figure 1.1 Illustration of heat transfer direction during in-pack and hot filling processes

For ‘in-pack’ processes, the slowest heating part of the product is generally the core of the product. If the product is sufficiently heated then the pack surrounding the product is also sufficiently treated as the heat transfer to the product is through the packaging.

However, in hot filling processes the food product is given the thermal treatment pre-filling. It is then filled into the pack and it is anticipated that the temperature of the product is sufficient to provide the necessary thermal treatment to decontaminate the inner surface of the food package. It is often the case that the food product temperature drops dramatically as it comes into contact with the food pack and, consequently, provides little thermal decontamination on the inside pack surface.

Therefore, it is the hot filling process that is of concern. It has always been assumed that the hot filling process gives the packaging and closures a sufficient thermal process to reduce any microbial hazards present, although limited data are available to support this view.

To understand this topic, the following issues need to be addressed:

1) The type and number of microorganisms present on the packaging surface, contamination mechanisms and control measures,

2) Thermal process efficacy in industrial hot-fill operations,

3) Possibility of optimising the thermal process delivered to the packaging surface to save energy and cost.

Unfortunately, limited information on the microbial contamination on packaging surface is available in the literature, and pack surface temperature measurement techniques have not been systematically reviewed. Levels of the heat treatment in hot filling and also many post filling processes delivered to the different packaging materials have also not been quantified and compared.

This report aims to provide such information and address these issues.

2. Microbial contamination survey on packaging surface and surrounding factory environment.

A literature review on microbial contamination on food packaging can be found in Campden BRI R&D report No. 357. In the same report, a survey on packaging surface and surrounding factory environments was conducted by a team of food hygiene specialists.

In this survey, three food production premises were visited on three separate occasions to determine the levels and types of microbial species commonly found on a range of different food packaging materials used in hot filling operations. The vectors of microbial contamination to the packaging were also assessed, e.g. through food contact surfaces, airborne contamination or water droplets.

2.1 General methods

Following a tour of each of the factory premises, several sampling areas were identified that followed the packaging through the factory, from initial receipt and warehousing of the packaging materials, through various handling operations and holding stores to the point of filling with the processed food product. At each sampling area, three potential sources of contamination were assessed:

1. Microbial contamination present on the surface of the food packaging material was measured by placing an individual piece of the pack into a sterile stomacher bag (Classic 400, BA6041 cpg standard) containing 500g Maximum Recovery Diluent (MRD) and shaking for 60 seconds.
2. Airborne microbial contamination present in the factory environment was measured by an air impaction sampler (Oxoid Microbiological Air Quality sampler M.A.Q.S.90) drawing 200 litres of air over 100 seconds across the surface of pre-poured 90mm diameter plates containing malt extract agar (MEA, for yeasts and moulds) or nutrient agar NA (for microbes).
3. Microbial contamination present on surfaces, and likely to come into contact with the food pack, was measured by either MEA or NA coated contact plates (pressed once by hand over the surface) or swab samples (Sterilin) recovered in sterile plastic tubes.

The medium used for the isolation of yeasts and moulds directly from the factory environment and from packaging samples was Malt Extract Agar (MEA) with an oxytetracycline supplement (LABM,

LAB37, Oxytetracycline, Oxoid SR0073A); this supplement inhibits the growth of bacteria and MEA acts as a selective medium that allows the growth of yeasts and moulds without competition from bacteria. The medium used for microorganisms on packaging and in the factory was Nutrient Agar (NA, Oxoid CM0067).

All sample processing and evaluation was carried out in a sterile microbiology laboratory environment and within a LEEC safety cabinet (Model: Trea 762x830x205, Serial No 1603001). Prior to processing the safety cabinet was cleaned down using Haz Tabs solution (Guest Medical, H8801, with 0.25% v/v concentration) and dried with a paper towel (Kruger - soft tissue standard). Alcohol (Methylated Spirit Industrial74, Fisher Scientific, 95%) was then sprayed over the cabinet interior and allowed to evaporate to prevent cross-contamination between samples. All samples were handled using sterile equipment and while wearing disposable protective gloves. These were re-sterilised / changed between samples to avoid potential cross-contamination.

2.2 Case Study 1

This food company produces a range of hot-fill products, including soups, sauces and pasta sauces. Packaging used by this company includes cardboard cartons, plastic pots (with lids) and cardboard boxes. Three separate visits were made to this factory.

2.2.1 Pack handling methods and sampling areas

Three pack types were analysed in this study:

- Cardboard cartons - three sizes (300g, 600g and 1000g) sourced from overseas (Israel, Germany and Denmark). Each carton collected was cut into squares of approximately 70mm x 70mm. The squares were then put into a sterile stomacher bag with 500ml of MRD and shaken by hand for 60 seconds.

- Plastic pots and lids – these were UK sourced. Each pot sampled was placed into a sterile stomacher bag with 500ml MRD and shaken by hand for 60 seconds. All plastic pots were processed individually.

- Cardboard boxes - single pieces of box, measuring approximately 50mm x 50mm were placed into a sterile stomacher bag with 500ml MRD and stomached for 60 seconds using a Colworth Stomacher 400.

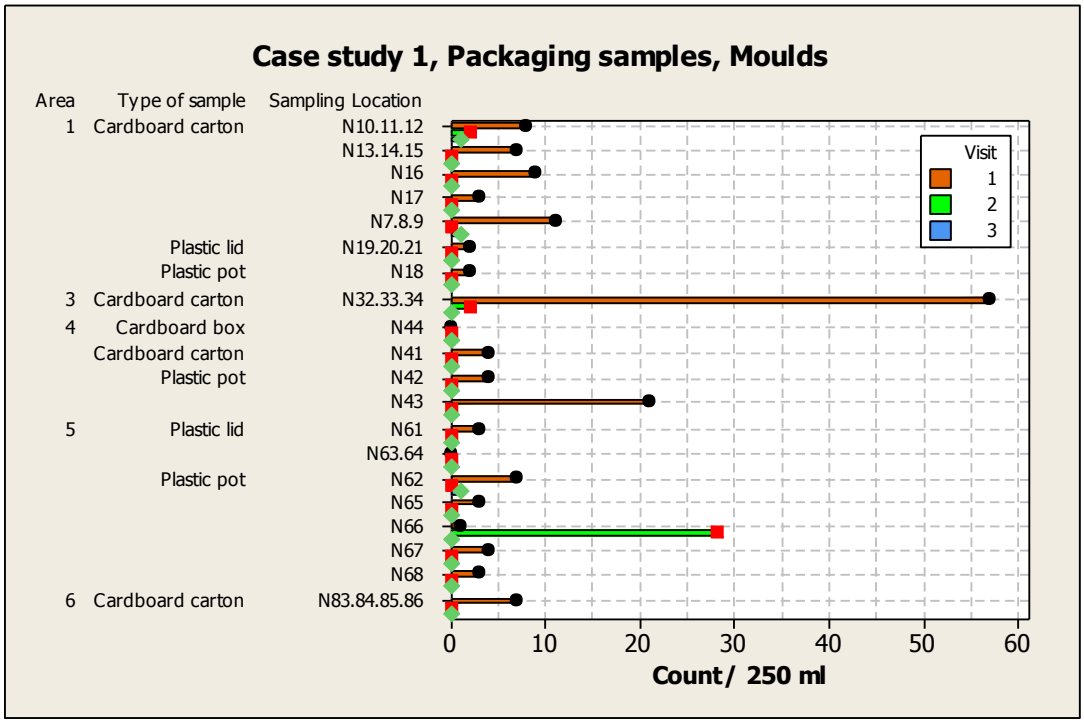
From the factory, measurements of pack contamination, environment contamination and surface contamination were made in six sampling areas, namely:

- Packaging store used for receipt of fresh packaging (Area 1)
- A secondary holding store for cartons (Area 2)
- Carton labelling room (Area 3)
- A secondary carton/pot storage area (Area 4)
- Filling area for plastic pots (Area 5)
- Filling area for cartons (Area 6)

2.2.2 Results from Case Study 1

Figure 2.1 shows the results of moulds and yeasts found on the packaging samples from the three visits to Case Study 1.

Figure 2.1: Moulds and yeasts found on packaging samples from Case Study 1



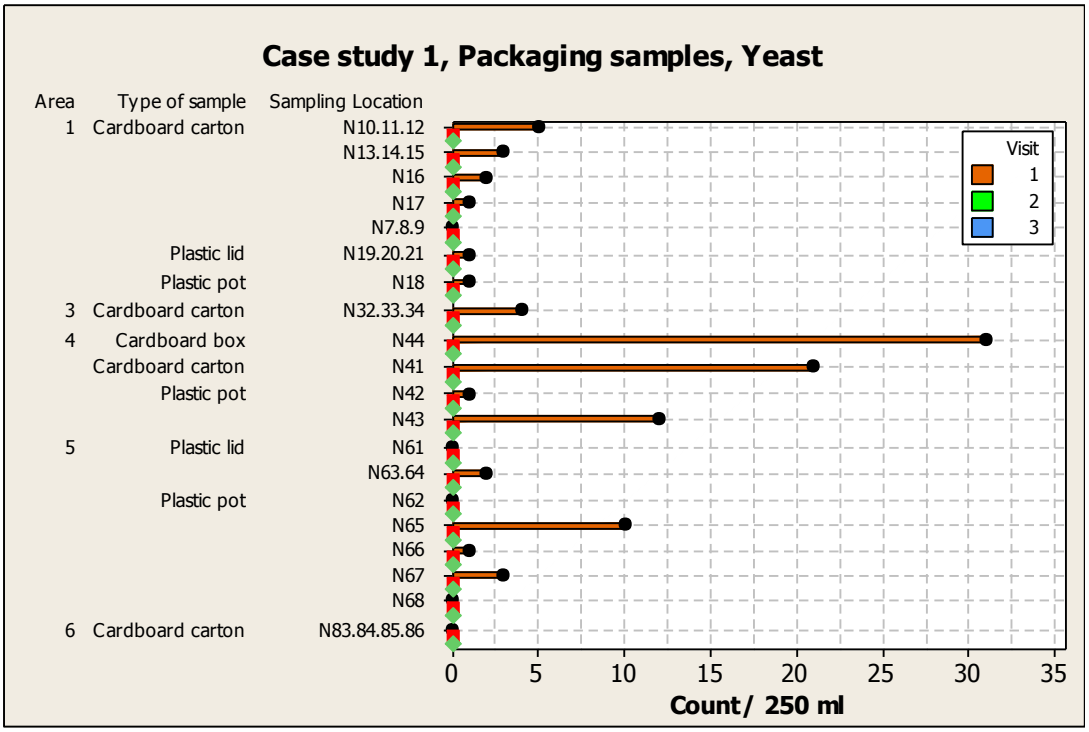


Figure 2.2 shows the results for total viable counts (TVC's) found on the packaging samples collected from each of the factory sampling areas.

Figure 2.2: TVCs found on packaging samples from Case Study 1

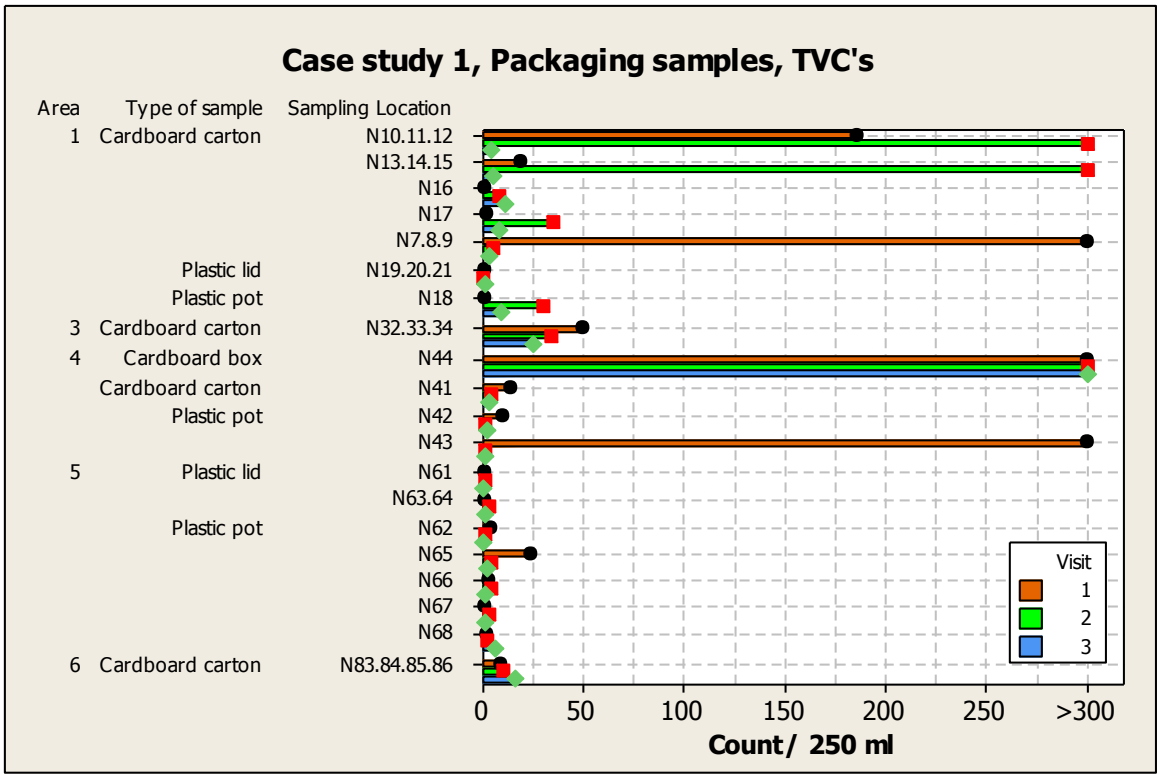
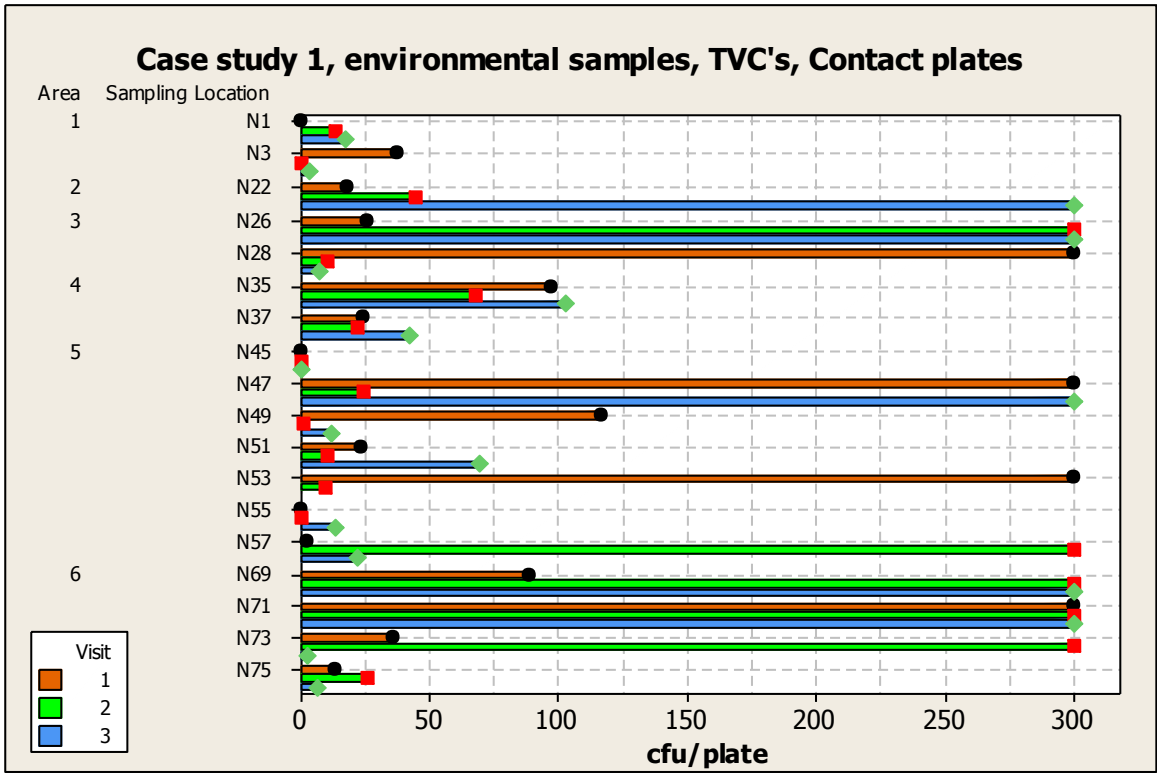


Figure 2.3: TVCs found on contact plates from Case Study 1



These results indicate that the packaging samples arrive at the packaging receipt store (Area 1) with a low microbial loading on the packs. It was noted, however, that the storage environment has a higher loading, reflecting the lack of hygiene control imposed on the pack outside the main food production area. The area of the factory that was consistently found to be the most contaminated environment was the filling room (Area 6), where the processed food product is brought into contact with the food pack.

It is interesting to observe that cardboard packaging has a higher level of microbial loading than plastic packaging, although the actual loading is considered to be low.

The microbial contamination found in the environmental samples is shown in **Figure 2.3**. There appeared to be a consistently higher degree of microbial contamination, across a number of surfaces, including conveyor guides and mandrels that are in close contact with the food pack. This increases the potential opportunities for cross-contamination to the pack. It is in Area 6 where the hot-filled product comes into contact with the pack and is expected to decontaminate the pack.

2.3 Case Study 2

This food company produces a range of hot-fill products, including sauces, preserves and condiments. Packaging used by this company includes glass jars and plastic pots (with lids) and cardboard boxes. Three separate visits were made to this factory.

2.3.1 Pack handling methods and sampling areas

Three pack types were analysed in this study:

- Large plastic tubs – MRD was poured into one tub and shaken for 60 seconds to rinse the inside. This MRD was then poured into a second tub and the process was repeated for this and a third tub (3 tubs making up one sample).

- Plastic lids – used for the large tubs. The lids were placed inside a stomacher bag, filled with 500ml MRD and shaken for 60 seconds before analysis.

- Glass jars – MRD (500ml) was poured into a stomacher bag along with three glass jars taken from each sampling location, and shaken by hand for 60 seconds before sealing the bag and subsequent analysis.

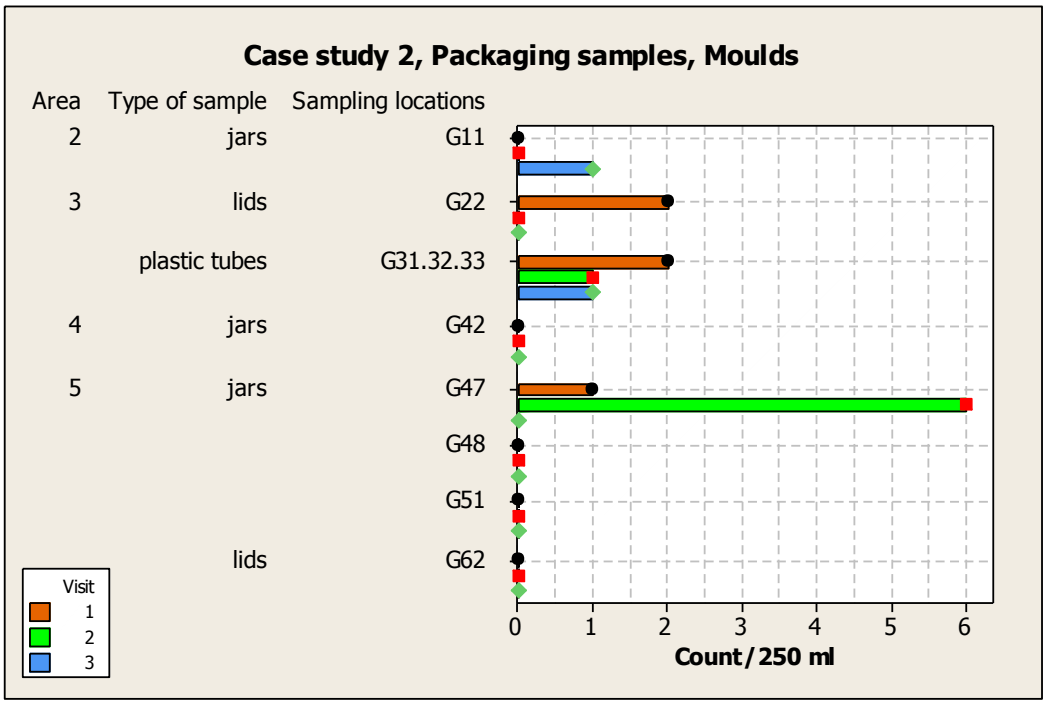
From the factory, measurements of pack contamination, environment contamination and surface contamination were made in six sampling areas, namely:

- The goods In area, where packaging samples arrive from the supplier (Area 1)
- The warehouse area, where jars and plastic tubs are stored (Area 2)
- A mezzanine temporary storage area for packaging, above the factory floor (Area 3)
- A de-palletising area for transferring packs onto the production lines (Area 4)
- The production filling area (Area 5)
- The packing room area (Area 6)

2.3.2 Results from Case Study 2

Figure 2.4 shows the results of moulds and yeasts found on the packaging samples from the three visits to the factory in Case Study 2.

Figure 2.4: Moulds and yeasts found on packaging samples from Case Study 2



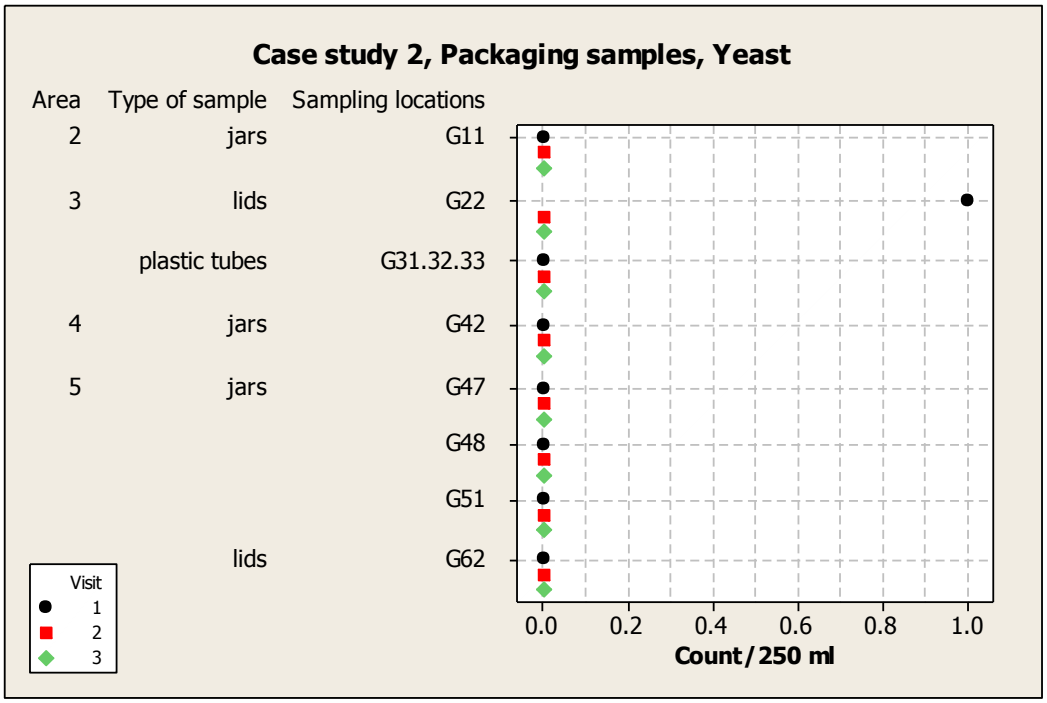


Figure 2.5 shows results for total viable counts (TVCs) found on the packaging samples collected from each of the factory sampling areas.

Figure 2.5: TVCs found on packaging samples from Case Study 2

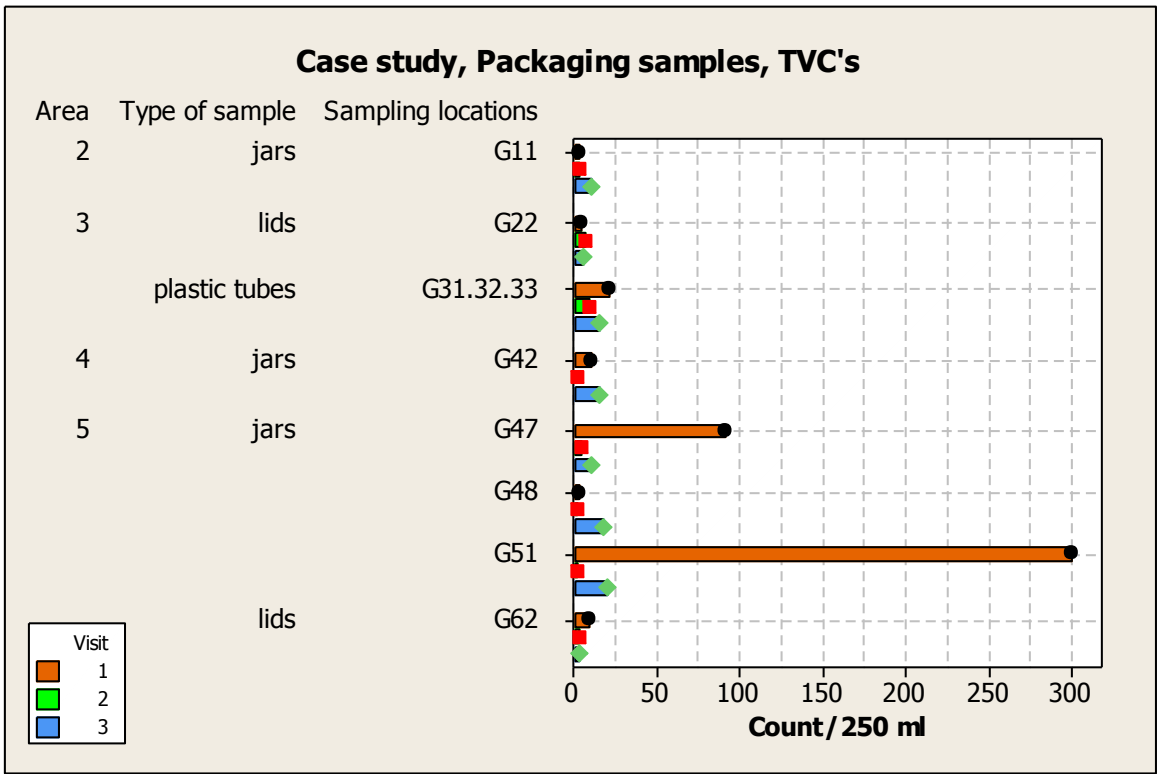
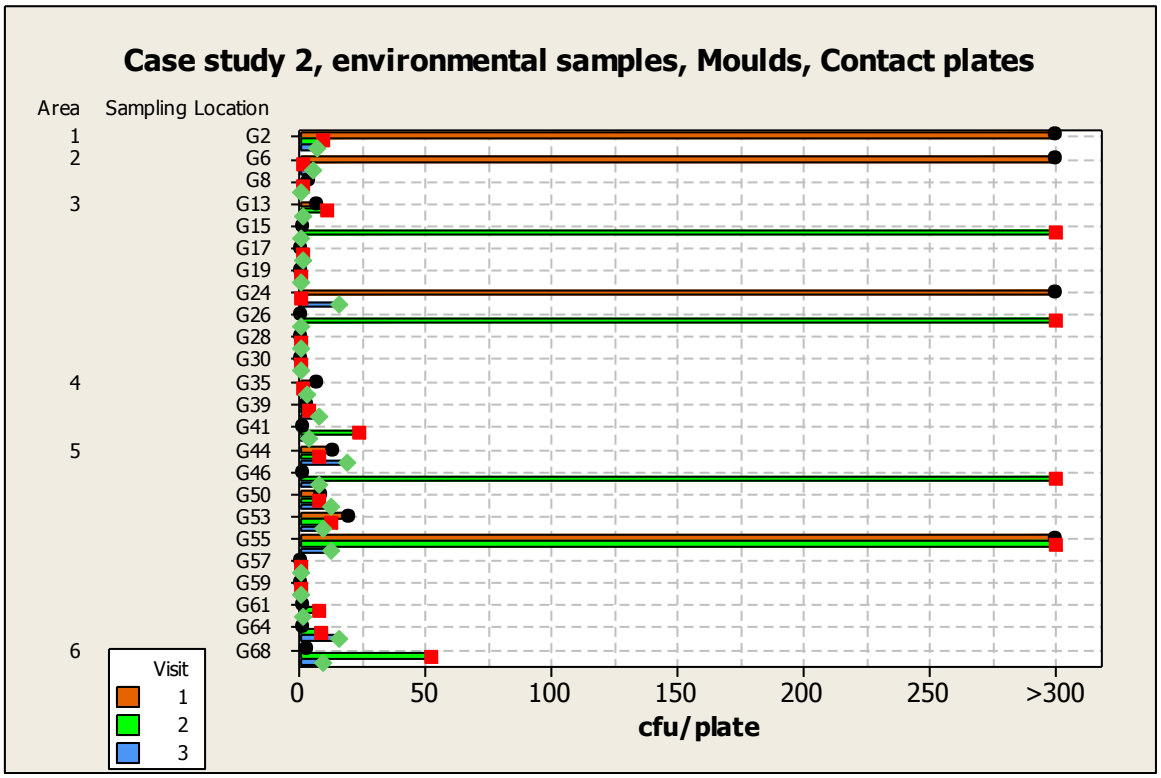


Figure 2.6: Mould samples found present in the environment of Case Study 2.



The trend across all three visits to this factory was that the packaging coming into the factory had very low levels of microbial contamination, although the environment surrounding the packaging had a greater level of contamination. This highlighted the potential for packs to pick up contamination from their surroundings. This was apparent in the mezzanine area and the filling area. In this factory, a heat resistant mould was found in glass jar samples prior to receiving a hot air blowing treatment to pre-heat the jars before filling. Following the second visit, the organism was identified as *Aspergillus fumigatus Fresen*. This observation highlights the importance of environmental control for the hot fill area. The results illustrate the need to control the hygiene of all areas, both contact and environmental, to control contamination of both the food and the packaging.

2.4 Case Study 3

This food company produces a range of hot-fill natural liquid stock products packed in plastic bags. Three separate visits were made to this factory.

2.4.1 Pack handling methods and sampling areas

The packs analysed in this study were large plastic bags (5kg and 10kg). Samples of the packaging were taken in each area where packaging was handled.

From the factory, measurements of pack contamination, environment contamination and surface contamination were made in three sampling areas, namely:

- A clean air room, where packaging samples arrive from the supplier (Area 1)
- A clean room, used as a changing room (Area 2)
- The packaging and labelling room, where the product was filled (Area 3)

2.4.2 Results from Case Study 3

Figure 2.7 shows the results of microbial contamination (moulds, yeasts, and TVCs) found on the packaging in Area 1 of the factory. This indicates low levels of TVC and yeasts/moulds. Counts were generally low for the packaging samples, on both NA and OMEA.

Figure 2.7: Microbial contamination on packaging samples from Case Study 3

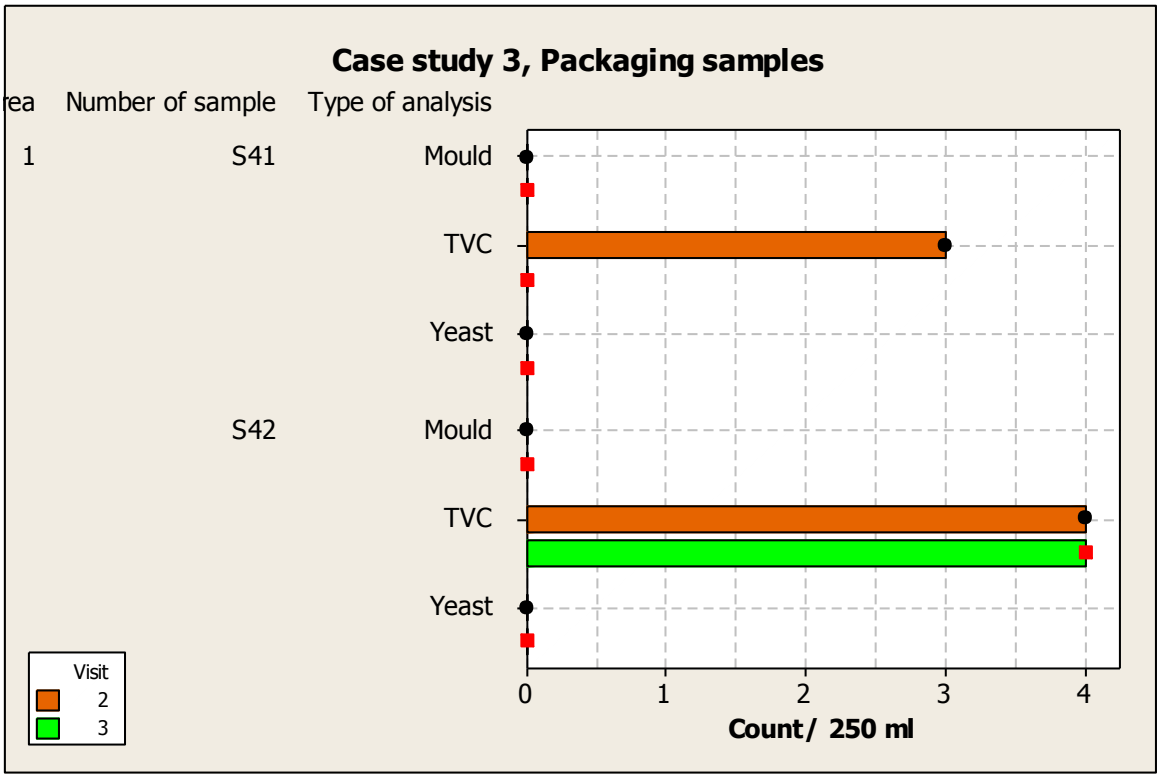
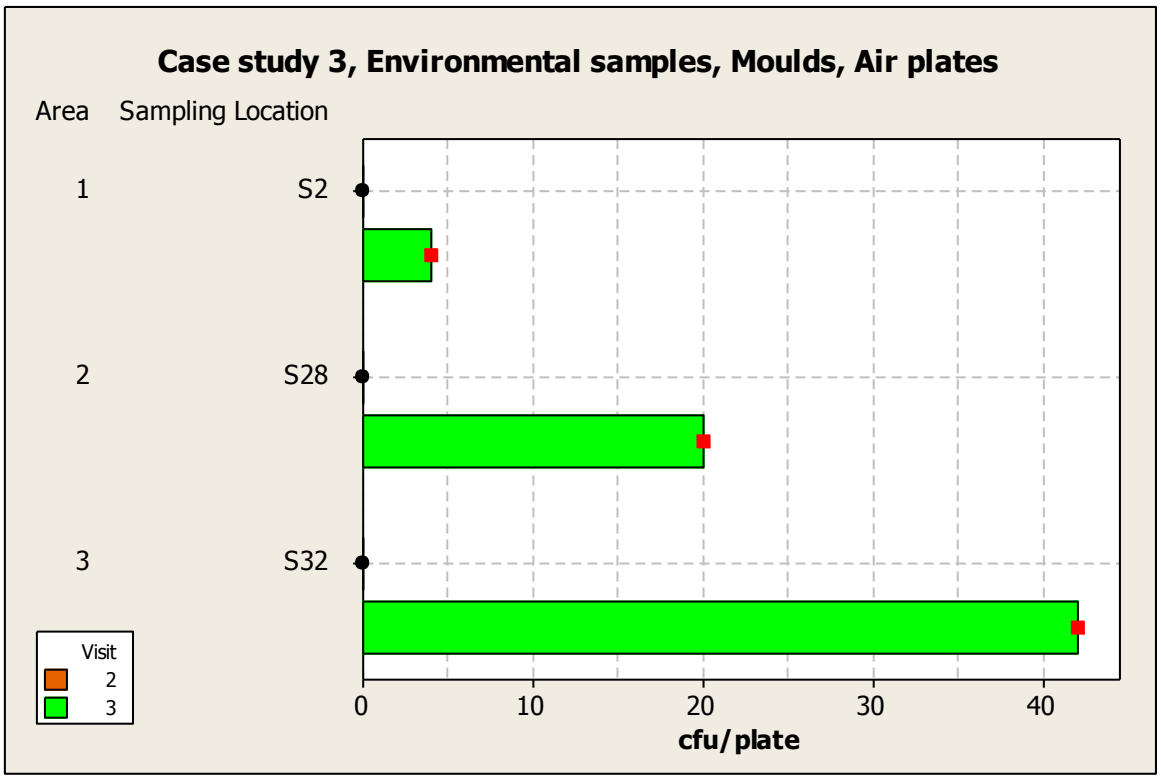


Figure 2.8 shows the results for moulds found on air plates and on contact plates from the three factory areas. Mould values were low in each area.

Figure 2.8: Moulds found on air and contact plates from Case Study 3



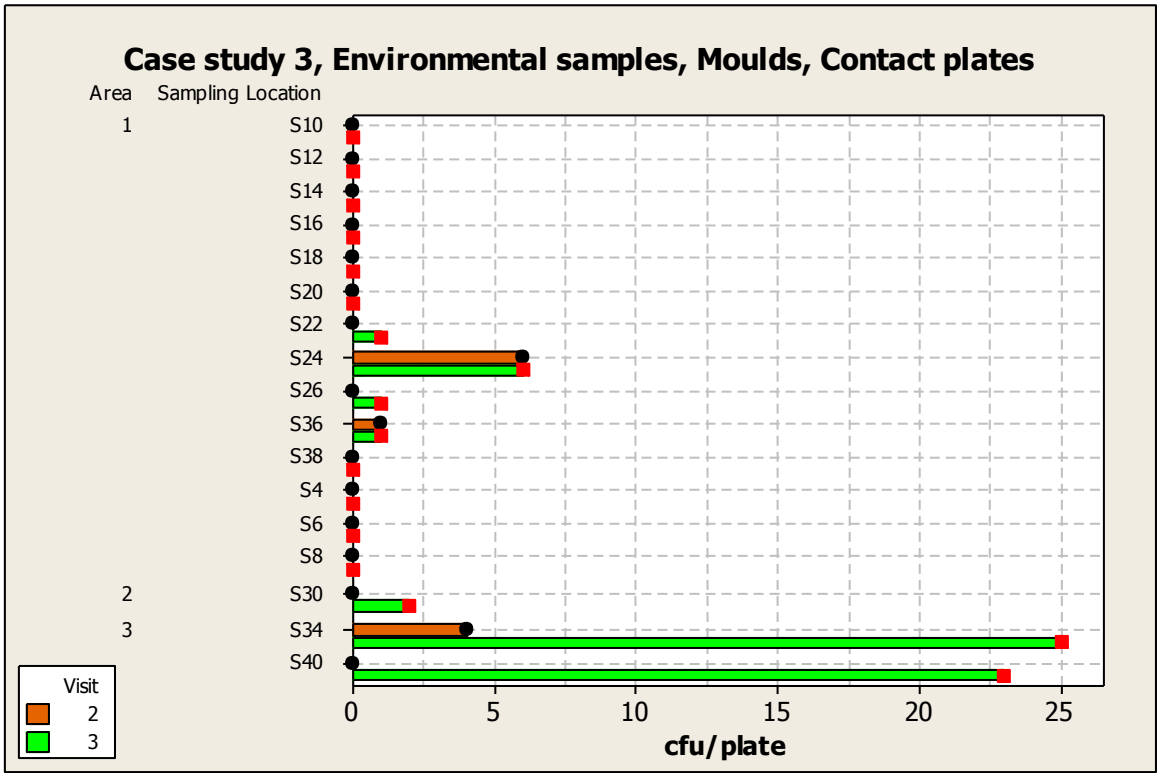
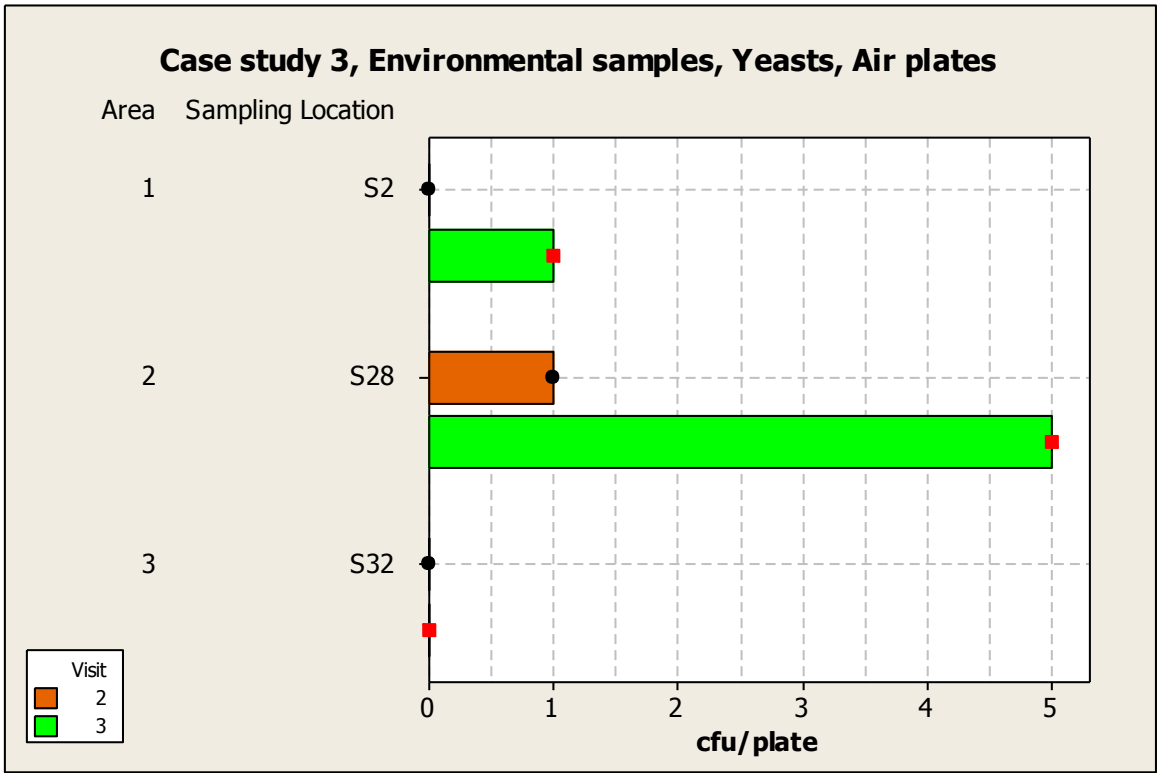


Figure 2.9 shows the results for yeasts found on air plates and on contact plates from the three factory areas. Yeast values were low in each area.

Figure 2.9: Yeasts found on air and contact plates from Case Study 3



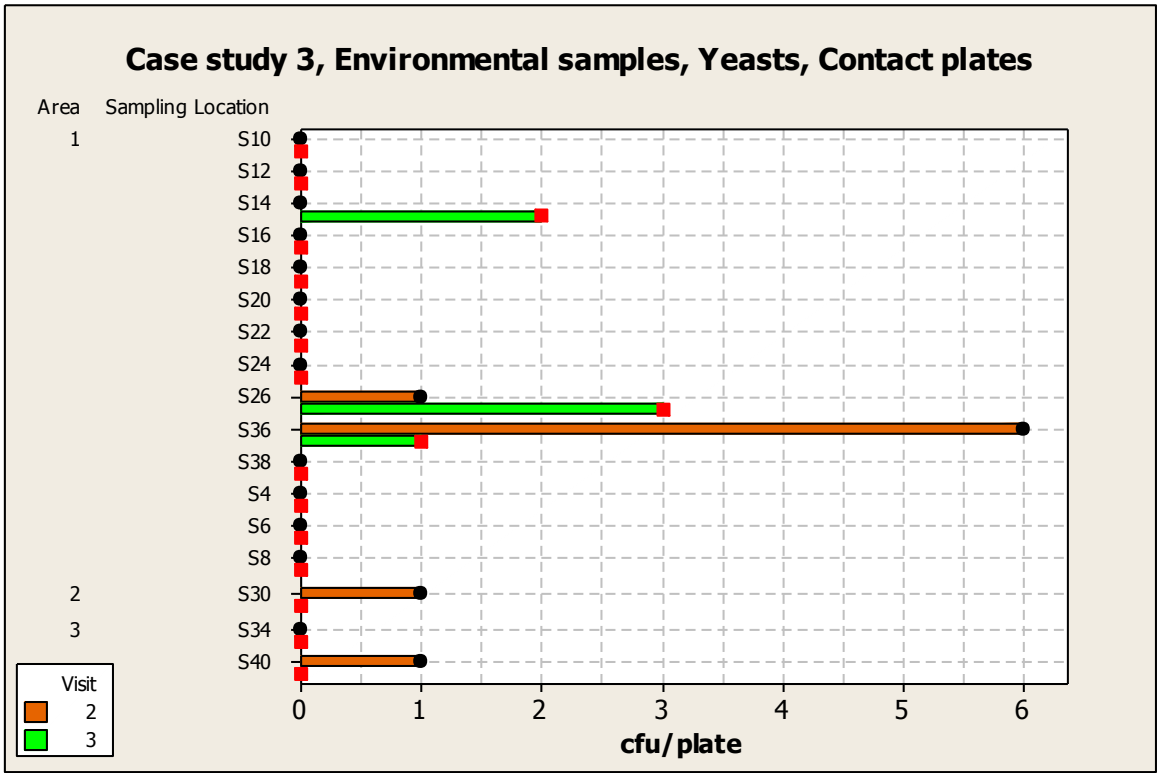
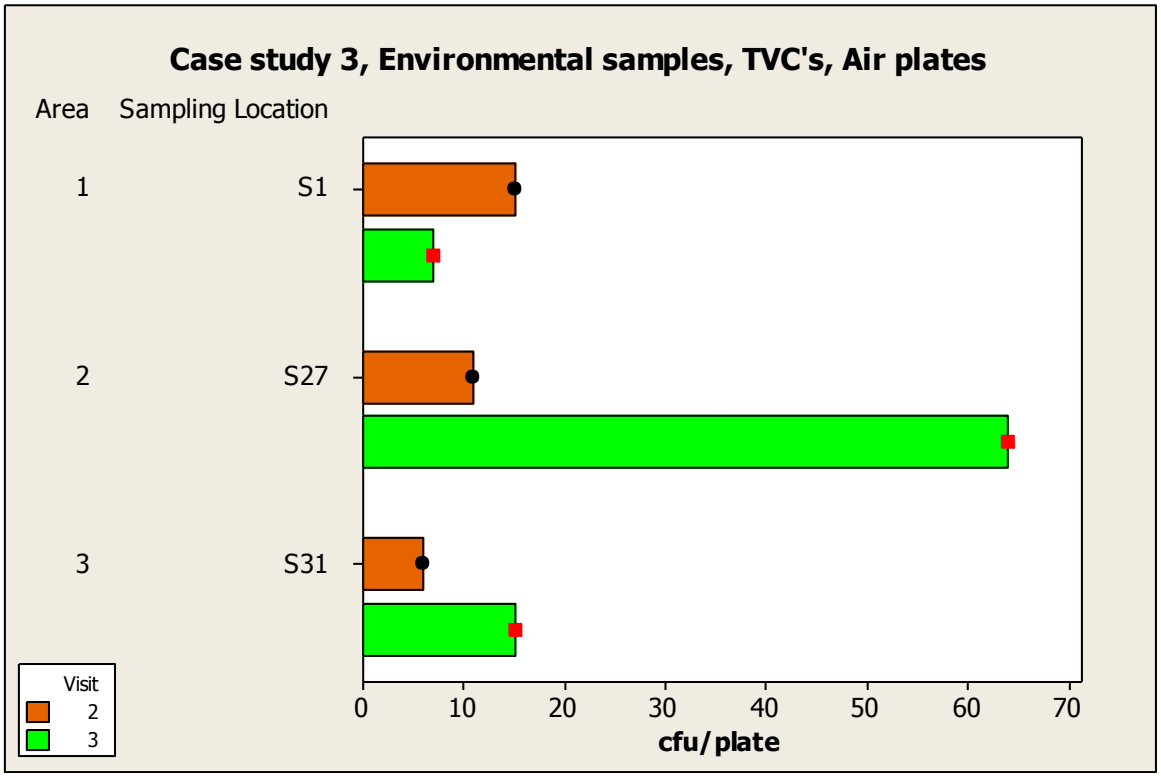
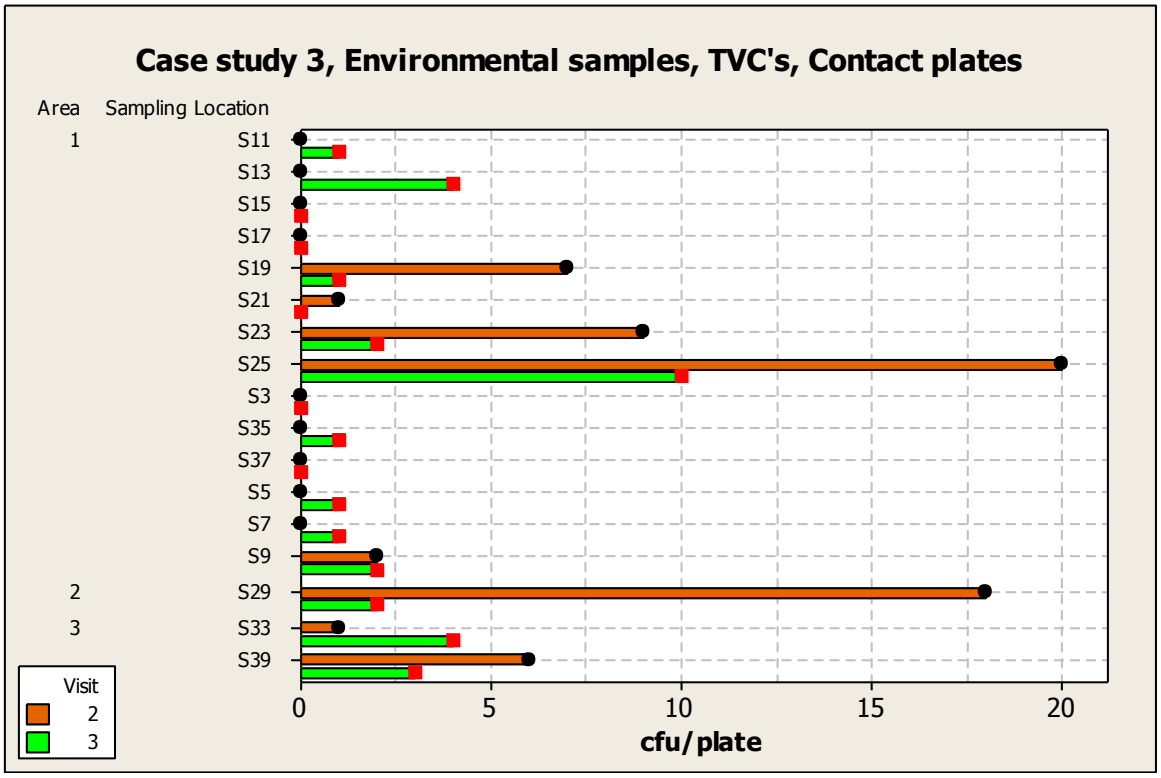

Case study 3, Environmental samples, Yeasts, Contact plates
Area
Sampling Location
1
S10
S12
S14
S16
S18
S20
S22
S24
S26
S36
S38
S4
S6
S8
2
S30
3
S34
S40
Visit
2
3
0
1
2
3
4
5
6
cfu/plate

Figure 2.10 shows the results for TVCs found on air plates and on contact plates from the three factory areas. TVC values were low in each area.

Figure 2.10: TVCs found on air and contact plates from Case Study 3





Analysis of the results from Case Study 3 showed that the packaging and the pack contact environments were relatively clean. This was indicated by the low colony counts on NA, which are not selective for the organisms to grow. While the air impaction plates recorded a higher level of airborne microorganisms on the third visit, these counts were still considered to be relatively low for this kind of environment.

2.5 Conclusion on microbial contamination survey on packaging surface and surrounding factory environment

The three case study trials provided similar trends and guidance for the future. In all cases, the packs coming into the food factory (including plastic pots, lids and pouches, glass jars, paperboard packs and cardboard outers) had little microbiological contamination in the form of moulds, yeasts and other microorganisms. However, the processing environment and surfaces that the packs may potentially come into (e.g. conveyors, guiderails, filling heads) had various degrees of higher level microbial contamination.

There is potential for the packaging to pick up contamination from both these sources. This was thought to be a particular issue for plastic packaging, as the electrostatic charges that can potentially build up on the plastic surface may attract airborne contamination more easily than other packaging materials. The surface and environmental contamination, although relatively low, was also different on different visit dates. This may have been the result of the microbiological measurements being made before or after the factory areas had been cleaned, or seasonal effects of the airborne microorganisms. This does stress the importance of maintaining good standards of hygiene within the process environment as a means of preventing food and pack contamination.

Although good hygiene practices are relevant to all food production and processing areas, they are particularly important in hot-fill environments. The food product will have been thoroughly processed, but it will come into contact with a food pack which has not received, at that point, any degree of thermal processing. If there is contamination present on the packaging, the only heat treatment that will be experienced by the pack is that delivered directly from the hot product. Thus, it is a combination of assurance of a microbiologically safe pack, the prevention of contamination of the pack within the factory before it is filled and sealed in the filling area, and the efficiency of heat transfer from the product to the pack that are particularly important. In the absence of any post-filling process operations, this is the principal means of producing microbiologically safe hot-filled food products.

3. Mould identification in a hot filled spoilage product.

It is of interest to understand the microorganisms that could survive under current hot filling process applied in the industry.

In hot filling process, products are usually cooked thoroughly before hot filling. Therefore, if there are spoilage issues in the final product, it is more likely to be as a result of one of the following reasons:

1) Insufficient heat treatment on packaging internal surface; or

2) Post-process contamination due to failure of the packaging.

To obtain a spoilage sample from a manufacturer is not easy, as spoilage incidence only occurs very occasionally for many manufacturers and may never occur for some others. Even if a spoiled pack sample is found by a customer, its normal fate is disposal rather than a return to retailer or manufacturer. In the unlikely event of a spoiled product pack being returned to the retailer, it more often than not fails to find its way back to the manufacturer.

Despite this, a spoilage hot filled sample was submitted by one of the industrial partners near the end of this project.

The packaging seal of this spoilage sample was intact, suggesting that spoilage may have been caused by insufficient cooking of the product or packaging.

Through DNA sequencing analysis, this spoilage organism was identified as *Xerochrysium xerophilum*.

Xerochrysium xerophilum has a maximum and minimum aw for growth of approximate 0.99 and 0.66 respectively, with an optimum of around 0.94. The optimum temperature for growth is 30-37°C. The species type was originally reported from Australia, isolated from spoiled prunes. This species has also been found on other sugar-rich products such as chocolate and coconut and has been reported from maize, stored for long periods. There is no evidence of this species being associated with human clinical cases, thus it is assigned to ACDP hazard group 1, a biological agent most unlikely to cause human disease.

4. Process targets for packaging surface decontamination

4.1 Process target for packaging to control vegetative pathogens

From this work, it is recommended that a minimum 70°C for 2 minutes equivalent heat process should be delivered to the worst case position of the entire interior packaging surface during a hot-fill operation.

This is established based on reducing the level of *Listeria monocytogenes* by a factor of 10^6 in products (6 log reduction) (Gaze *et al*., 1989), and the risk that various vegetative pathogens and spoilage organisms can appear on the packaging surface.

Most vegetative pathogens and some spoilage organisms would be reduced significantly by this process. It has not, however, been designed to destroy bacterial spores such as *Bacillus cereus* or *Clostridium* species, or preformed toxins (Campden BRI Guideline 51). The surviving spores should not be able to germinate if pH level within the products are controlled to less than pH 4.5.

The main concerns after this heat treatment are spoilage organisms such as moulds.

4.2 Process target for packaging to control spoilage organisms

This process target is still unclear and controversial. This is because the types and numbers of the organisms that may be found on packaging could vary significantly among different packaging materials and individual food manufacturers.

Also, if the packaging and hot filling environment is not aseptic, the packaging is potentially exposed to the risk of microbial contamination. This contamination (as suggested in Section 3 of this report) suggests such contamination may be unlikely from the packaging supplier but more likely from the environment surrounding the packaging in the factory. This may be in the packaging store, factory floor or any other pack holding areas. The routes of pack contamination may be (1) cross contamination through the direct contact with other surfaces (e.g. conveyor, filler head), or (2)

electrostatic force building up on the packaging surface during processing that could potentially attract airborne organisms or contamination.

Process targets for food packaging on hot fill are therefore related to the packaging materials, hygienic conditions, pre-filling processes and air quality at the individual factory.

Thus, it is difficult to have one target that is suitable for all packaging formats and designs, and for all processes and for all manufacturers.

Currently, different manufacturers are implementing different target processes for packaging to control spoilage organisms on packaging surfaces. Example time temperature treatments are:

- 75°C for 5 minutes equivalent (z=12°C)
- 85°C for 1.7 minutes equivalent (z=8.3°C)
- 85°C for 5 minutes equivalent (z=8.3°C)
- 95°C for 5 minutes equivalent (z=9°C)

A very conservative approach to pack decontamination in hot fill operations is to propose that the pack receives the same level of heat treatment as the heat processed food product to control spoilage organisms on packaging. This will be a severe heat process for packaging decontamination which can not be achieved by hot filling alone and requires a post filling heat treatment.

A more realistic approach is probably to establish a process target for packaging to control spoilage organisms on a case-by-case basis.

For example, for food products with a pH<4.0, the product process target as recommended in Campden BRI Guideline 51 is 85°C for 5 minutes equivalent (z = 8.3°C). In the conservative approach, the packaging is expected to receive the same level of heat treatment as the product to control spoilage organisms. This product target is aimed at making a 6 log reduction of the target microorganisms. However, if in this factory, there is consistent and repeatable evidence over a significant period of time that shows that the packaging surface (and its surrounding environment) before hot filling always has less than a 2 log initial loading, perhaps in this case the recommended process could be reduced to 85°C for 1.7 minutes equivalent (z = 8.3°C) that aims to achieve a 2 log reduction instead of a 6 log reduction in the target microorganism population.

Good examples of such evidence are shown in Section 3 of this report. By visiting the food factory at different times of the year (including at least one visit during the warmer days of summer) a microbiological sampling regime could be established. Sampling areas for microbiological tests

should cover the packaging goods-in areas, the pack storage areas and the hot filling area. Packaging surfaces, other surfaces possibly in contact with the packaging and air quality should all be investigated. A good manufacturing practice would be to demonstrate the controls of preventing contamination through these vectors.

The following processes and controls shown in **Figure 4.1** have been known by industry to have positive effects on reducing the level of the microbial contamination on packaging, which would be worthwhile to be considered when establishing a target for packaging decontamination.

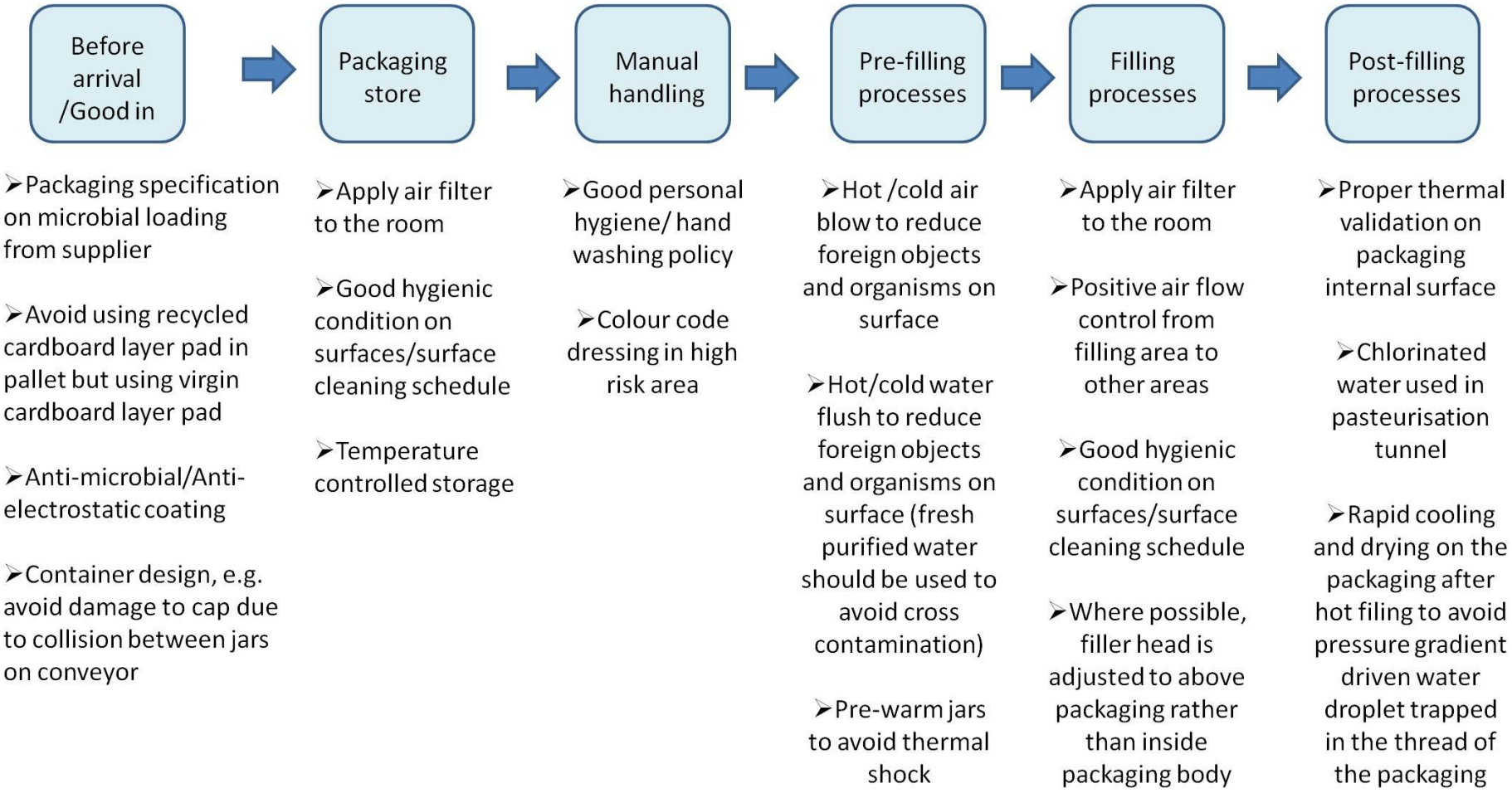


Figure 4.1: Processes and controls that may have positive effects on reducing the level of microbial contamination on packaging

5. Surface temperature measurement techniques

Techniques for surface temperature measurements, particularly pack surface temperature measurements, are compared to determine their effectiveness as thermal validation techniques.

5.1 Thermochromatic inks

These are paper/plastic sheets containing a type of dye that changes colour when the temperature changes. (See **Figure 5.1**)

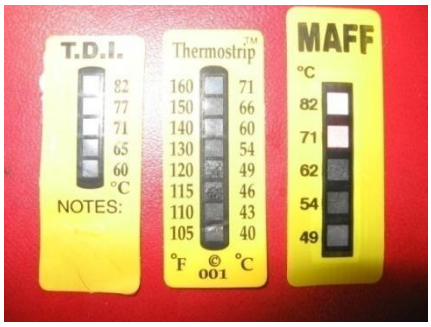


Figure 5.1: Thermochromatic ink paper

Advantage

- Easy to use - thermochromatic ink sheets can be directly adhered to the desired surface for temperature measurement, the colour change indicating the temperature experienced.

Disadvantages

- Lack of sensitivity - thermochromatic ink is usually triggered by a range of temperatures rather than a specific temperature reading. Therefore, it is not able to indicate an accurate temperature reading.
- Lack of process time measurement - thermochromatic ink indicates the highest temperature range it is exposed to in its recent history but currently cannot indicate the length of time it has been exposed to any particular temperature.

Comment

Thermal validation on pack surfaces requires accurate measurements of both the temperature and time profile in order to predict the reduction in target organisms from a heat treatment. A thermochromatic ink sheet is not suitable for this purpose. However, this has been used extensively in industry, to distinguish cooked batch product from uncooked product to avoid cross contamination, and to check temperature abuse during product distribution and storage.

5.2 Thermocouples and dataloggers

These are either wired or wireless temperature measurement kits with sensors at the tip of their probes. Typical applications on packaging surfaces are shown in **Figure 5.2**.

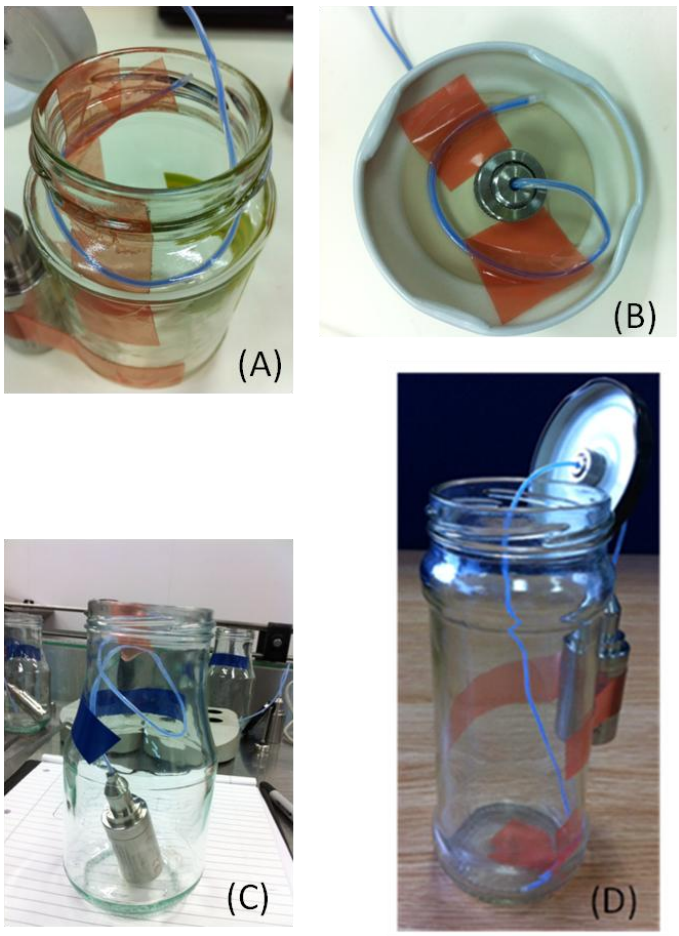


Figure 5.2: Application of temperature sensors that attached to different positions on internal packaging surface: (A) headspace wall, (B) Lid, (C) headspace wall, and (D) bottom corner. Logger body could be put inside or outside the jar (e.g., C and D)

Advantages

- Easy to use - thermocouples and dataloggers are user friendly and set-up and download of time temperature data requires only minimal training.
- Accurate and consistent reading - typical offset for thermocouple and resistance thermometer connected to dataloggers is below 0.2°C.
- Immediate result - thermocouples and dataloggers can be set to either simultaneously export the temperature/time data or data can be downloaded immediately after dataloggers are retrieved after the process.

Disadvantages

- Introduce new factors to the system - either datalogger bodies or compression glands put into the pack to allow time-temperature measurements at the cold points in the pack. These also take up some volume of the packaging, which could result in overfill of the pack. The stainless steel materials can also absorb a significant amount of heat energy from the system and result in inaccurate measurements.
- Limited accessibility - because of the limitation of size and design of thermocouples and dataloggers, they are limited on where they can be applied in some packs and processes, e.g. capping processes, pistol filling process, sachet filling process.
- Lengthy preparation time - it is a time consuming and challenging task to fix the sensor probes to the desired position on internal packing surfaces in practice.

Comments

Thermocouples and dataloggers are the preferred and default methods for thermal validation on packaging surfaces, but can be limited in their accessibility.

5.3 Time and temperature integrators (TTIs)

A micro-litre quantity of food grade enzyme (e.g. amylase) encapsulated in silicone tubes can be made to have similar thermal kinetics to the target microorganisms (Van Loey *et al*., 1996; Tucker 1999 and Tucker *et al*., 2009). Thus, these enzymes respond to heat in a way that is very similar to the target microorganisms.

By measuring the enzyme activity change before and after the heat treatment step, pasteurisation levels given to the enzyme can be determined. Encapsulating the enzyme in a silicon envelope makes the basis of a time temperature integrator (TTI) and these TTIs, when placed in the product or on the food pack, can give an indication of the level of heat treatment experienced.

Figure 5.3: TTI tubes and particles

Advantages:

- Easy to use – once made, TTIs can be directly applied to the desired surface position and immobilised by high adhesive tape.
- Best accessibility - thanks to its small size, TTIs can access and measure any surface, even in complicated processes or pack configurations.
- Large numbers possible - TTIs can be made and applied in large numbers.
- Consistent results - under careful fabrication, calibration and analysis, the variability of TTI results is small.

Disadvantages:

- Lengthy preparation and analysis time - TTIs are prepared manually and require typically 5 minute per sample for analysis time on a spectrophotometer.
- Limited temperature range measurement - TTIs are capable of measuring temperature range between approximately 60 and 90°C. The capacity to measure outside this range is still in experimental development.
- Delayed result output - results measured by TTIs are not revealed until the samples have been analysed by the spectrophotometer in the laboratory. This delay is sometimes not acceptable if a quick decision is needed immediately after measurement.
- Accuracy depends on how well the enzyme D and Z values match those of target microorganisms.

Comments

The TTI technique is widely used in thermal validation where conventional probes cannot be applied. The example below highlights one of these many occasions.

Cryovac bag filling is a typical ‘form-fill-seal’ process. The product is processed in a pre-cook tank and heat exchanger before filling. The cryovac bag is formed into a tube with a seal at the bottom before hot filling. When the desired weight of product is filled in the bag, a heat sealer seals the top of the bag, leaving no headspace (see **Figure 5.4**)

In such a continual process, it is not possible to measure internal packaging surface temperature by any dataloggers or thermocouples. TTIs will be the only appropriate technique.

To apply the TTIs, the process can be paused, and within a few minutes, TTIs can be attached to the internal surface of the packaging before hot filling and the bag is formed. After attachment, the machine is re-started and the attached TTIs stay in the bag until the end of the process. TTIs can then be retrieved and analysed using a spectrophotometer.

A TTI arrangement is shown in **Figure 5.5** and some actual results are shown in **Table 5.1**

Figure 5.4: Process equipments: (a) pre-cooker tank, (b) heat exchanger, (c) divert valve and sieve, (d) cryovac filler upper part and (e) cryovac filler lower part.

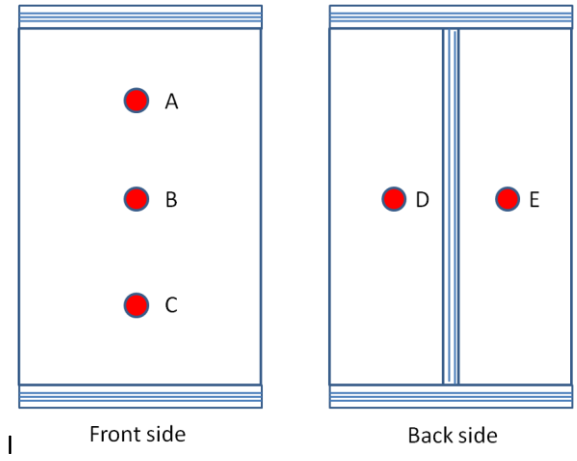


Figure 5.5: TTIs attached to different positions on the internal surface of the 10 kg cryovac bags: (A) front top (B) front middle, (C) front bottom, (D) back left and (E) back right positions

Initial enzyme activity 0.2733 ± 0.04 (8 individual repeats)
Calibrated D value: 7.14 minutes
Calibrated Z value: 8.3˚C
Reference Temperature: 70˚C

Table 5.1: Hot filling 10kg sweet sauce in cryovac bags

Positions*	Final enzyme activity	P Value (T_{ref} = 70 ˚C, z =7.5˚C)
2B	0.0114	9.85
3A	0.0007	18.50
3E	0.0024	14.68
4B	0.0004	20.24
4E	0.0277	7.10
5D	0.0003	21.13
6E	0.0093	10.48
7A	0.0002	22.39
8A	0.0001	24.54

*The number of the position represent separate cryovac bag hot filling in sequence, the letter represents the corresponding positions on the cryovac bag surface as shown in **Figure 5.5**.

5.4 Infra-red imaging

The amount of radiation emitted by an object increases with temperature; therefore, thermography

Can provide a visual indication of variations in temperature.

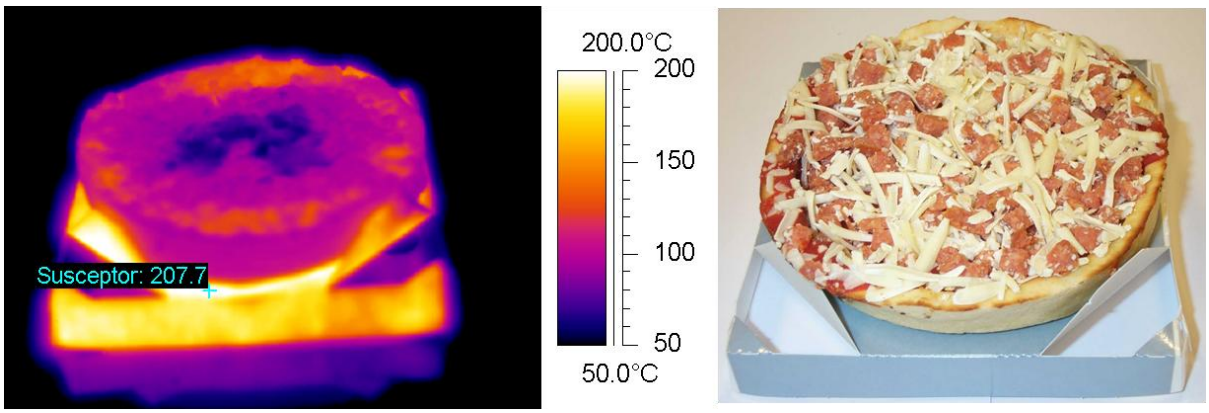


Figure 5.6: Thermal imaging of susceptor temperature measurement.

Advantages:

- Provides direct reading of the surface temperature
- 'Non-invasive' measurement
- Easy to operate
- High temperature range possible

Disadvantages:

- Easy to misuse (false reading due to inaccurate data on emissivity of packaging)
- Measures only the outside surface rather than inside surface of packaging

Comments

Can be used in thermal validation where conventional probes can not be applied, requiring knowledge and experimental emissivity data on the packaging surface in order to provide an accurate reading.

6. Thermal validation on packaging surface - Industrial trial results

It is of paramount importance that proper thermal validation on packaging surfaces is carried out to ensure that packaging surfaces receive the recommended heat treatment.

In this project, industrial trials were carried out for the disparate industrial partners to quantify the level of heat delivered to packaging surfaces in their processing lines. These trials were carried out on a wide range of packaging materials such as glass, plastic and metallised foil etc. to gain a full understanding of the practical difficulties in pack validation under different conditions.

6.1 Hot filling alone

6.1.1 Hot filling glass jars

Significant temperature loss on the surface of the glass jar was observed in the hot filling process (once the product came into contact with the glass jar surface). For example, with a core product temperature recorded at 85˚C during hot filling, only 66˚C was recorded at the middle position on the packaging surface. This was even lower for other positions such as the bottom corner (56˚C), headspace (55˚C) and lid (54˚C) (see **Figure 6.1**).

Typically, it was seen that more than 20˚C temperature loss occurred once the food product had come into initial contact with glass jar surface.

It was observed that, among the various positions tested on the pack, the cold points on the packaging after hot filling were usually found at the lid, headspace and bottom corner. If steam capping is implemented at the point of hot fill, then lid temperatures remained higher during and immediately following the hot fill step, and cold points were usually found at the bottom corner or headspace areas of the glass jars.

6.1.2 Hot filling 'squeeze' plastic bottles

Significant temperature loss on the plastic bottle surface was observed in the hot filling process (once the product came into contact with the bottle surface). For example, with a core product temperature recorded at 84˚C during hot filling, only 74˚C was recorded at the middle position on packaging surface. This was even lower for other positions, such as the bottom corner (58˚C), headspace (64˚C) and lid (57˚C) (see **Figure 6.2**).

Typically, more than 10˚C temperature loss was observed once the product came into contact with the plastic surface.

It was observed that among the various positions tested on the pack, the cold points on the packaging were usually found at the lid, headspace or bottom corner.

6.1.3 Hot filling hard plastic pots

Reasonable temperature loss on the plastic pot surface was observed in the hot filling process. For example, with a core product temperature recorded at 70˚C during hot filling, 66˚C was recorded at the middle position on the packaging surface. This was even lower for other positions such as the bottom corner (61˚C) and headspace (60˚C) (see **Figure 6.3**)

Typically, more than 5˚C temperature loss was observed once the product came into contact with the plastic surface.

It was observed that cold points were usually found at the lid, headspace or bottom corner.

6.1.4 Hot filling of pouches

Small temperature losses from the pouch surface were observed in the hot filling process. For example, with a core product temperature recorded at 80˚C during hot filling, about 78˚C was recorded at other positions on packaging surface, see **Figure 6.4**. For Doypack or Gualapack, in which product may not contact the headspace position until later in the hot fill operation, the

headspace wall may then have a lower temperature, usually a couple of degrees Celsius lower than the product.

Typically, more than 2˚C temperature loss was found just after product contact with the pouch surface.

Typically, no real cold spot was found on the pouch surface, as the flexible pack allowed product to move around the entire internal surface of the packaging during processing. Doypack and Gualapack were exceptions to this, where the cold spot was usually found at the headspace wall or closure areas of the pack after hot filling.

Figure 6.1: Typical time/temperature graph of glass jar during hot filling

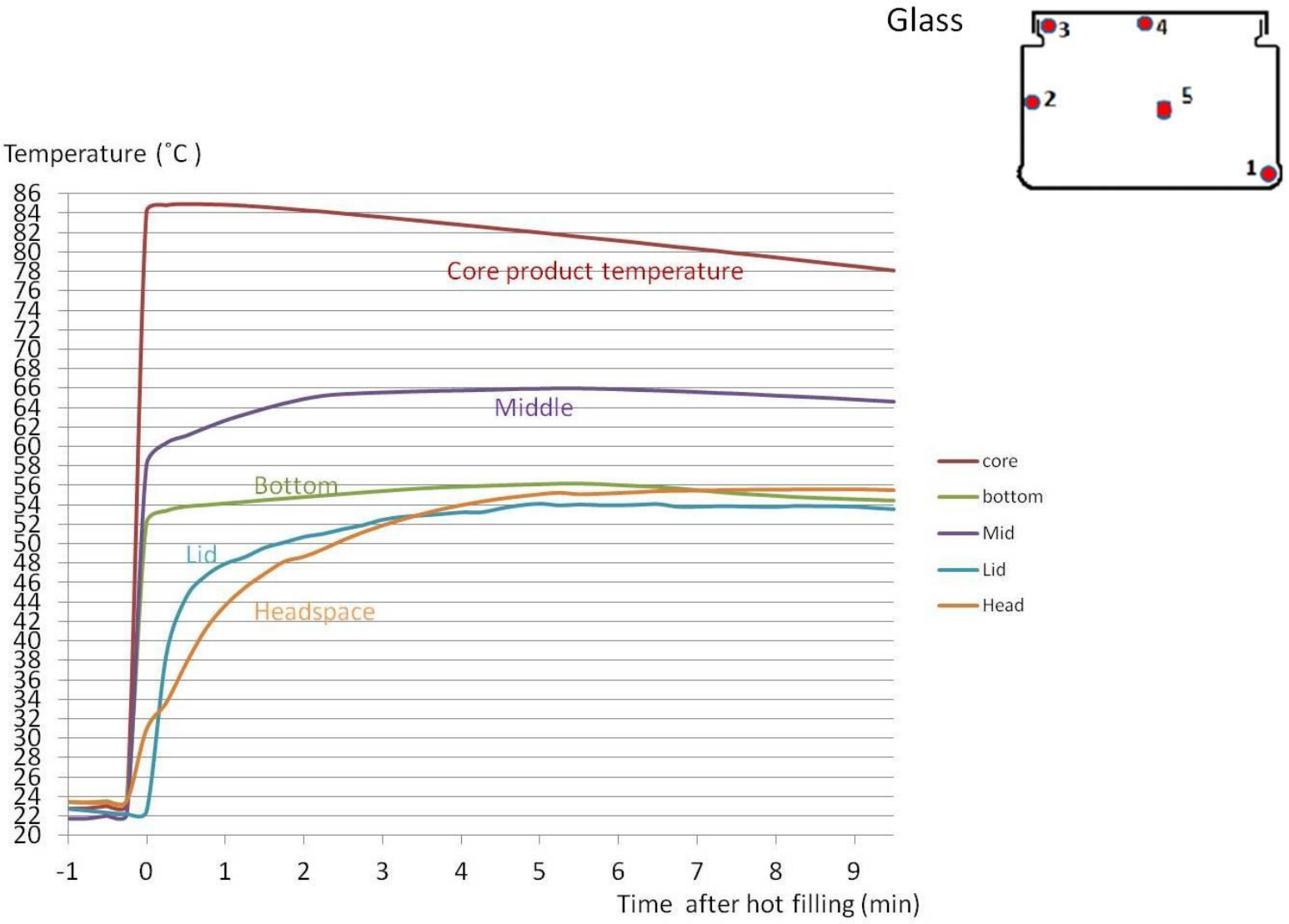


Figure 6.2: Typical time/temperature graph of squeeze plastic during hot filling

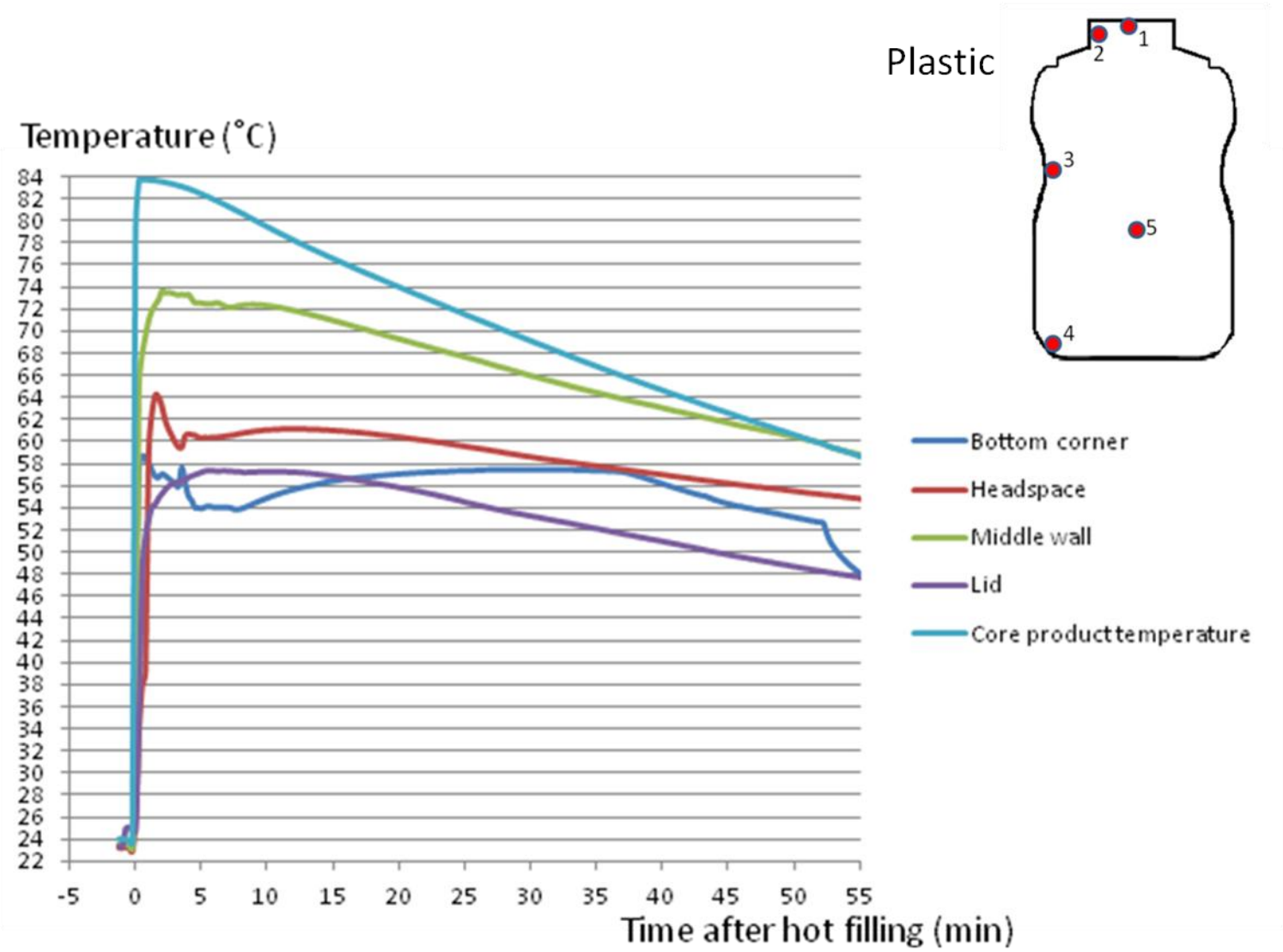


Figure 6.3: Typical time/temperature graph of hard plastic during hot filling

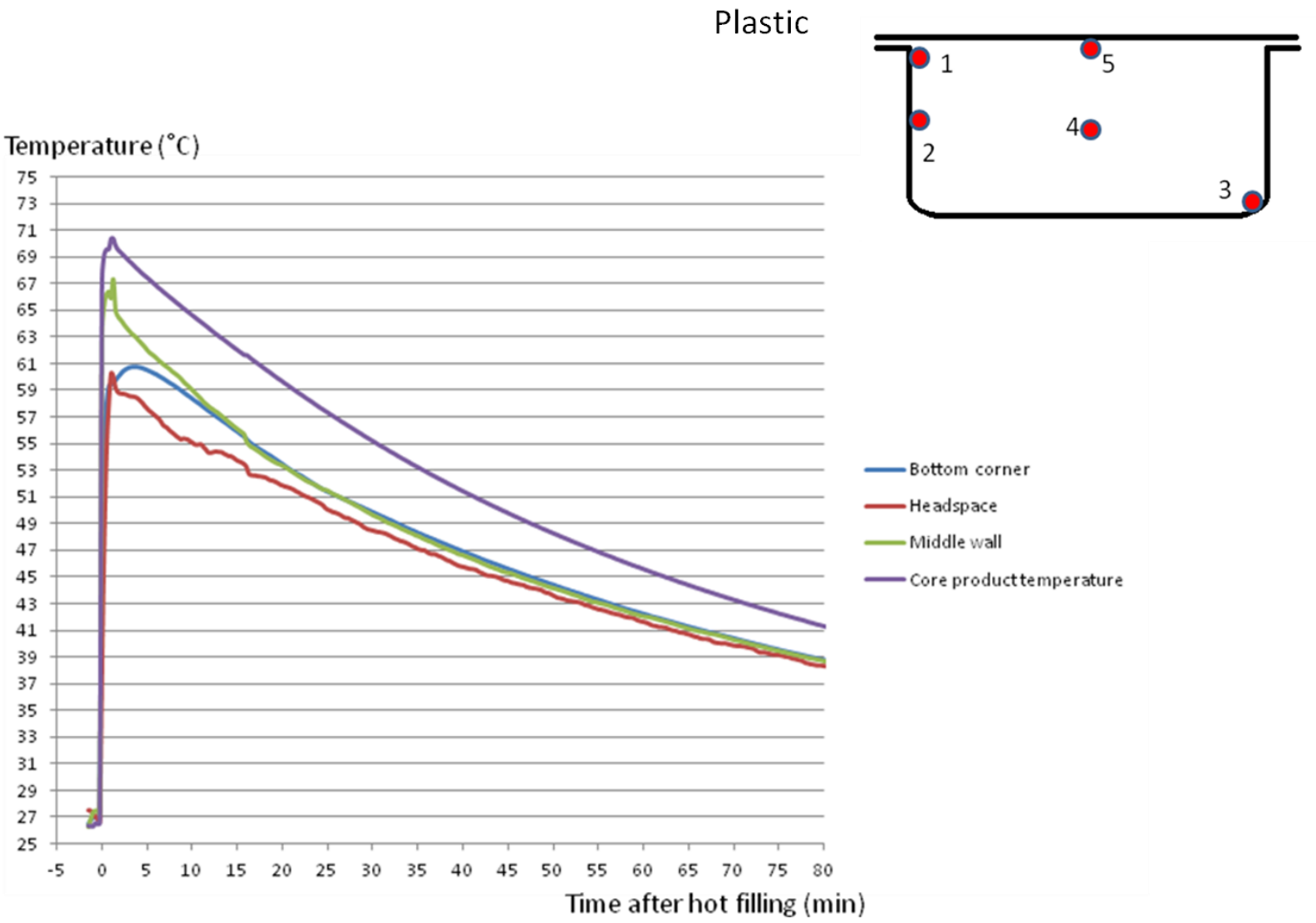
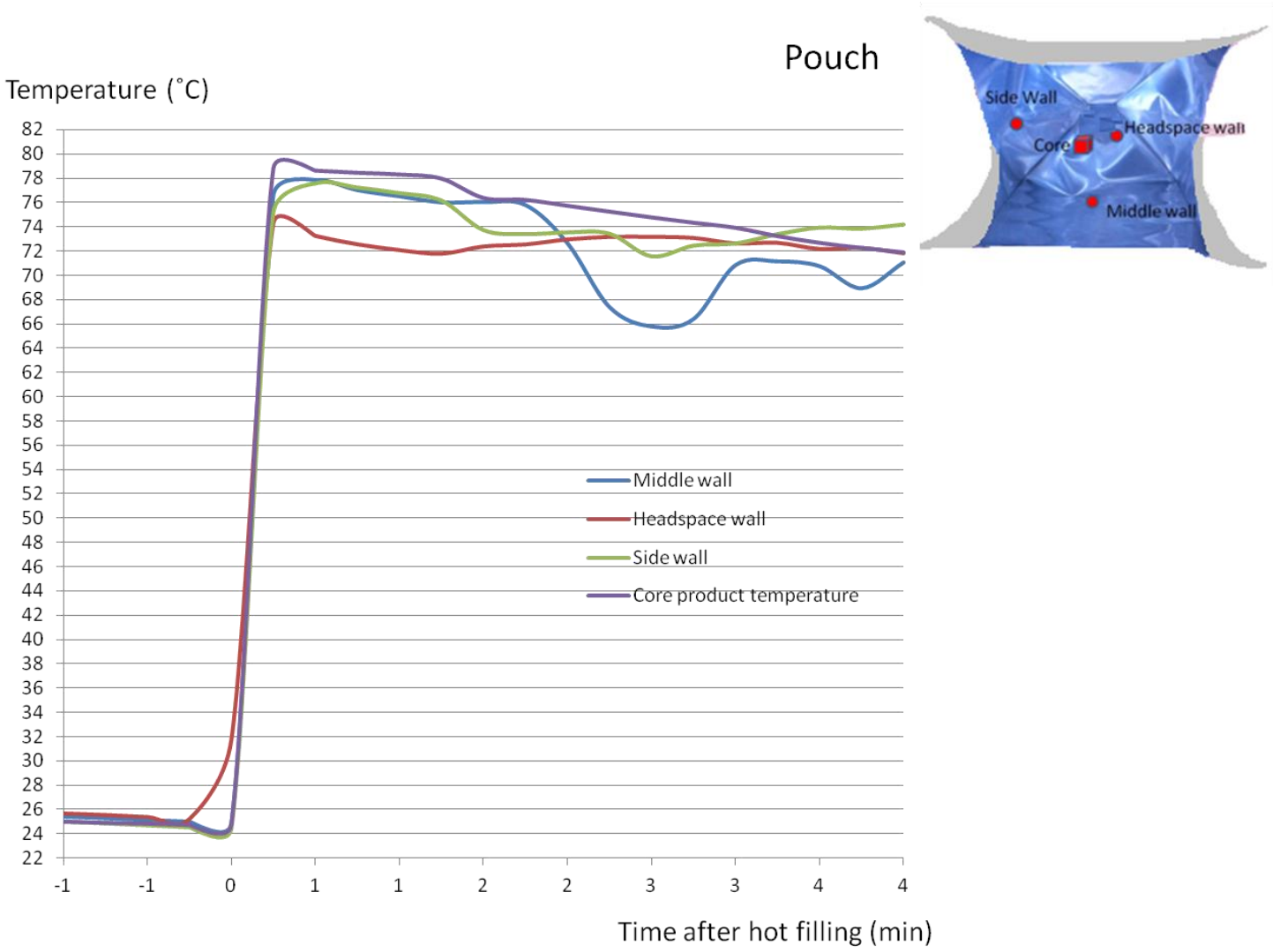


Figure 6.4: Typical time/temperature graph of pouch during hot filling



6.2 Post filling processes

If hot filling alone is not able to deliver the desire thermal process target to the inner packaging surfaces, then post filling processes may be crucial to the safety of the hot fill operation.

In the following trials, post filling options and their validation are reviewed.

6.2.1 Pasteurisation tunnel

The pasteurisation tunnel is one of the most common post filling options for additional pasteurisation on packaging surfaces after hot filling. For cold filled products, the pasteurisation tunnel can also be used as an in-pack pasteuriser to deliver the necessary heat treatment to the final, packed product.

The filled product packs are loaded at one end of the pasteurisation tunnel and pass under sprays of heated water as they move along the conveyor belt (see Figure **6.5**).

The tunnel is usually divided into different zones (e.g. heating, holding, and cooling). In each zone, the spray bars are positioned above the belt and heated water is sprayed downward onto the product. When the containers pass through the tunnel, they are gradually heated up to the desired pasteurisation temperature and then cooled down towards to the exit of the tunnel.

The used water from each zone is usually collected in individual tanks and re-circulated in the same zone; where necessary, steam may be used to re-heat the water within individual tanks to maintain the desired water temperature.

The length of the process depends on the product and the packaging.

Validation of a pasteurisation tunnel comprises two tests:

(1) Temperature distribution test to determine the slowest heating locations within the tunnel, (i.e. the point that is slowest to reach the scheduled processing temperature) and also to confirm that the range of temperatures experienced throughout pasteurisation is within prescribed limits.

A typical datalogger arrangement in a tunnel pasteuriser temperature distribution test and typical environmental temperature profiles of a pasteurisation tunnel are shown in **Figures 6.6, 6.7 and Figure 6.8**.

(2) Heat penetration test on the packaging surface to determine the slowest heating location on the internal surface of the product packaging, i.e. that point on the pack that receives the lowest overall heat treatment (lowest P value).

Figure 6.5: pasteurisation tunnels

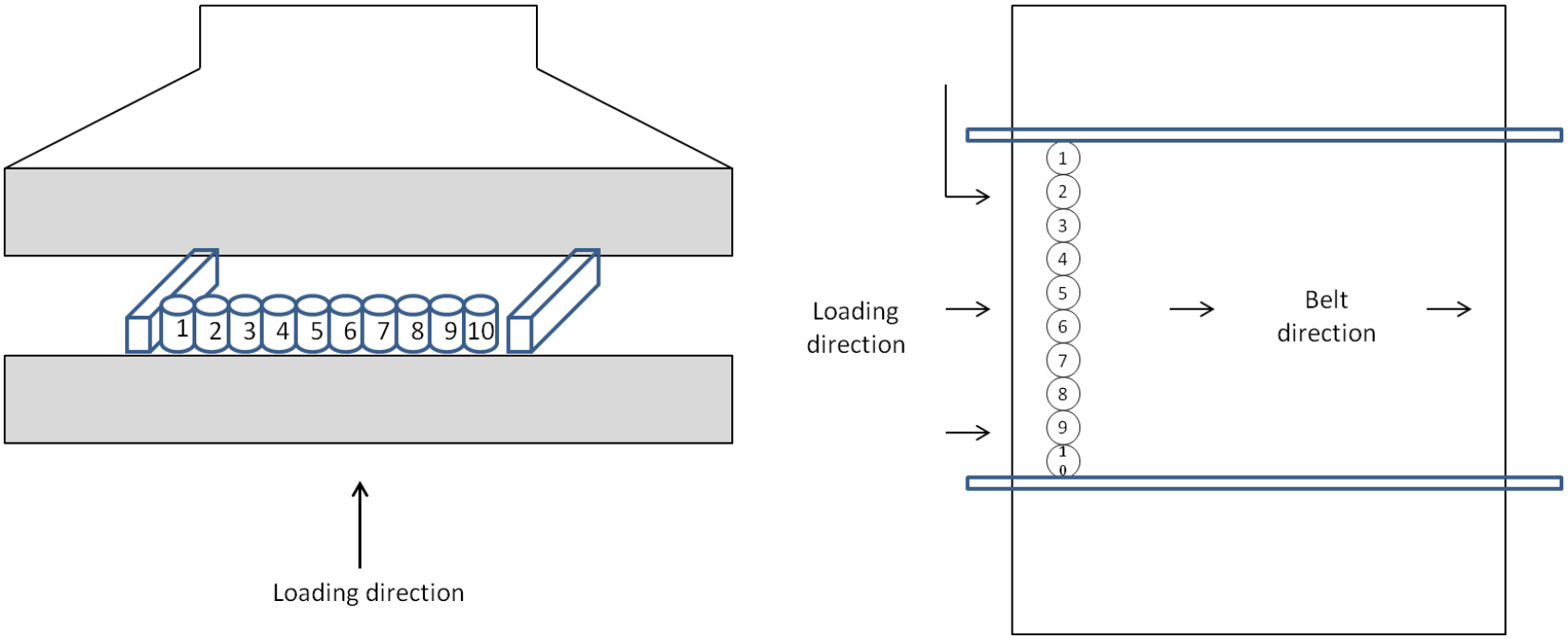


Figure 6.6: Dataloggers arrangement in pasteurisation temperature distribution test (Pictures courtesy of Harry Williams)

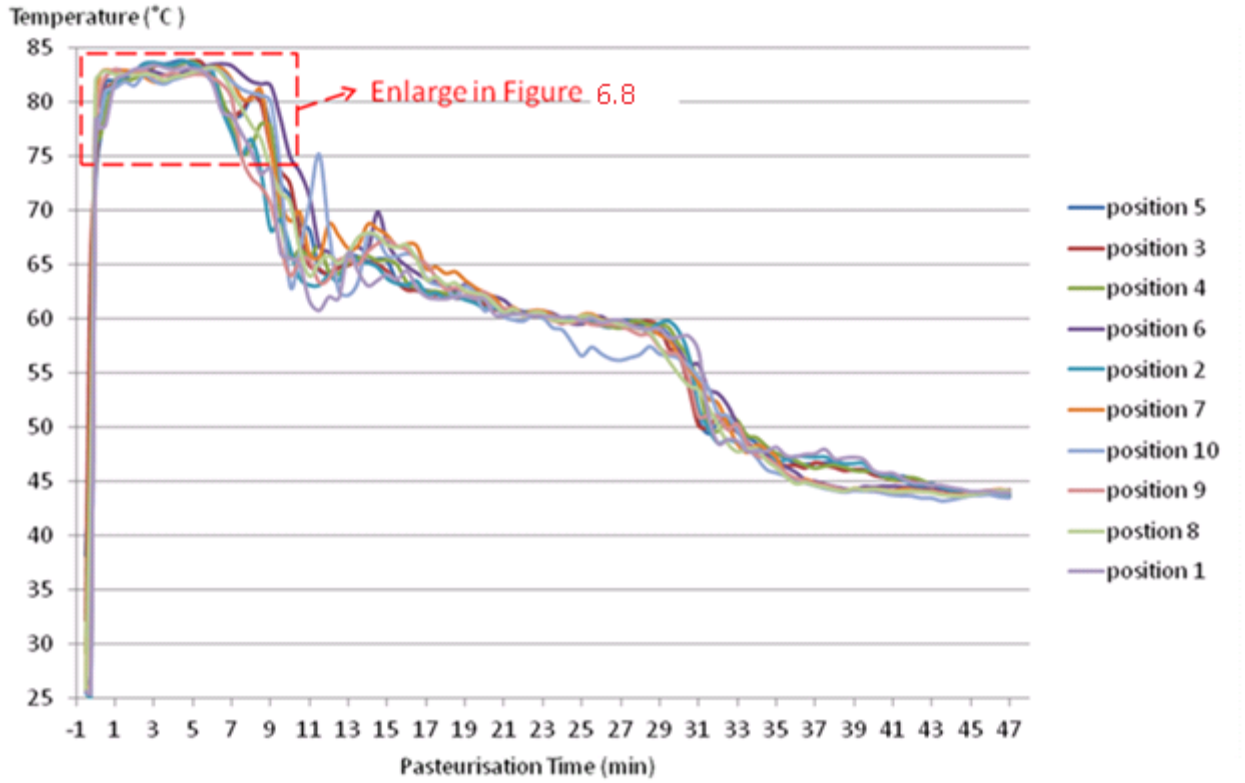


Figure 6.7: Typical environmental time and temperature profile of different positions in pasteurisation tunnel

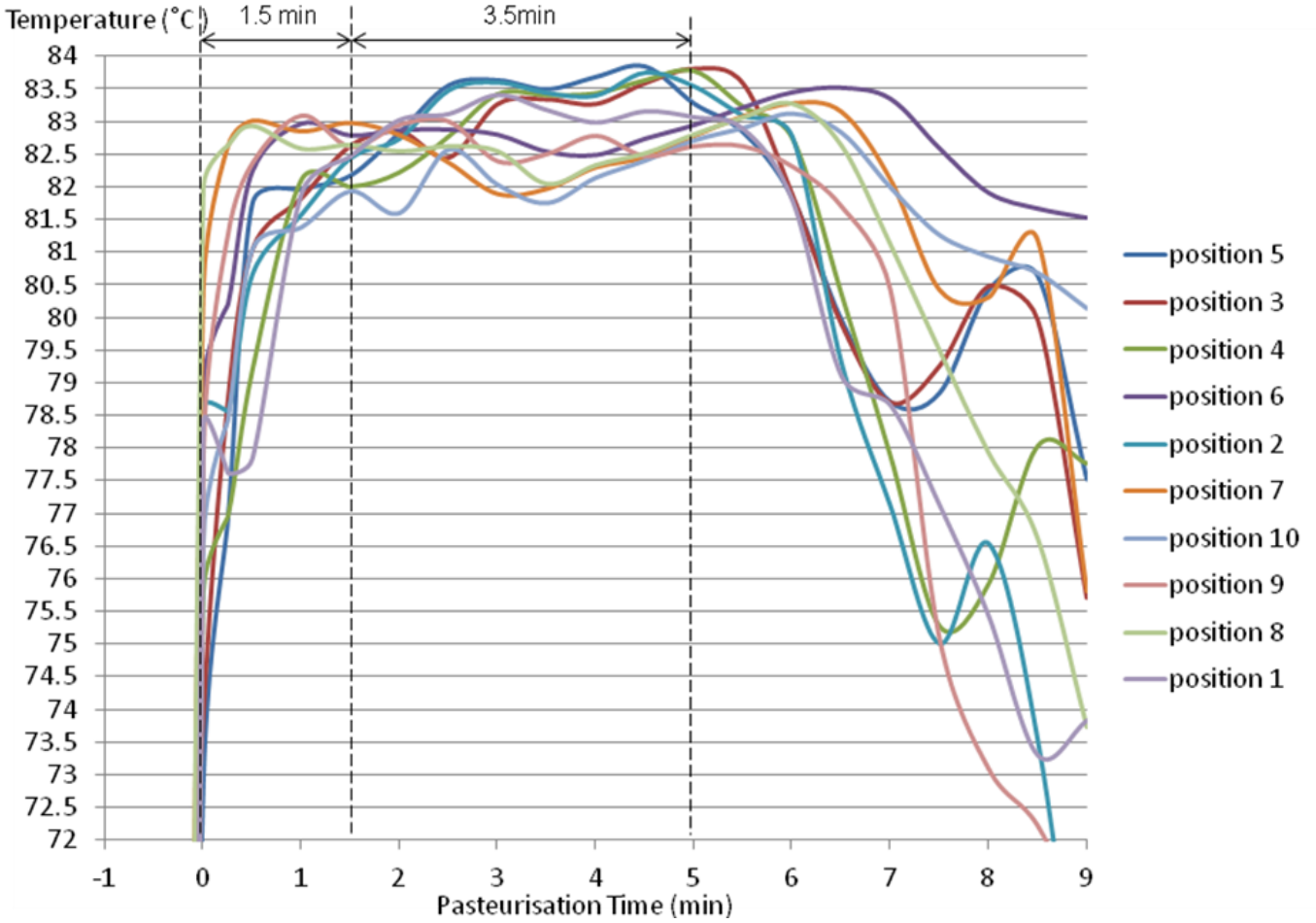


Figure 6.8: Enlargement of Figure 6.7

The pasteurisation tunnel delivered further heat treatment to the pack surface. Typically, middle wall position or bottom corner position on the container internal surface receive the lowest heat treatment comparing to other positions.

A typical temperature profile of a product and at different positions on the internal surface of a glass jar during hot filling and tunnel pasteuriser are shown below.

At the exit of tunnel, the product temperature ideally should be around 40°C, to minimise the risk of any surviving thermophile growth.

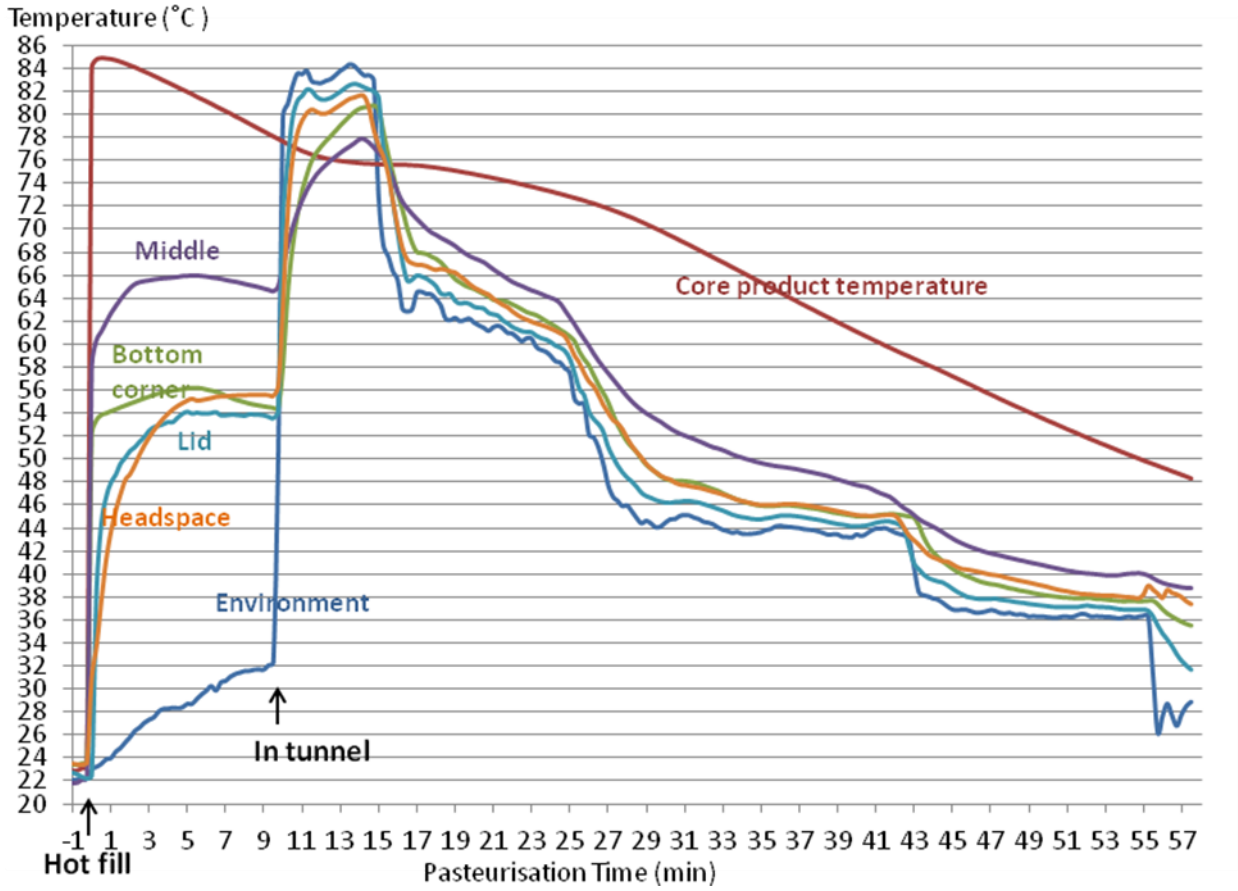


Figure 6.9: Typical product and glass jar surface temperature profile during pasteurisation tunnel treatment

Table 6.1: An example of P values on different positions of the glass jar surface before and after pasteurisation tunnel treatment

(Pasteurisation tunnel heating zones processed at 92°C for 10 mins)

No.	Positions	loggers ID	Dataloggers T_{ref}=70°C z=7.5°C P value (mins)		Dataloggers T_{ref}=85°C z=8.3°C P value (mins)		Dataloggers T_{ref}=95°C z=8.3°C P value (mins)
			hot fill only	hot fill +pasteurisation	hot fill only	hot fill +pasteurisation	hot fill +pasteurisation
1	Headspace	134802	1.30	2273.06	0.02	21.06	1.31
2	Headspace	134804	0.12	2530.93	0.00	23.54	1.47
3	Bottom corner	135767	0.07	2267.92	0.00	20.84	1.30
4	Bottom corner	134772	0.06	1962.54	0.00	18.29	1.14
5	Middle	134805	1.40	2268.97	0.03	21.14	1.32
6	Lid	134818	0.05	3633.06	0.00	32.58	2.03
7	Lid	134822	0.55	3675.00	0.01	33.75	2.11

6.2.2 Overpressure retort.

An overpressure retort can also be used for pack surface pasteurisation.

Steam/air mixtures or hot water/air mixtures (either water immersion or water spray) may be used depending on the product and packaging type. During the pasteurisation process, air is injected to apply an environmental overpressure, so that the pack remains pressure balanced during cooking.

Figure 6.10 shows a typical steam/air overpressure retort (Lagarde).

Figure 6.10: The author with a prototype Lagarde steam/air overpressure retort.

Temperature distribution tests in retorts have been well documented in several guidelines (e.g. Campden BRI Guideline 56).

Typical temperature profiles of different positions on the internal surface of glass jars during overpressure retorting are shown in **Figure 6.11**.

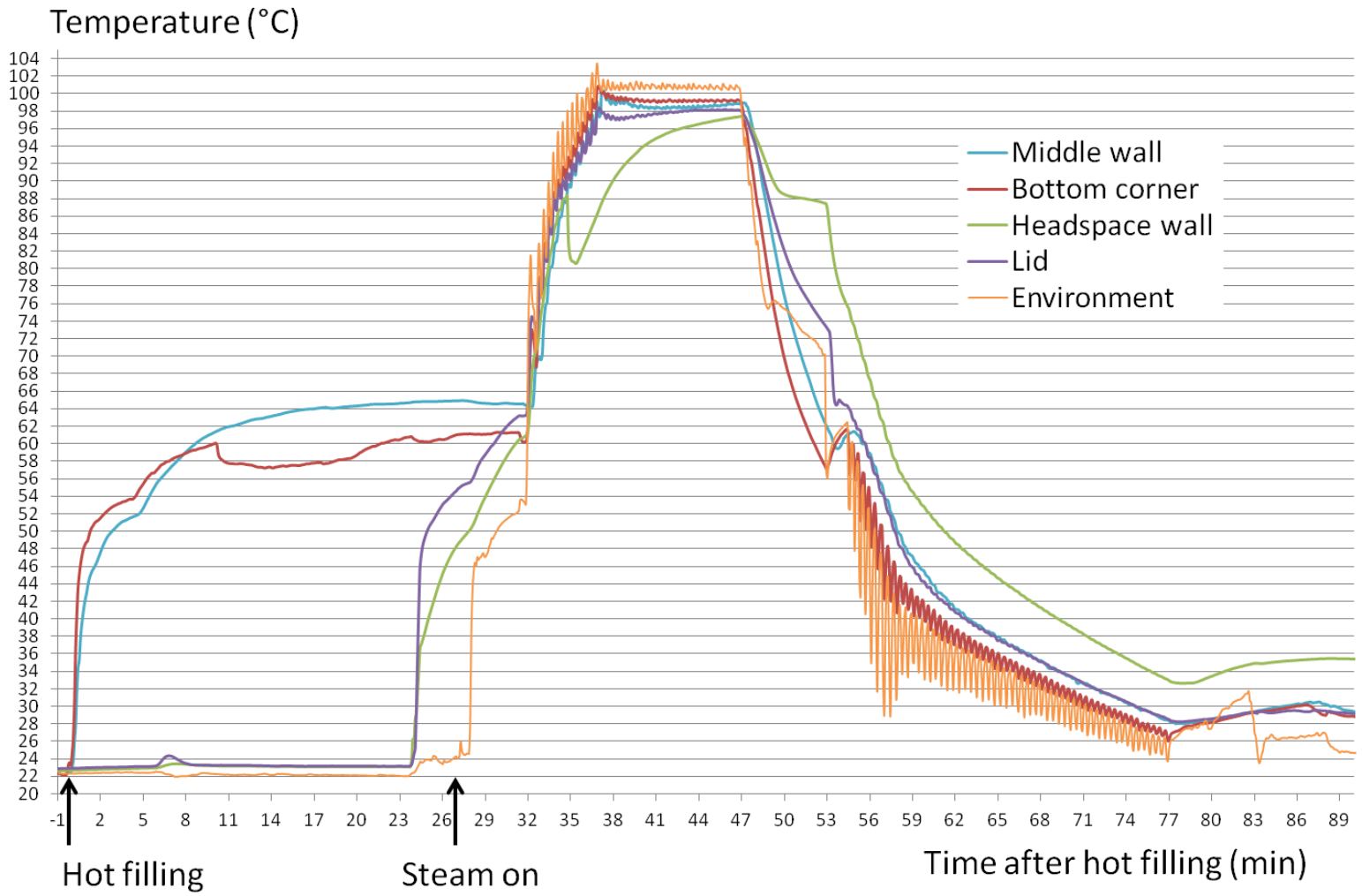


Figure 6.11: Typical temperature profile of different positions on the internal surface of glass jar during overpressure retorting.

Table 6.2: An example of P values on different positions of the glass jar surface before and after overpressure retorting

(Retort setting as shown in environmental probe in Figure 7.11)

No.	Positions	P value (minutes) T_{ref}=70°C, z=7.5°C		P value (minutes) T_{ref}=85°C, z=8.3°C		P value (minutes) T_{ref}=95°C, z=8.3°C
		hot fill only	hot fill +retorting	hot fill only	hot fill +retorting	hot fill +retorting
1	Headspace wall	19.2*	32205.7	0.3	502	22.1
3	Bottom corner	25.7	22646.6	0.4	353	29.1
5	Middle	0	29960.3	0	467	31.3
7	Lid	0	37658.8	0	587	36.6

*product overfilled in the jar.

6.2.3 Inversion

Inversion is one of the post filling options that may force the product to come into contact with the positions on the internal surfaces of packaging which it would not normally contact during a normal static process. Example locations are the pack lid and headspace areas.

Figure 6.12 shows the two basic types of inversion lines: the camel back type inversion, and the horizontal flip inversion.

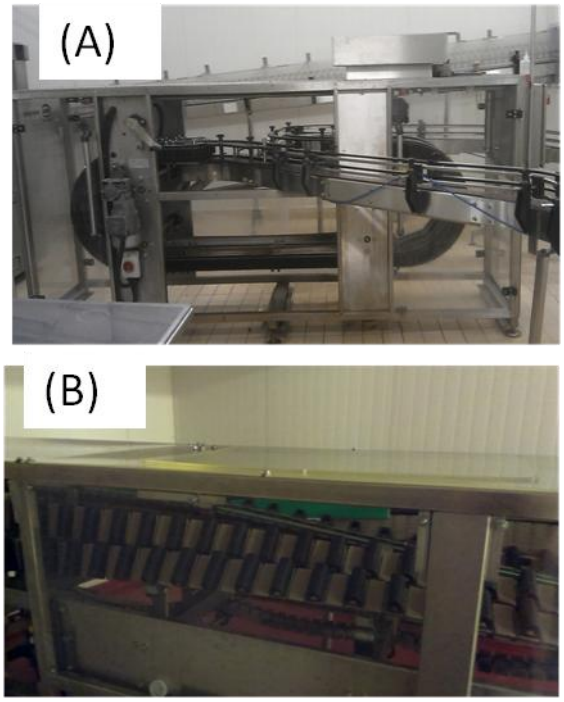


Figure 6.12: Typical inversion lines: (A) camel back type and (B) horizontal flip type

(Picture courtesy of Glenpatrick Spring Water Company)

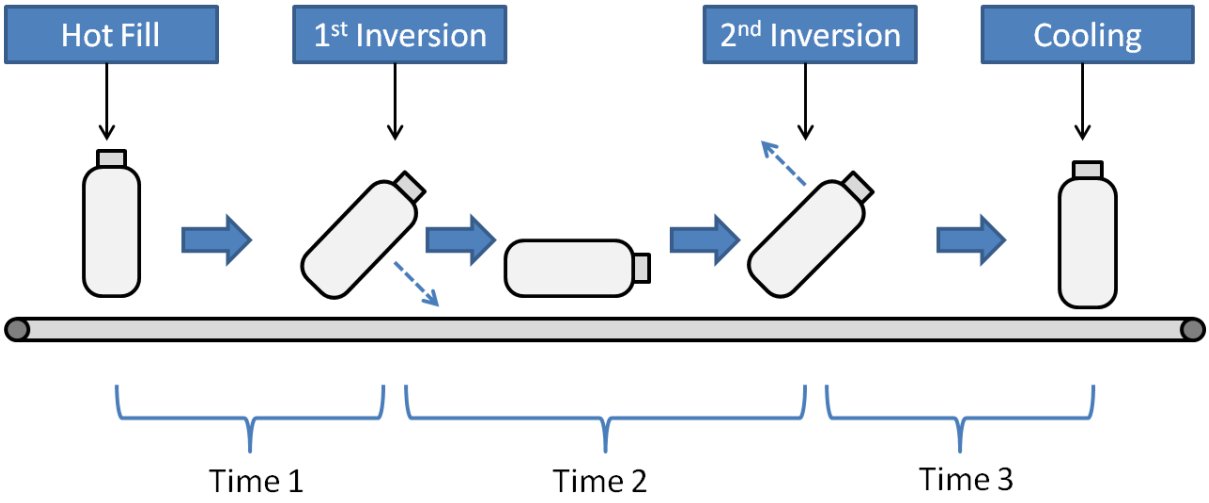


Figure 6.13: Illustration of typical horizontal flip inversion process

Figure 6.13 shows a typical horizontal flip inversion process. It could be divided into three time segments. The first segment of time extends from hot filling to the point of inversion, the second segment covers the inversion hold time, and the third segment is the time after the container reverts back to its original vertical position until it enters cooling.

The length of the first segment determines the level of heat treatment received by the positions, such as bottom corner on internal packaging surface. The length of the second time segment determines the heat treatment received by other positions, such as the pack lid and headspace. The third time segment provides a further opportunity for all the positions on the pack to build up P values.

It should be noted that the temperature gradually decreases during the inversion process. Therefore, it is crucial to delicately balance the execution and timing of the post-fill steps to ensure that the entire internal packaging surface receives sufficient heat treatment.

Figure 6.14 shows a typical time and temperature profile for a low viscosity product during hot filling and inversion. At the point of 1st inversion, the bottom corner temperature has dropped significantly as the liquid product is no longer in contact with this pack position. At the same time, temperature at the headspace wall sharply increases. At the point the 2nd inversion occurs, the product comes into contact with the bottom corner position again, which explains the rise of temperature at this position, as well as the decrease of the rate of increasing temperature at the headspace wall position. Heat treatment and lethality is continuously building up during the entire

process up to the point when the container enters cooling. This also highlights the importance of leaving sufficient time to build up an acceptable P value after the completion of inversion before allowing the product and packaging to enter the cooling stage.

For hot filling of viscous food products, inversion becomes much more challenging. This is because the more viscous the product, the longer it takes to pass the energy from the food product to the packaging. This situation is shown in **Figure 6.15**. Inversion was quickly made after hot filling and held for 2 minutes to make sure that the headspace achieved a P value of 2 minutes (Tref= 70°C, z=7.5°C). However, this process only allowed the bottom corner position to build up a P value of 1.7 minutes, thus failing to reach the 2 minutes target. If the inversion was delayed or inversion holding time was shortened, the bottom corner is able to receive more than 2 minutes equivalent, but then the thermal treatment at the pack headspace position become insufficient.

Several different conditions (different hot filling temperatures, inversion hold time and different sizes and designs of the PET bottles) were tested for inversion.

Examples of the results are shown in **Figure 6.16** and **6.17**.

It is clear that increasing the hot filling temperature can significantly increase the final P value achieved at all the positions during hot filling and inversion. Increasing inversion hold time also resulted in the P value significantly increasing at the headspace position. Bottle design (e.g. surface area of the headspace wall) could also significantly contribute to final surface P value.

The final P value on the pack surface is a combined effect of product, packaging and process parameters. Overall, hot filling temperature is probably the most important factor that contributes to the final P value. The hot filling and inversion process is a complicated thermal process that requires regular and practical process validation.

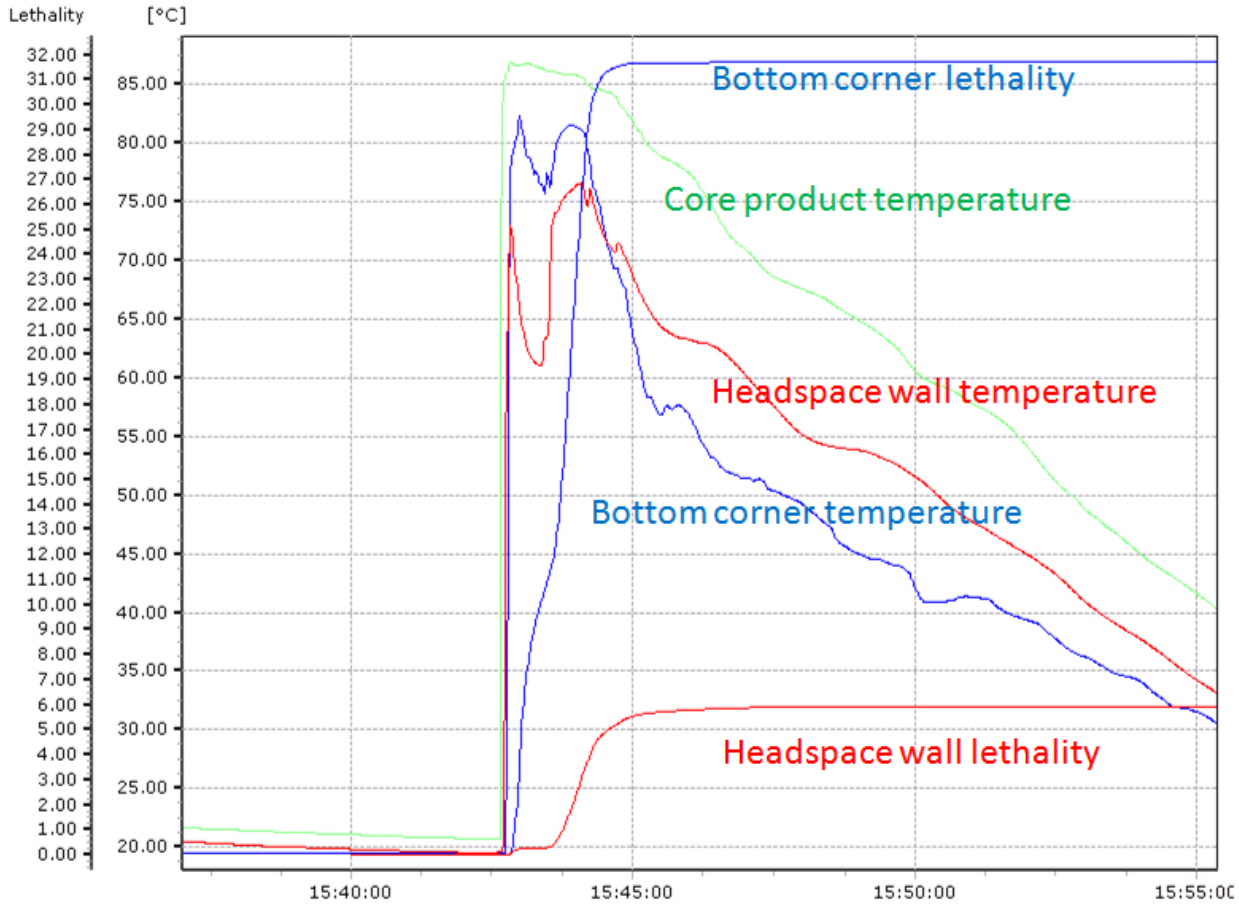


Figure 6.14: Hot filling and inversion of low viscosity product in PET bottle.

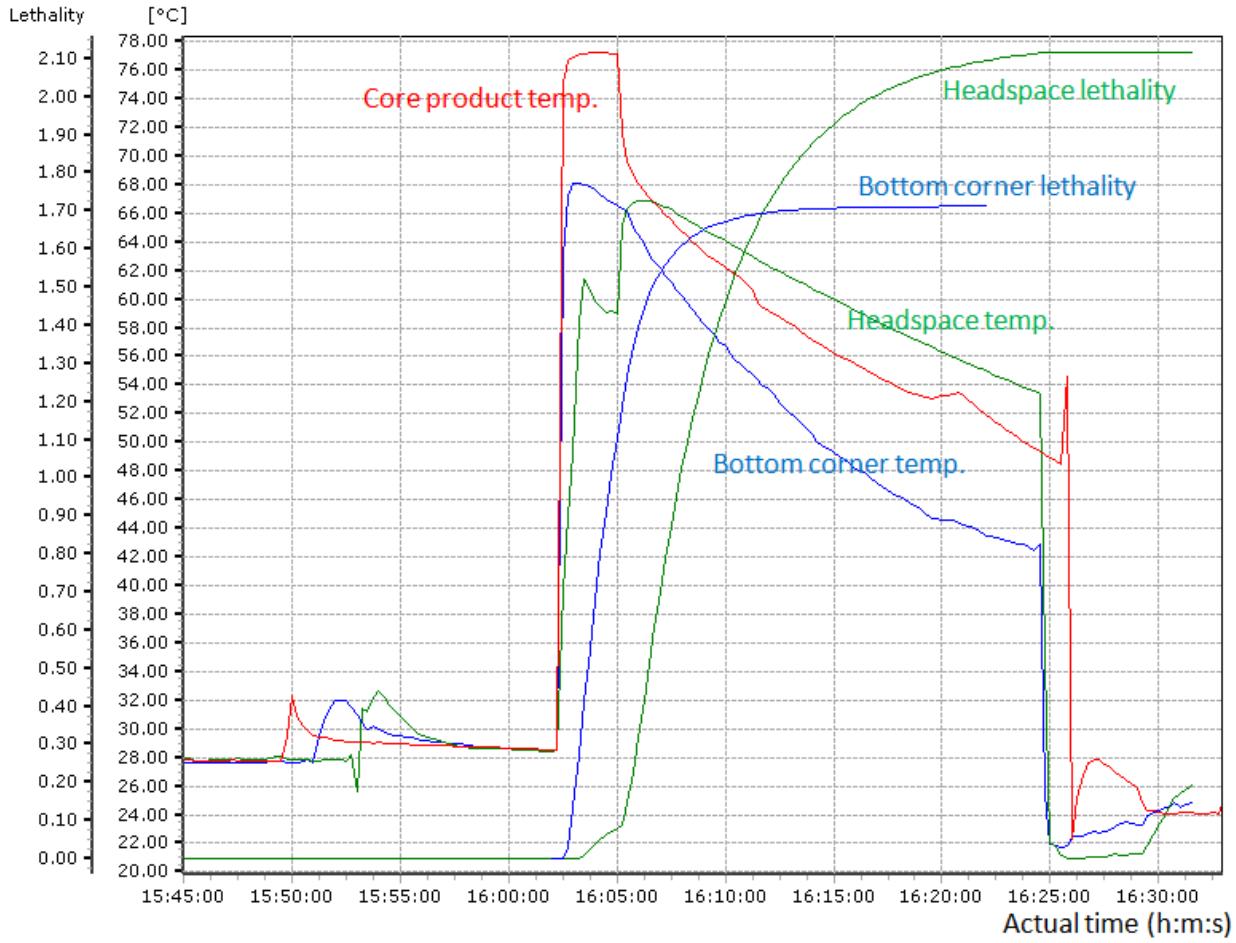
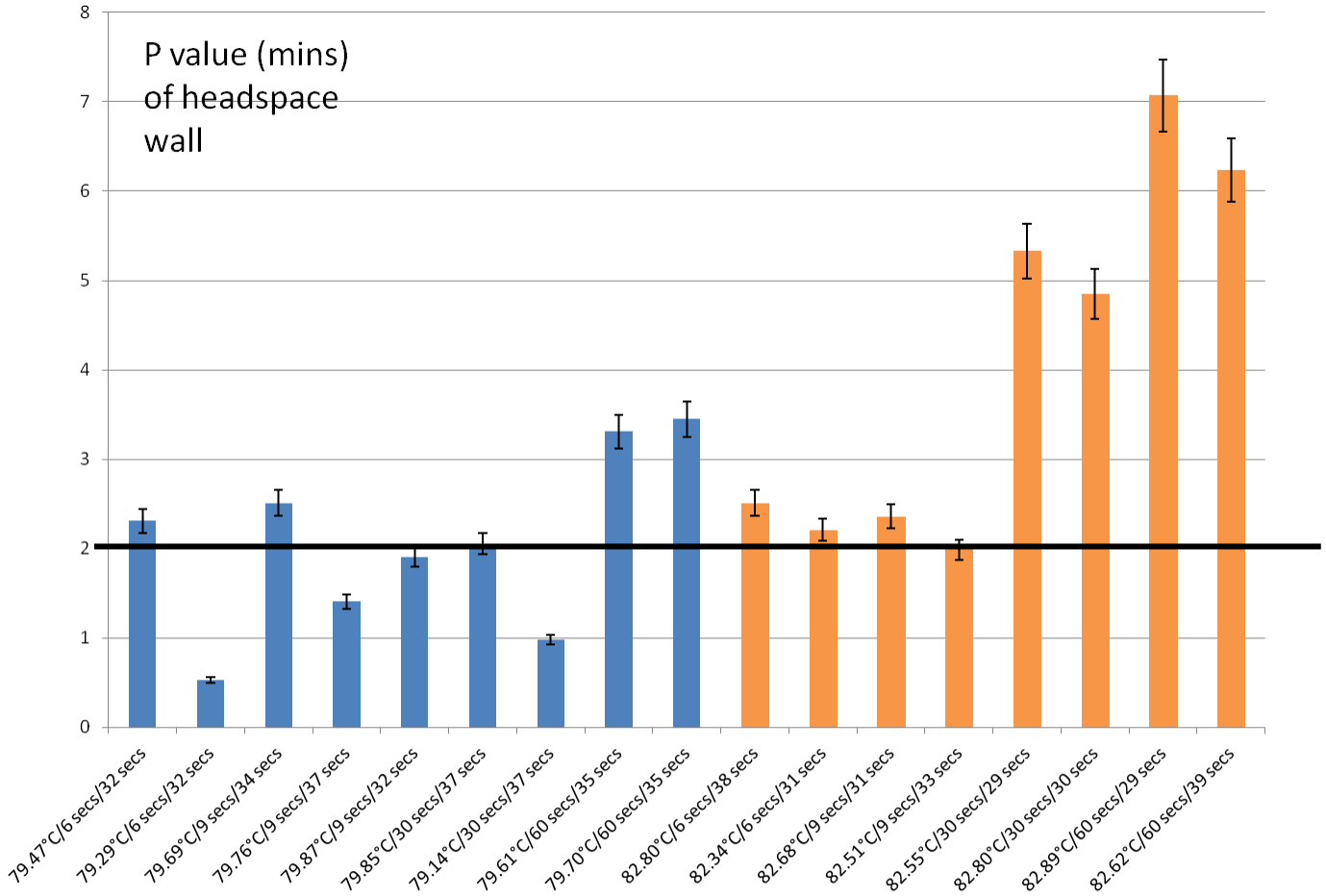


Figure 6.15: Hot filling and inversion of high viscosity product in plastic pot



Conditions: In bottle temperature / inversion hold time / lead time before inversion

Error bar represents the datalogger offset 0.2°C in P value (5.7%)

Figure 6.16: P values of headspace wall on PET bottle against changes in product temperature and inversion hold time.

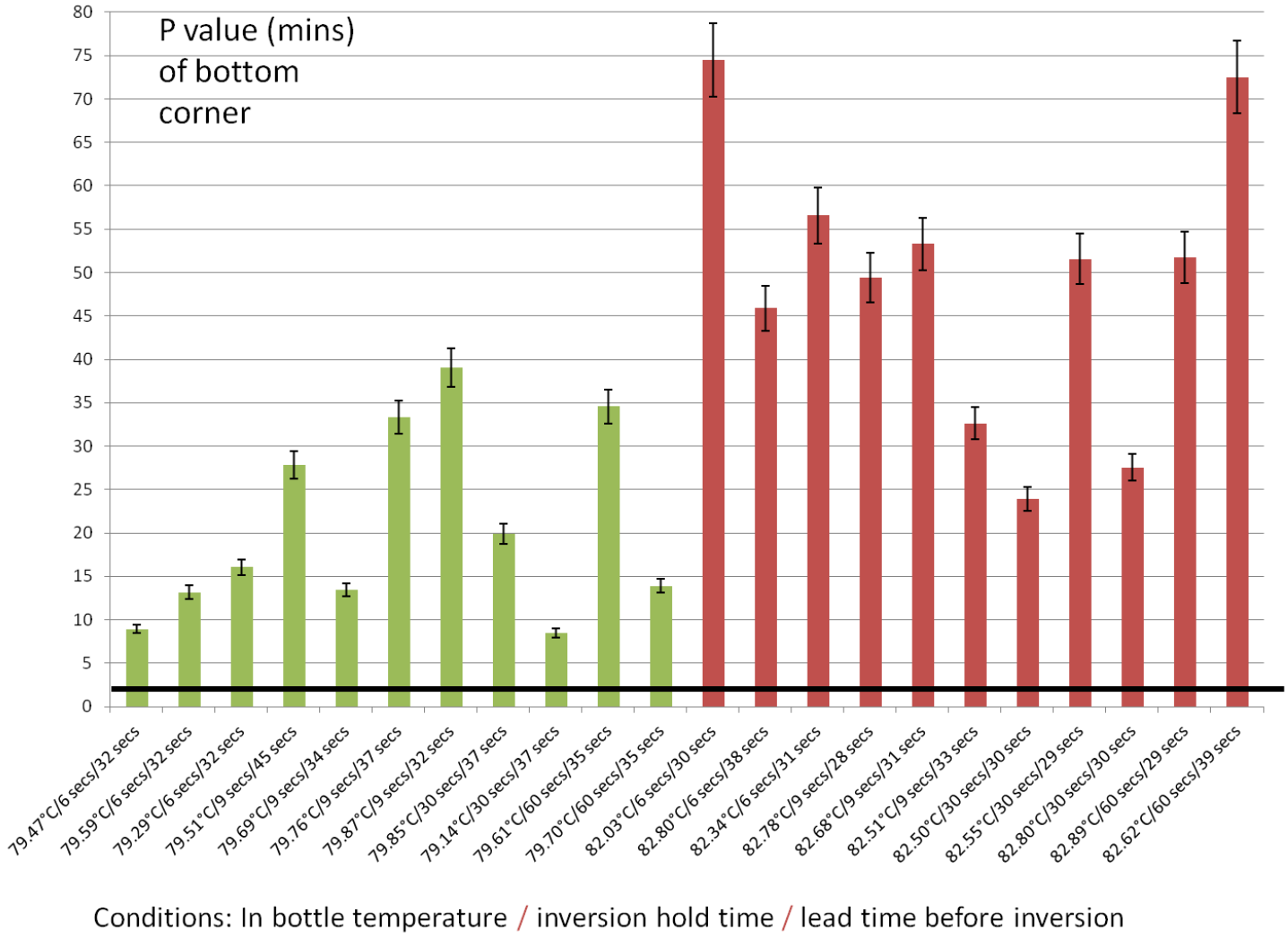


Figure 6.17: P values of bottom corner on PET bottle against changes in product temperature and inversion hold time

6.2.4 Other post filling processes in industry

There are other post filling processes options available for industry that have not been covered in current reports, such as infra-red tunnels (**Figure 6.18**) and hot air tunnels. Infra-red tunnels and hot air tunnels have been of growing interest in recent years, as there is no requirement for water in such processes. These techniques also have advantages for packs that are difficult to dry. As for other processes, they also have limitations, e.g. a shiny surface packaging will receive less efficient infrared heat transfer than a matt-coloured surface due to the small emissivity of the former. Also, air is generally not a good heat transfer medium as compared with steam and water, having a surface heat transfer coefficient that is reduced by up to a factor of 10.

t

Figure 6.18: Infra-red tunnels (Pictures courtesy of Heraeus)

6.3 Understanding of the heat process impact on packaging surfaces

In theory, a pack surface treatment of 70°C for 2 minutes equivalent target for a nominal 6 log reduction of the vegetative pathogen is not difficult to achieve. **Table 6.3** highlights the temperature and time combination that is equivalent to 70°C for 2 minutes.

In practice, however, to achieve 70°C for 2 minutes equivalent target on packaging by hot filling alone is often challenging, due to a number of factors:

1) Upon contact between the hot food product and pack, there is significant temperature loss.

This temperature loss has been demonstrated in **Figures 6.1-6.4**. Some packaging materials are better than others in terms of minimising the temperature loss during hot filling. Despite the temperature loss, if the packaging receives an instantaneous temperature of >85°C upon first contact with the food product, it could still achieve 70°C for 2 minutes equivalent target (**Table 6.3**). Considering the typical temperature loss (product against hottest place on packaging surface) on different packaging materials: Glass (20°C) > Squeeze plastic (10°C)> Hard plastic (5°C)>Pouch (2°C), it is not realistic to achieve 70°C for 2 minutes equivalent target for some packaging (e.g., glass) by hot filling alone.

2) Hot filling is a dynamic process, i.e., after the point of hot filling, the product temperature gradually decreases instead of maintaining a constant temperature.

As illustrated in **Table 6.3**, a 70°C for 2 minutes equivalent could be achieved by achieving a constant temperature of 70°C and holding this temperature for 2 minutes. If the temperature drops, the product pack combination will require a longer holding time (e.g. at 68°C it requires about 4 minutes to achieve an equivalent process of 70°C for 2 minutes). Additionally, if the initial temperature experienced by the packaging is too low, it will not achieve a thermal process equivalent of 70°C for 2 minutes, irrespective of holding time.

3) Depending on the pack material, pack design and the manufacturing process, there could be a position (worst case) on the internal packaging surface that receives much lesser contact with the product while it is hot.

The bottom corner of a glass jar is a good example. Regardless of the high product temperature during hot filling (e.g. 85°C as an example in **Figure 6.1**), only 56°C is achieved at the bottom corner position. According to **Table 6.3**, it requires more than 80 minutes to reach 70°C for 2 minutes

equivalent, even if it could be uniformly held at this temperature, which is not the case during hot filling.

Table 6.3: Calculated theoretical time and temperature equivalent to 70°C for 2 minutes target (Z = 7.5°C)

temperature (°C)	time (minutes)	time (seconds)
58	79.6	4777.3
59	58.6	3514.4
60	43.1	2585.3
61	31.7	1901.9
62	23.3	1399.1
63	17.2	1029.2
64	12.6	757.1
65	9.3	557.0
66	6.8	409.7
67	5.0	301.4
68	3.7	221.7
69	2.7	163.1
70	2.0	120.0
71	1.5	88.3
72	1.1	64.9
73	0.8	47.8
74	0.6	35.1
75	0.4	25.9
76	0.3	19.0
77	0.2	14.0
78	0.2	10.3
79	0.1	7.6
80	0.1	5.6
81	0.1	4.1
82	0.1	3.0
83	0.0	2.2
84	0.0	1.6
85	0.0	1.2
86	0.0	0.9
87	0.0	0.6
88	0.0	0.5
89	0.0	0.4
90	0.0	0.3

Further theoretical calculations can also support the practical findings of temperature loss on different packaging materials.

The term 'specific heat capacity' needs to be introduced in order to make these calculations. The specific heat capacity of a substance is the amount of energy needed to change the temperature of 1 kg of the substance by 1 °C (relative to that of water).

The equation relating energy to specific heat capacity:

$$\mathbf{E = m \times c \times \theta}$$

Where:

E is the energy transferred in joules, J

m is the mass of the substance in kg

c is the specific heat capacity in J/ kg· °C

θ is the temperature change in °C

In the literature, specific heat capacity of each packaging material can be found and typical examples are:

Glass 0.835 KJ/kg.K = 835 J/kg. °C

Polyester 1.15 KJ/kg.K = 1150 J/kg. °C

Aluminium 0.896 KJ/kg.K = 896 J/kg. °C

Polypropylene 1.88 KJ/kg.K = 1880 J/kg. °C

Hence, the energy needed to change the temperature of the entire packaging from 20 to 70 °C :

Glass jar

$E = m \times c \times \theta = 0.183\ kg \times 835\ J/\ kg\cdot\ °C \times (70\text{-}20)\ °C = 7640.25\ Joules$

Plastic bottle

$E = m \times c \times \theta = 0.0402\ kg \times 1150\ J/\ kg\cdot\ °C \times (70\text{-}20)\ °C = 2311.5\ Joules$

Pouch

$E = m \times c \times \theta = 0.0065\ kg \times 896\ J/\ kg\cdot\ °C \times (70\text{-}20)\ °C = 291.2\ Joules$

The values of the pack mass listed above are typical pack weight of each type. There may be different specific heat capacity values in the literature other than those stated above, and different types of plastic will have different values. However, from the equation governing heat transfer, it should be noted that the mass of the different packaging materials is the major cause of the difference in energy needed to change the temperature of the packaging. Minor amendments to specific heat capacity have minimal effect on the actual heat transfer.

From a mass of packaging perspective, pouches will generally require the least energy to reach the same temperature as compared to glass and plastic packs. It is not surprising then, that for a given amount of energy input (e.g. hot fill temperature), the pouch pack temperature rise will be greater than either plastic or glass, assuming all the conditions are the same.

A complete picture of hot filling may look much more complicated. A few more factors related to energy transfer rate need to be considered in addition to energy absorption.

An illustration is shown in **Figure 6.19**.

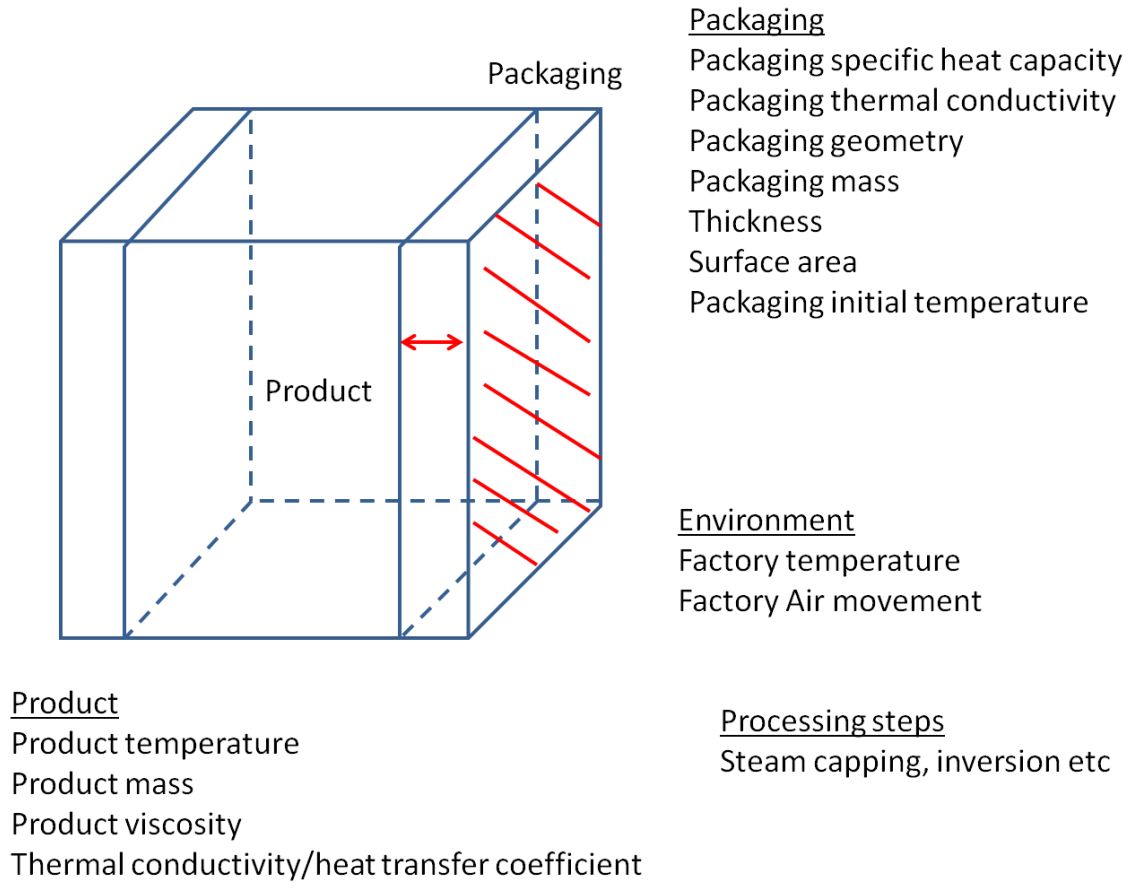


Figure 6.19: Illustration of factors to be considered in a hot filling process

Product temperature and mass determine how much energy is available in the system, and product viscosity and thermal conductivity/heat transfer coefficient determine how quickly this amount of energy can be transferred to the packaging material.

The specific heat capacity, thermal conductivity and mass of the pack determine how much energy can be taken up by the pack from the hot fill operation, while the geometry, thickness, and surface area of the pack will govern how quickly the absorbed energy could be lost to the surrounding environment.

Factory temperature and air movement could also have an impact. For example, forced convection could be implemented in the factory air ventilation system to avoid cross contamination to the high risk area. This air movement may have the detrimental effect of enhancing the heat transfer from the packaging surface to the environment.

Some processing steps could also have an impact on hot fill temperatures. Operations such as steam capping can deliver significant levels of heat treatment to the lid position on the packaging.

7. Post-filling process optimisation through modelling to save energy and cost.

After hot filling, if the target process on the packaging has not been delivered, a post-filling process will be required. To deliver the sufficient amount of heat on to the packaging is important, but excessive amounts of heat delivery should be avoided. This is because the excessive amount of energy not only costs in the heating stage, but also in the cooling stage when removing heat from the product to achieve stable shelf life.

Mathematical modelling of the conditions that can optimise the heat treatment on the surface of food packs during hot filling can be a useful tool. A software pack developed by Campden BRI (CTemp) may be used as a tool to predict the P values on packaging as a factor of changing process settings in post filling process.

CTemp has been widely used in process validation and optimisation for ‘in-pack’ cooking processes. In canning, it has been proven to be successful.

If practical time and temperature profiles of the packaging during the post-filling process can be obtained to initially set up the mathematical model, the model can subsequently be used to predict the likely P value under different conditions of processing.

Below is an example of hot fill process optimisation through CTemp modelling. Time and temperature profiles of the inside packaging surface during a hot filling and tunnel pasteuriser process were taken from the experimental set up shown in **Figure 6.9**.

The slowest heating position on the inner packaging surface from the pasteurisation tunnel was the middle wall in this case, and it was this set of data, together with environmental data in the pasteurisation tunnel, that has been applied to the software to build up the model.

From the experimental data, the heating and cooling characteristic (fc and j values) of the packaging were calculated; these are shown in **Figure 7.1**.

The CTemp model, based on the calculated f_c and j value of the packaging, is shown in **Figure 7.2.**

The P value from experimental data is 0.55 minutes (T_{ref} = 85°C, z = 8.3°C) at the exit of the tunnel, and the CTemp model predicted P value is 0.50 minutes (T_{ref} = 85°C, z = 8.3°C). Therefore, the developed model is a good match with the experimental data.

The next step may be to answer certain 'what if' questions regarding hot filling. For example, what if the tunnel pasteuriser is now running at 85°C instead of the original setting of 83°C?

By applying a new value of 85°C in the model instead of 83°C, the model will generate the new predicted P value, which is 1.23 minutes (T_{ref} = 85°C, z = 8.3°C).(See **Figure 7.3**)

Other process parameters could be changed to observe the contribution to the final P value, for example processing time in the tunnel, initial packaging temperature (for example, a different hot filling temperature) and many other factors.

Such a modelling prediction would reflect which product and process factors contribute most to the P value on the food packaging surface. This helps the understanding of the most cost effective way to deliver a desired P value on the packaging during hot filling.

The optimised settings will require practical validation to confirm the findings.

Figure 7.1: Experimental data of middle inside wall of the packaging and the calculation of the heating and cooling characteristic of the packaging

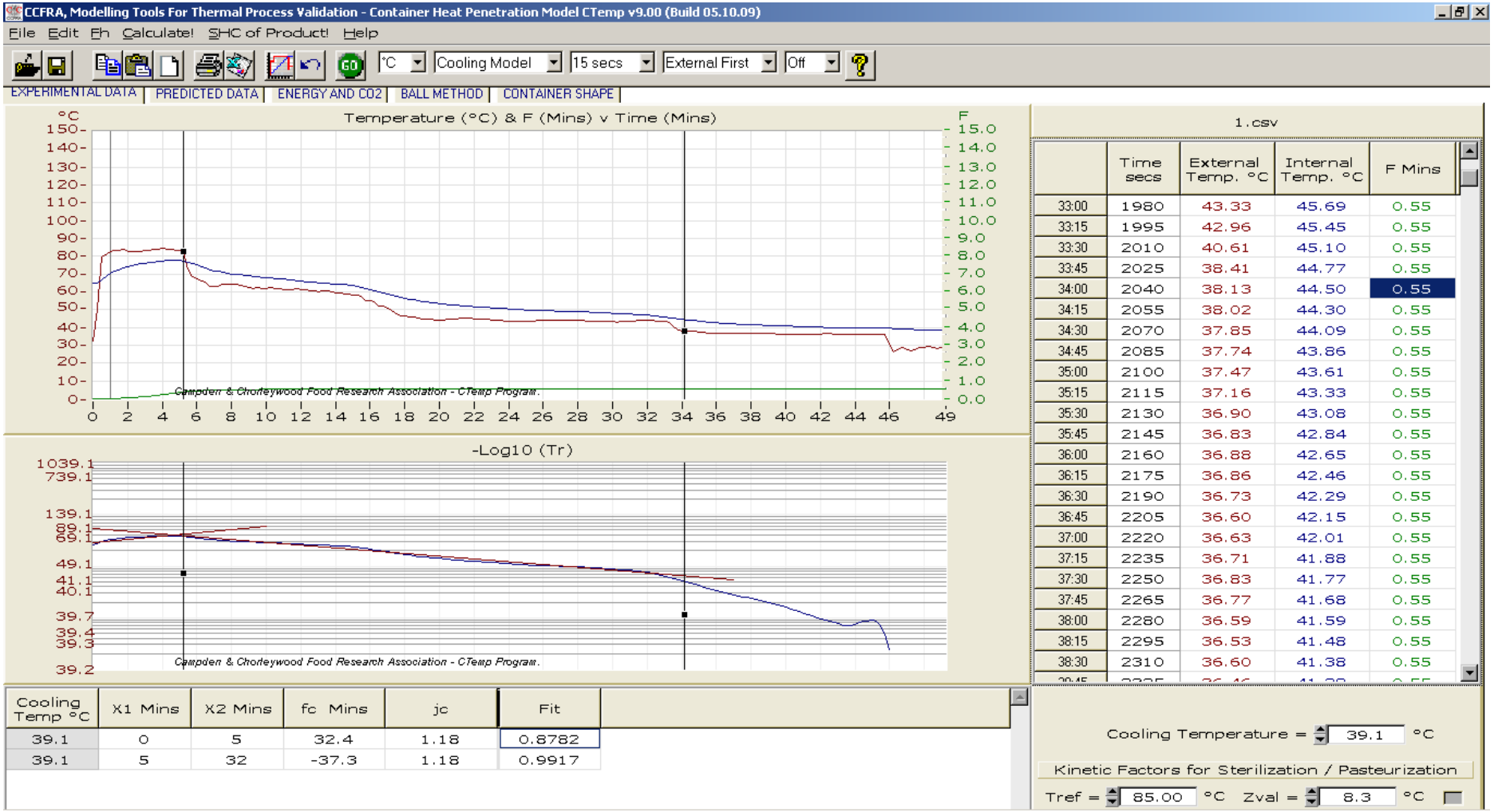
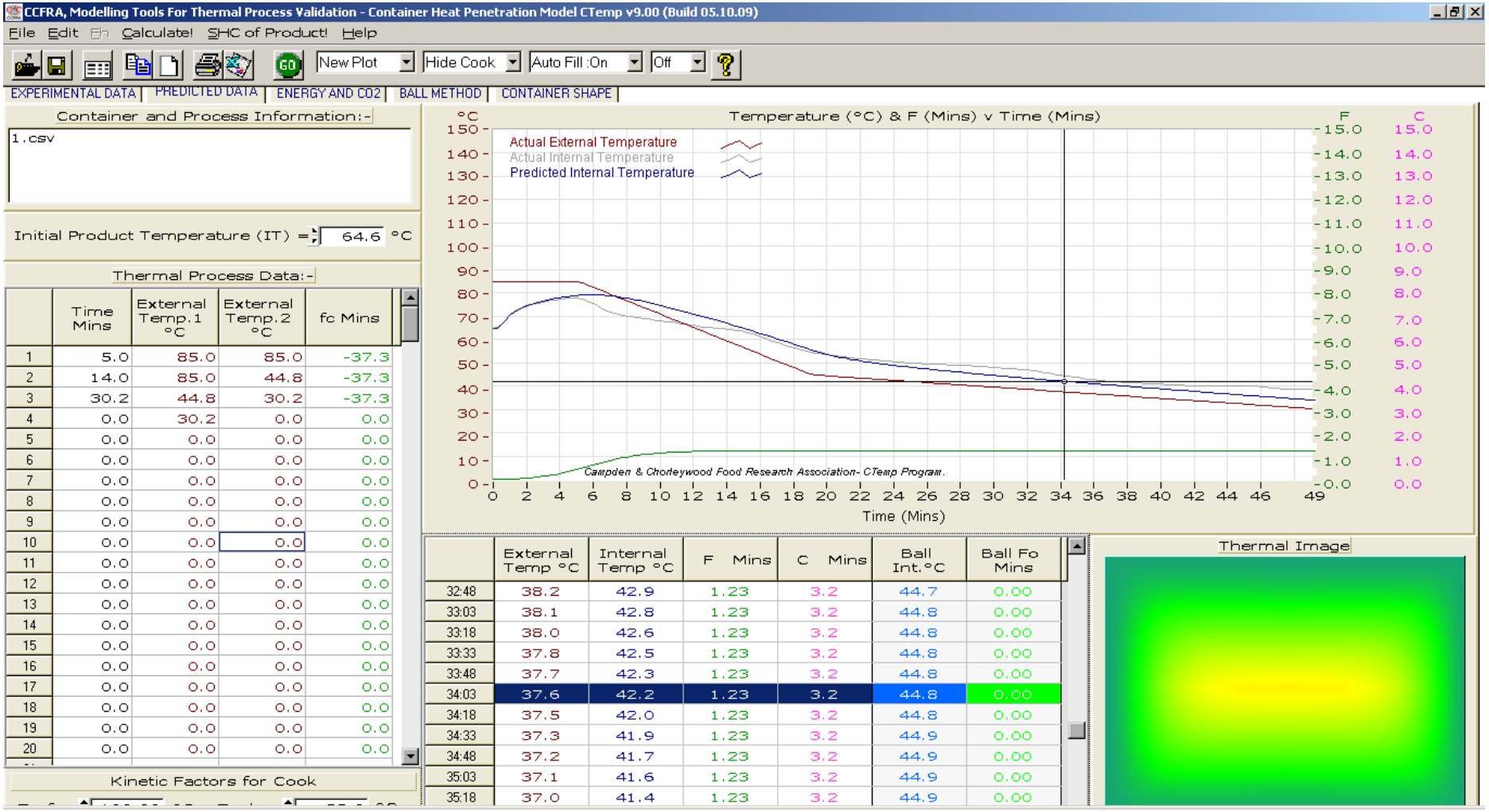


Figure 7.2: CTemp model base on calculated fc and j value of packaging

Figure 7.3: CTemp predicted P value when pasteurisation tunnel operated at 85°C



8. Conclusions

In hot-fill pasteurisation processes, it has always been assumed that the heat transfer from the hot food to the packaging during filling helps to reduce risks from microbial contamination that may be present on the surface of the food pack. However, guidance is not widely available on this and, as a result, hot-fill products often require a second processing step of heating the filled product pack to assure food safety. It is anticipated that a better understanding of the risks associated with hot filled products and the heat transfer between food and pack at the point of filling could make a significant contribution to deliver appropriate process times, temperatures and energy/water consumption, whilst assuring food safety and quality.

The three case study trials in a microbial contamination survey on packaging surfaces and their surrounding factory environments provided similar trends and guidance for the future. In all cases, the packs coming into the food factory (including plastic pots, lids and pouches, glass jars, paperboard packs and cardboard outer packaging) had little microbiological contamination in the form of moulds, yeasts or other microorganisms. However, the processing environment and contact surfaces that the packs may potentially come into contact with in the factory (e.g. conveyors, guiderails, filling heads) had varying degrees of higher level microbial contamination.

There is potential for the packaging to pick up contamination from these sources. This was thought to be a particular issue for plastic packaging, as it is known that there is potential for electrostatic charges to build up on the plastic surface and this may attract airborne contamination more easily than other packaging materials. The surface and environmental contamination, although relatively low, was also different on different visit dates. This may have been the result of the microbiological measurements being made before or after the factory areas had been cleaned, or possibly seasonal effects of the airborne microorganisms. This does stress the importance of maintaining good standards of hygiene within the process environment as a means of preventing food and pack contamination.

It is recommended that a minimum of 70°C for 2 minutes equivalent heat process is delivered to the worst case position on the interior packaging surfaces to control vegetative pathogens. The main concern following this heat treatment is the contamination by spoilage organisms such as moulds.

Process targets to control spoilage organisms on food packaging are still a controversial topic. This is because the types and numbers of such organisms on the packaging could vary significantly among different packaging materials and individual food manufacturers.

If the packaging and hot filling environment is not aseptic, the packaging may be exposed to risk of microbial contamination. This contamination, as suggested by the the microbial surveys within factory environments in this project, was unlikely on packaging received directly from the packaging supplier but more likely from the factory environment surrounding the packaging during storage or hot filling stages. The major vectors of pack contamination were thought to be:

(1) cross contamination through direct contact with other surfaces (e.g. product conveyors, filler heads)

(2) electrostatic force build up on the packaging surface during processing that attracts airborne organisms from the surrounding environment

The likelihood of contamination is therefore related to the packaging materials, hygienic conditions, pre-filling processes and air quality at the individual factory. Consequently, it is difficult to have one single process target for food packaging that will be suitable for all packaging formats and designs, and for all processes and for all manufacturers. Currently, different manufacturers are implementing different target processes for packaging to control spoilage organisms on packaging surfaces.

It is recommended that process targets for packaging to control spoilage organisms are established on a case by case basis. A risk assessment based approach is proposed in this document. Processes and controls that have been known by industry to have positive effects on reducing the level of the microbial contamination on packaging have also been listed.

To quantify the surface heat treatment on the packaging during hot filling and post filling processes, several different validation techniques are reviewed in this report. It is recommended to use flexible probe wireless dataloggers as default measurement tool where possible, and use TTIs and infra-red imaging where dataloggers cannot be applied.

Industrial results show that a significant temperature sink could occur in certain packaging materials immediately after the hot filling step. Typically, around 20˚C temperature loss was measured once the product had made the initial contact with a glass jar surface, about 5-10˚C temperature loss for a plastic surface, and less than 3˚C temperature loss for a pouch surface. This suggests that hot filling alone is not sufficient even to deliver a minimum target process of 70°C for 2 minutes equivalent process on a non-preheating glass surface. It is possible that plastic surfaces may be able to achieve a 70°C for 2 minutes equivalent process, and it is more likely to be successful on pouch surfaces, if the hot filling temperature is validated.

It should be pointed out that the packages tested in this study are those without preheating treatment before hot filling. Proper preheating treatment on the glass jars for example, would raise the initial temperature on the pack and therefore minimising the temperature loss once product comes into contact with the pack surface. Changes in equipment parameters setting, e.g., steam capper, may also have impacts on the final results. It is likely that with significant energy input before hot filling process, glass jar may still be possible to achieve 70°C for 2 minutes equivalent after hot filling process, although a practical thermal validation will be required to confirm this possibility.

The significant temperature loss on pack surface during hot filling may be an important factor to consider during packaging selection in the initial product development stage. Some packaging materials, such as glass and some plastics, tend to require an additional pre filling or post filling heat treatment, which might increase the capital investment.

The slowest heating spot on the surface of rigid packaging varies depending on the processes. Typically headspace and bottom corner were found to be the worst case. For non-steam capping processes, lid position could also be the worst case. For flexible packaging, no real cold spot was found, as the flexible packaging allows product to move around the entire internal surface of the packaging during processing. Doypack and Gualapack are exceptions, where cold spots are usually found at the headspace walls or closures.

Several post filling options are reviewed in this report. All of them are able to deliver further heat treatment to the packaging. This post filling process does require validation to confirm their contribution. This could be challenging in some cases (e.g. viscous product inversion) where the product is forced to move to different areas within the pack during the process, while the product temperature decreases with time.

Optimising the thermal processes applied to packaging is possible through CTemp modelling. Understanding the heat transfer mechanism and characteristics of the packaging material is crucial to the success. From experimental time and temperature data obtained from the internal packaging surface during a post-filling process, a model could be built to predict the P values changes as process parameters change. This modelling prediction would reflect which factor contributes most to the P value on the packaging surface and therefore help to understand the most cost effective way to deliver a desired P value. The optimised setting will require practical validation to confirm the finding.

With better understanding of the factors influencing microorganism contamination and the thermal processes that need to be applied in hot filling and post filling processes, it is now possible to dictate the level of pack surface pasteurisation to save energy and cost without compromising food safety.

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