Improving Hygiene in Food Processing

The foundation of hygiene

S. Notermans, and E. Hoornstra

TNO Nutrition and Food Research institute, P.O.Box 360,

3700 AJ Zeist, The Netherlands

Dr. S.C. Powell

Lancashire Postgraduate School of Medicine and Health, Preston PR12 H, United Kingdom

Hygeia the goddess of healing

Her name survived until the present times in the word hygiene

*) This document will also appear as chapter in the book entitled 'Food authenticity and traceability'. Woodhead Publishing Ltd. Cambridge, UK

Contents

1. Introduction into food hygiene

The art of healing is almost as old as man himself. His instincts, needs and experiences taught man the art of healing. In history medicine and hygiene have always been counterparts in healing and preventing diseases. However, both disciplines have mostly gone hand in hand in improving human health. This introductory chapter starts with the early aspects of hygiene and where necessary interfaces between healing and preventing diseases will be discussed. After the recognition of germs as causing agent of diseases the significance of hygiene developed rapidly and is now considered as the corner stone of safe food production.

1.1 The roots of hygiene

Hygeia the goddess of health

In Greek mythology, Asclepius, son of Apollo and referred to as the god of medicine or healing, was a healer who became a Greek demigod, and was a famous physician. Actually he was the most important among the Greek gods and heroes who where associated with health and curing disease. Shrines and temples of healing, known as Asclepieia, were erected throughout Greece were the sick came to worship and sought cures for their ills. Among the children of Asclepius the best known are his daughters Hygeia and Panacea. Hygeia became the goddess of healing and she focuses on the healing power of cleanliness. She introduced and promoted the idea of washing patients with soap and water. She had lots of hospital shrines and played an important role in the cult of Asclepius as a giver of health. At the beginning she was the goddess of corporal well-being. Later she was also connected to mental health; the aphorism ‘mens sana in corpore sano’ applies to this, ‘a healthy mind in a healthy body’. Her sister was faced, like her father, for healing by medicines.

Hygeia was celebrated on many places in Greek and Roman world. She was sung and represented by many artists from the 4th century BC until the end of the Roman period. The statues of Hygeia originated from well-known masters like Skopias, Tomotheos and Bryaxis. A sculpted head of Hygeia is presented in figure 1.

The name of Hygeia survived until the present times in the word hygiene and its components and her sacred snake together with the rod of Asclepius which is the medical sign for actual medicine.

Figure 1. Head of Hygeia. National Archaeological Museum, Athens, c. 360 BC.

Hippocrates (460-377 B.C.)

Hippocrates, the most famous doctor in ancient Greece, was titled as Father of Medicine. Hippocrates based medicine on objective observation and deductive reasoning. His medical school and sanatorium on the island of Kos developed such principles and methods in curing that have been used ever since. Hippocrates and his followers elaborated an entirely rational system which was based on the classification of the symptoms of different diseases. He taught that medicine should build the patient's strength through diet and hygiene, resorting to more drastic treatment only when necessary. All historians agree that he taught validly concerning epidemics, fever, epilepsy, fractures, the difference between malignant and benign tumours, health in general, and most of all the importance of hygiene, the healing power of food and the need for high ethical values in the practice of medicine. He laid utmost stress on hygiene and diet, but used herbal remedies and surgery when necessary.

An overview of the work of Hippocrates is presented in the book 'Magni Hippocratis Coi Opera Omnia' (Hollier, 1623). It contains everything that had been described to Hippocrates up to the 17th century.

Other hygiene measures

Over many millennia, mankind has learned how to select edible plant and animal species, and how to produce, harvest and prepare them for food purposes. This was mostly done on the basis of trial and error and from long experience. Many of the lessons learned, especially those relating to adverse effects on human health are reflected in various religious taboos, which include a ban on eating specific items, such as pork, in the Jewish and Muslim religions (Tannahill, 1973). Other taboos showed a more general appreciation of food hygiene. In India, for example, religious laws prohibited the consumption of certain 'unclean' foods, such as meat cut with a sword, or sniffed by a dog or cat, and meat obtained from carnivorous animals (Tannahill, 1973). Most of these food safety requirements were established thousands of years ago when religious laws were likely to have been the only ones in existence. The introduction of control measures in civil law was of a much later date.

The re-emerge of hygiene

In the middle ages folk-medicine developed rapidly. Use was made of medicinal plants, animal parts and minerals have been used to get rid of disease symptoms. Later surgery was used as a cure. In the beginning of the 1800's the excesses of doctors and the cottage industry drugs led to general loathing and ridicule of the medical profession by the public in USA and Europe. For at least a century strychnine was the best remedy the profession had for palsy and paralysis. It was used to kill rats, cats and dogs. But when given as medicine, it was tonic, a nerving, a remedy for palsied men. It was standard medical practice to withhold water from the actually ill and thousands of patients literally died of dehydration. Alcohol was a foundation of the many bitters that were sold to the people as tonics, as it was the chief ingredient in many of the patent nostrums sold. Remedies were sold against alcoholism that were chiefly alcohol. In addition to drugging their patients to death, physicians have frequently bled them to death. Bleeding was employed in wounds and head injuries that resulted in unconsciousness. Not only were pregnant mothers bled, but physicians also drew blood from blue babies. In these days patients were bled, blistered, purged, puked, narcotized, mercurialised alcoholised into chronic invalidism or into the grave. Death rate was high and the sick man who recovered without sequelae was so rare as to be negligible. In that time hygiene was very poor as well. Physicians not only frowned upon, but opposed bathing. Surgeons performed operations without washing their hands, and operating rooms of hospitals were veritable pig sties. Physicians would go from the post mortem room directly to the delivery room and assist in the birth of a child without washing their hands. Child-bed fever was a very common disease and the death rate from it was very high.

This is the time when the revolt, 'hygiene' re-emerged. Out of the contradictions, confusions, chaos and delusions called the science of medicine, grew a need for new thoughts and a crusade for health reform developed.

The 'Natural Hygiene' concept

One of the first pioneers was Isaac Jennings (see the book *Awakening Our Self-Healing Body* by Arthur Michael Baker MA, NHE). In 1822, after having practiced medicine for 20 years and being thoroughly discouraged with the results, Jennings begins to administer placebos of bread pills, starch powders, and coloured water tonics to patients, while instructing them in healthful living. Jennings and physiologist/minister Sylvester Graham started to fed-up citizens with failures and contra-dictions of current medical practice and theory. Graham developed a significant following of grahamites in response to his eloquent lectures and writings. To the temperance movement he offered a vegetarian diet as a cure for alcoholism. He also advocated sexual restraint and hygiene measures such as bathing.

The truths proclaimed by Jennings and Graham found immediate and widespread acceptance. After becoming fully convinced of the correctness of his "Do-Nothing Cure," and the "No-Medicine Plan," Jennings announced his discovery to the world, but he was misunderstood. The work of Jennings in the USA was continued by many others**.** People were learned to bath, to eat more fruit and vegetables, to ventilate their homes, to get exercise and sunshine. Hygiene became so popular, that traditional medicine finally had to adopt parts of the 'Natural Hygiene' concept. Later, when it became clear that 'germs' where the cause of many diseases, the new "hygiene" was incorporated with the drug-usage of medicine and the word hygiene got the meaning it has today.

Hygienic developments in Europe

In the mid of the 19 century two persons lay the foundation of modern hygiene. It was the Hungarian physician Semmelweis and the British surgeon Lister. Both introduced hygienic methods which still appear to be essential in modern society.

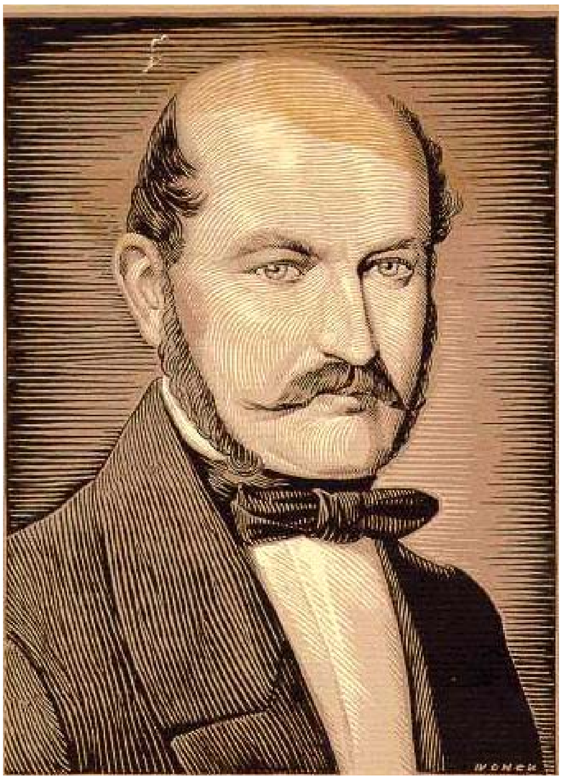
Semmelweis. Ignác Fülöp Semmelweis (1818 - 1865) was a Hungarian physician who demonstrated that puerperal fever[1] (also known as "childbed fever") was contagious and that

---

[1] Serious form of septicemia contracted by a woman during childbirth or abortion (usually attributable to unsanitary conditions); formerly widespread but now uncommon.

its incidence could be drastically reduced by enforcing appropriate hand-washing behaviour by medical care-givers. Figure 2 presents a portrait of Semmelweis.

Figure 2. Portrait of Ignác Fülöp Semmelweis (1818 – 1865). From http://clendening.kumc.edu/dc/pc/semmelweis01.jpg



Semmelweis made this discovery in 1847 while working in the Maternity Department of the Vienna Lying-in Hospital. He realized that the number of cases of puerperal fever was much larger in the clinic 1 where students did both post mortem examinations with human cadavers in the autopsy rooms and midwifery in the maternity rooms. In clinic 1 the average death rate amounted to 9.92%. In clinic 2 where students were only involved in midwifery and not allowed to do autopsies, the average death rate was much less and amounted 3.38%. After testing a few hypotheses, Semmelweis found that the number of cases was drastically reduced if the doctors washed their hands carefully before dealing with a pregnant woman (see table 1). Risk was especially high if they had been in contact with corpses before they treated the women. The germ theory of disease had not yet been developed at the time. Thus, Semmelweis concluded that some unknown ‘cadaveric material’ caused childbed fever. Since the cadaverous matter could not been removed from the doctors hands merely by washing them with soap and water Semmelweis started experiments with different chemicals. Finally he prescribed the additional use of chlorinated lime. Due to this the death rate caused by puerperal fever deceased to zero (see table 1).

Tabel 1. The effect of hand washing and hand washing and the use of chlorinated lime on maternal death caused by puerperal fever.

Year/period	Maternal death rate in (%)	
	Medical students (clinic 1)	Mid wife students (clinic 2)
1841-1846	9.92	3.38
May 1847	12.42	
Introduction of hand-wash		
June 1847	2.38	
July 1847	1.20	
August 1847	1.89	
Introduction of chlorinated lime hand-wash		
October 1847	1.27	1.33
March 1848	0	0
August 1848	0	0

He lectured publicly about his results in 1850. However, the reception by the medical community was cold, if not hostile. His observations went against the current scientific opinion of that time, which blamed diseases on an imbalance of the basical "humours" in the body. It was also argued that even if his findings were correct, washing one's hands each time before treating a pregnant woman, as Semmelweis advised, would be too much work. Nor were doctors eager to admit that they had caused so many deaths. Semmelweis spent 14 years developing his ideas and lobbying for their acceptance, culminating in a book he wrote in 1861 (Semmelweis, 1861). The book received poor reviews, and he responded with polemic. His failure to convince his fellow doctors was also caused by a poor way of communication by Semmelweis. In 1865, he suffered a nervous breakdown and was committed to an insane asylum where he soon died from blood poisoning. Only after Dr. Semmelweis's death the germ theory of disease developed. He is now recognized as a pioneer of antiseptic policy and prevention of nosocomial disease.

Joseph Lister. It was Lord Lister (1827-1912) who introduced the antiseptic surgery. Figure 3 presents a portrait of Lister.

Figure 3. Portrait of Joseph Lister (1827-1912). From: http://clendening.kumc.edu/dc/pc/lister07.jpg

By the middle of the nineteenth century, post-operative sepsis infection accounted for the death of almost half of the patients undergoing major surgery. A common report by surgeons was: operation successful but patient died. For many years he had explored the inflammation of wounds, at the Glasgow infirmary. These observations had led him to consider that infection was not due to bad air alone, and that 'wound sepsis' was a form of decomposition. When, in 1865, Louis Pasteur suggested that decay in wounds was caused by living organisms in the air, which on entering matter caused it to ferment, Lister made the connection with wound sepsis. As a meticulous researcher and surgeon, Lister recognized the relationship between Pasteur's research and his own. He considered that microbes in the air were likely causing the putrefaction and had to be destroyed before they entered the wound. In 1864

Lister had heard that 'carbolic acid' was being used to treat sewage in Carlise (UK), and that fields treated with the affluent became free of parasites causing disease in cattle. Even before the work of Pasteur on fermentation and putrefaction, Lister had been convinced of the importance of scrupulous cleanliness and the usefulness of deodorants in the operating room. In 1865 he begins spraying a carbolic acid solution during surgery to kill germs. In the end, it's Lister who gives Semmelweis his due by saying '*Without Semmelweis, my achievements would be nothing*'. Through Pasteur's researches, he realized that the formation of pus was due to bacteria, he proceeded to develop his antiseptic surgical methods. The immediate success of the new treatment led to its general adoption, with results of such beneficence as to make it rank as one of the great discoveries of the age.

Lister began also to clean wounds and dress them using a solution of carbolic acid.
He was able to announce at a British Medical Association meeting, in 1867, that his wards at the Glasgow Royal Infirmary had remained clear of sepsis for nine months. German surgeons were beginning to practice antiseptic surgery, which involved keeping wounds free from micro-organisms by the use of sterilized instruments and materials. The 1870's were some of the happiest years of Lister's life, largely due to the German experiments with antisepsis during the Franco-German War. His clinics were crowded with visitors and eager students. Lister made a triumphal tour of the leading surgical centres in Germany in 1875. Here he met Robert Koch who demonstrated in1878 the usefulness of steam for sterilizing surgical instruments and dressings.

1.2 Foodborne diseases and hygiene since 1850

1.2.1 Foodborne diseases

Public health concern with foodborne diseases emerged around the 1880's. This was after micro-organisms were recovered as infectious agents and Koch and his assistants devised the techniques for culturing bacteria outside the body, and formulated the rules for showing whether or not a bacterium is the cause of a disease (Koch, 1883). Before that time two types of illness with foodstuffs were recognized: the one associated with aging, the other with foods normally not causing illness and apparently incapable of adulteration such as meat and fish. The last type had long been associated with decomposition; in the early nineteenth century it was thought to be due to chemical poisons, later to ptomaines[2], or putrefactive alkaloids (Dewberry, 1959). Uncooked fruit and vegetables were also associated with upset stomachs, but here illness was generally attributed to unripeness or acidity (Hardy, 1999).

It was no until the later 1880s that the generic term ‘food poisoning’ emerged: before this, and still occasionally for decades thereafter, episodes were usually described by the precise item of food involved: cheese poisoning’, ‘meat poisoning’, ‘pork-pie poisoning’, etc. Despite Robert Koch’s identification of specific organisms causing foodborne diseases, such as anthrax, in 1876 (Koch, 1876) the above terms for food poisoning remains in use and examples have been described by among others Durham (1898) and Peckham (1923-24) who reported on respectively outbreaks of meat poisoning and pork pie poisoning.

The 1880 was also the decade were bacterial food poisoning displaced that of ptomaine poisoning. In the late 1870s, German researchers had begun to draw attention to connections between septic and pyaemic[3] diseases in animals used for food and meat poisoning outbreaks. In the early 1880s they started to investigate meat poisoning outbreaks bacteriologically (described by Ostertag, in his handbook for meat inspection (Ostertag, 1902)).

Hard historical information about the incidence rate of foodborne infections in nineteenth-century are lacking. One of the reasons is that food poisoning was not made notifiable. In the UK food poisoning became notifiable in 1939. There are, however, two indicators for the behaviour of food infections in cities: typhoid and epidemic diarrhoea. Typhoid emerged in the UK as a major urban hazard in the 1830s and was largely water-borne and the role of human carriers and of contaminated foodstuffs is likely to have been significant. Death rates from typhoid fell rapidly between 1870 and 1885, as urban water supplies were improved, but then stabilized until the early of the 20th century (Greenwood, 1935). With the discovery of the human carrier and of foodstuffs as a vehicle of infection, and with greater (hygienic) care of patients, death rates fell rapidly and disappear around 1920. Epidemic diarrhoea contributed even more to food poisoning. The term encompasses infant diarrhoea, the condition responsible for some for some 30% of infant mortality before 1901.

---

[2] Food poisoning, erroneously believed to be the result of ptomaine ingestion. The word ptomaine was invented by the Italian chemist Selmi for the basic substances produced in putrefaction. They belong to several classes of chemical compounds and are any of various amines (such as putrescine or cadaverine) formed by the action of putrefactive bacteria

[3] The invasion of bloodstream by pyogenic (pus forming) organisms.

Huck's local studies (Huck, 1994) have shown that rising infant mortality was closely associated with the growth of industrial towns in the early nineteenth century. Other contemporary studies found that infant death was only the visible tip of the iceberg of extensive familial episodes of diarrhoea (Woods et al., 1988) which emphasised a very high degree of multiple infections in households. It was Ballard (1887, cited by Hardy, 1999) who linked the infections with contaminated foodstuffs. When the first bacteriological analyses of epidemic diarrhoea came to performed, the leading contenders for causation came from bacteria belonging to the family of *Salmonellae* (Niven,1909-1910). In 1888 the German Gärtner (1888) discovered and described the *Salmonella* bacteria, which he named *Bacillus enteritidis.* He demonstrated the presence of the organism in a slaughtered cow that had caused gastro-enteritis in the people who had eaten her meat. The discovery of other such organisms quickly followed in the pioneering bacteriological laboratories of the 1890s and actually the identification of specific agents of disease became a competitive game. Despite new isolation and identification techniques, the bacteriology of food poisoning and infection appeared to be an immensely complicated subject, partly because of the number of different organisms apparently involved in the process, and partly because of the vexed questions of their nature and natural habit. For example questions whether *Salmonella* was belonging to the natural inhabitants of the intestinal tract of human and animals, were they present in flesh of the animal or were they only present in diseased animals needed to be solved.

Identification of agents involved in foodborne diseases and the etiological research of foodborne diseases began at the end of the nineteenth century when the work of Van Ermengem served to clarify the aetiology of botulism in man (Van Ermengem, 1897). Later milestones in this category included the recognition of *Clostridium perfringens* as a foodborne pathogen in 1943 (McClane, 1979) and *Bacillus cereus* in the 1950s (Kramer and Gilbert, 1989). Human infections with *Listeria monocytogenes* were well known by the 1940s and foodborne transmission was suspected (Rocourt and Cossart, 1997), but it was not until the occurrence of an outbreak in Canada in 1981 that proper evidence was obtained. In this case, illness followed the consumption of contaminated coleslaw (Farber and Peterkin, 2000). Since then, numerous foodborne outbreaks have been reported in different countries, and prevention of listeriosis has become a major challenge for the Food Industry. Around 1980 – 1985 *S*. Enteritidis re-emerged via the internal contamination of chicken eggs. At the same time a new emerging pathogenic started to emerge: *Escherichia coli* O157: H7 (Willshaw *et al*., 2000). This organism causes hemorrhagic colitis. In some victims, particularly the very young, may develop the hemolytic uremic syndrome (HUS) which is characterized by renal failure and hemolytic anemia. From 0 to 15% of hemorrhagic colitis victims may develop HUS. The disease can lead to permanent loss of kidney function.

Athough the enormous developments in foodborne disease research in the beginning of the 20th century the reporting of incidents remained low. Unless one or more deaths were involved, or an outbreak was on a considerable local scale, incidents of gastro-enteritis rarely came to the knowledge of the authorities. Savage and Bruce White (1925) complained after a case in which an elderly woman died as a result of eating canned salmon. Investigations were not carried out. Difficulties in reporting and adequate investigations were acknowledged obstacles to a fuller understanding of the nature of and factors in bacterial food poisoning. Before the second World War, most food poisoning incidents undoubtedly remained hidden. To improve the situation in 1939 the UK established the 'Emergency Public Health Laboratory Services – a network of 19 provincial and ten metropolitan laboratories, whose services were to be available free of charge to medical officers of health if required for the investigation and control of infectious diseases.

The second World War is generally seen as a seminal event in history of food poising. During and after the war, there was a rapid extension of mass catering, both in terms of feeding large numbers of people in canteens and restaurants, and in mass production of prepared foodstuffs. This resulted in many new problems. Egg-borne *Salmonella* infections received widespread publicity when incidents were traced to the use of bulk-imports of American powdered eggs (Hardy, 1999). Trade in both human and animal foodstuffs became internationalized and opened many European countries to a large number of exotic *Salmonella*-types from all over the world.

After the introduction of the compulsory notification food-borne diseases acquired a statistical profile. After an uncertain start notifications began to rise steadily. For example in the UK the notifications increased in a 10 year period (1941-1951) from an initial couple of hundred to over 3000 a year.

As indicated by Hardy (1999) in her historical overview of food poisoning in Britain the history of foodborne disease is a history of social and scientific change, but is not simply one of an increasing preference for foodstuffs prepared outside the home rather then within it. Rather, it is the story of how social and scientific change has gradually exposed unchanging economies of time and hygiene which most people have always made in their everyday lives. However, information about foodborne diseases is yet still from complete. A current problem is that although most countries have mandatory systems for notifying food-borne diseases, the information provided is generally poor and there is a dramatic under reporting. This came to light after modern analysis were used, including sentinel and population studies. It became clear that in developed countries in average 10,000 – 20,000 persons per 1000,000 population suffer yearly form a foodborne disease (de Wit *et al*., 2001; Fitzgerald *et al*., 2004). In addition in about 37,5 % of the cases investigated in sentinel studies a causative organisms was identified (see table 2).

Table 2. Microorganisms detected in patients with symptoms of acute enteritis and controls. (de Wit *et al*., 2001)

	Patients (N=857)		**Controls (N=574)**	
	No	**%**	**No**	**%**
Salmonella spp.	33	3.9	1	0.2
Campylobacter spp.	89	10.4	3	0.5
Yersinia spp.	6	0.7	6	1.1
Shigella spp.	1	0.1	0	0.0
VTEC	4	0.5	3	0.6
Rotavirus	45	5.3	8	1.4
Adenovirus	19	2.2	2	0.4
Astrovirus	13	1.5	2	0.4
Norwalk-like viruses	43	5.0	6	1.1
Sapporo-like viruses	5	2.1	1	0.2
Parasites	64	7.4	26	4.5
Total	322	37.6	58	10.1

1.2.2 Hygiene

Following the discovery, around 1880, that food can be an important source of disease-causing organisms, investigations started to concentrate on the reservoirs and routes of transmission of pathogens. The research of Buchanan (cited by Oddy and Millar, 1985) revealed an association between infant diarrhoea, refuse tips and flies. Further elucidation of reservoirs and routes of transmission, stimulated the British public health authorities to include this emerging field in preventive medicine. As an example, the health authorities began extensive anti-fly campaigns, both through public education and by tackling the breeding grounds of the flies themselves. At much the same time, attention began to focus on the presence of pathogenic bacteria in the intestines of animals, as a source of food contamination, and foods of animal origin, as routes of transmission to humans. Savage (1909) observed that faecal contamination of food must be very common. Milk, in particular, was suspected to be a vehicle of infection. Theodor Escherich, a German paediatrician, who devoted his efforts to improving childcare, particularly in relation to infant hygiene and nutrition, was the first to make a plea for heat-processing of milk to prevent infant diarrhoea (Escherich, 1890). After that time, the heating processes used for food began to improve. Real progress was made when Esty and Meyer (1922) developed the concept of process-performance criteria for heat treatment of low-acid, canned food-products to reduce the risk of botulism. Later, many other foods subjected to heat treatment were controlled in the same manner. An outstanding example is the work of Enright *et al.* (1956, 1957), who established performance criteria for the pasteurisation of raw milk that provided an appropriate level of protection against *Coxiella burnetii*, the causative agent of Q Fever. Studies on the agent responsible for tuberculosis had been carried out earlier. These are early examples of the use of risk-assessment principles in deriving process criteria for control purposes.

The recognition of animal reservoirs of *Salmonella* served to reinforce the perceived complexity of the food poisoning problem. It was known that the key to preventing typhoid lay in blocking the routes by which the causative bacteria might pass from animals to man and then among the human population. From the public health viewpoint, it became clear that there were several elements in the food poisoning situation: firstly, there was the animal-health aspect, with veterinary, slaughterhouse and culinary factors to consider; then, there was the matter of personal hygiene, which involved toilet and hand-washing habits. The question of developing suitable legislation was also apparent and, finally, there was the bacteriological aspect, with the need for more extensive laboratory provision to help in unravelling evidence from the field. Based on the need to improve hygiene in slaughter plants, the USA was one of the first countries to introduce a Meat Inspection Act in 1906. This brought the following reforms to the processing of cattle, sheep, horses, swine and goats destined for human consumption:

- all animals were required to pass an inspection by the US Drug Administration prior to slaughter;
- all carcasses were subject to a post-mortem inspection;
- standards of cleanliness were established for slaughterhouses and processing plants.

In the UK, it was recognized that legislation alone was not sufficient to protect consumers against foodborne diseases, and the health authorities became aware of the need for public education to achieve cleaner food supplies. Food handling practices were very poor.

Some examples from the 1920s were described by Porter (1924-1925) and included the following:

Glass washing:

- it was common for glasses to be dipped only in dirty water before being re-used.

Personal cleanliness among food handlers:

- food handlers regularly licked their fingers when dealing with wrapping paper;
- they blew into paper bags to open them;
- butchers often failed to wash their hands after eviscerating animals;
- the habit of fingering the nose and / or mouth, while serving food, was common.

When wrapped bread was introduced into the UK, the innovation proved unpopular among housewives. One reason was that the wrappers became dirty and people failed to realise that, without wrappers, the dirt would be on the bread (Hardy, 1999). Hand-washing facilities were mostly unavailable and, where present, were rarely used initially. Toilet paper, too, was accepted reluctantly and, when it became available, the quality was very poor (Whitebread, 1926). Only when a new Food and Drug Act was introduced in the UK in 1938, was it necessary to use hygienic conditions and practices in handling, wrapping and delivering food, and adequate hand-washing facilities were required for food handlers.

A clear breakthrough in public health was the processing and disposal of domestic and sewage wastes, in conjunction with the purification of water supplies to ensure that any pathogens present were not passed to consumers via drinking water. Also, sanitary microbiologists were appointed to inspect food-processing and eating establishments to ensure that proper food-handling procedures were followed. These made a significant contribution to the development of appropriate hygiene standards.

2 Definitions of hygiene

In ancient times, it was clear that diseases could be overcome, either by actively curing (Asclepius) or through the power of cleanliness (Hygeia). Curing diseases with the use of medicines was traditionally the role of the physician. Preventing diseases, on the other hand, became the domain of the hygienist. The first definitions of ‘hygiene’ are derived from the work of the Goddess Hygeia:

-‘ healing through cleanliness’;

- ‘the science dealing with the preservation and promotion of health’.

In the course of time, medicines became the principal means of curing diseases. However, because of the many failures during the 18th and 19th centuries, hygiene re-emerged as the key discipline. In the USA, the ‘Natural Hygiene’ movement came into being. The main objective of this science-based movement was not to treat the effect, but remove the cause of a disease (treating the effect without addressing the root cause was then the usual practice of medicine). Natural Hygiene addresses all aspects of living: the environment, food, work, home, economics, spirituality, psychology, politics etc and those other factors that positively influence health and well-being.

Following the recognition of germs as the principal causes of disease at the end of the 19th century, hygiene measures rapidly became established. By the beginning of the 20th century, it had become clear that preventive measures were the only way to produce safe food, and the discipline of food hygiene was born. Current definitions of ‘food hygiene’ are presented in Table 3.

Table 3. Definitions of food hygiene in current use.

Definition (*and references*)
• Conditions and practices that preserve the quality of food to prevent contamination and food-borne illnesses. http://www.nlm.nih.gov/medlineplus/ency/article/002434.htm
• All measures necessary to ensure the safety and wholesomeness of foodstuffs. *EU’s General Food Hygiene Directive (Anon., 1993)*
• All conditions and measures necessary to ensure the safety and suitability of food at all stages of the food chain. *Codex Alimentarius Commission(Anon., 1997)* *CAC/RCP 1-1969, Rev. 3 (1997), Amended 1999*
• The measures and conditions necessary to control hazards and ensure fitness for human consumption of a foodstuff, taking into account its intended use *Environmental Health Journal, 2000, 108/9* *http://www.ehj-online.com/archive/2000/september/sept10.html* COM (2000) 438. final. Brussels, 14 July 2000.

Based on these definitions, it can be concluded that the concept involves all necessary measures to produce safe and healthy food. Any means to prevent contamination, decontaminate food (such as pasteurisation) and measures to improve wholesomeness and fitness for consumption are considered to be part of the hygiene concept. Various factors are contributory, such as personal hygiene and hygienic design of facilities, equipment, etc, as well as activities relating to cleaning and disinfection of food premises and hygienic disposal of waste, which are referred to as 'sanitation'.

Personal hygiene

Personal hygiene is of great importance for the maintenance of health in general. Human beings are natural carriers of many micro-organisms and sources include the hair, skin, mucous membranes, digestive tract, wounds, infections and clothing. Good personal hygiene is primarily directed towards preventing both disease and discomfort. Hand-washing, dental care, avoidance of spitting, daily showering, etc, as well as clean living, play an important part. Disposal of waste is also important. All these measures are preventive in character and are readily carried out.

Hygienic design of facilities and equipment

Hygienic design of food-production facilities, processing equipment etc. is a most important factor in ensuring that food is safe and wholesome. Poorly designed farms, factories, and equipment can easily result in contamination of food products and lead to food-poisoning incidents. Furthermore, design deficiencies may result in losses of product due to spoilage, increased cleaning costs and reduced production time. These aspects are also of possible environmental concern. Therefore, it is essential that both manufacturers and users of food-processing equipment are aware of hygienic design principles and requirements such as those described in EU Directives 98/37/EC and 93/43/EEC, and Hygienic Design DIN EN 1672/2 (1997). Hygienic production of food thus depends upon a combination of food-processing procedures and hygienic design of buildings and equipment, in full compliance with legislation.

Sanitation

Sanitation is a term for the hygienic disposal or recycling of waste materials, particularly human excrement. In consequence, sanitation is an important public health measure that is essential for the prevention of disease. In the USA, there is a particular focus on the concept of food sanitation, which may be defined as ‘the hygienic practices designed to maintain a clean and wholesome environment for food production, preparation and storage’ (Marriot, 1999). This second definition links hygiene more specifically with maintaining a clean working environment for food processing. Even here, hygiene requirements extend beyond the practice of cleaning itself to incorporate those elements that make effective cleaning possible and allow control of insects and other pests. In the microbiological sense, sanitation is defined as ‘a cleaning and disinfection process that results in a 99 – 99.9 % reduction in the number of vegetative bacteria present’.

3. Sources of food contamination[4]

There are three main types of food contaminant:
- microbiological;
- chemical;
- physical.

Foods can become contaminated during growth and harvesting of raw materials, storage and transport to the factory, and processing into finished products. The final product may then become (re-)contaminated during subsequent storage and transport to shops, and during storage and preparation by the consumer. The main sources of contamination are the environment, animals and people. The main transmission routes (vectors) of contamination are contaminated surfaces, air, water, people and pests. Processing, packaging material and equipment, and transport vehicles may also act as vectors. Contact between food material and an inert surface leaves residual food debris that favours the growth of microorganisms. Over time, these can multiply to significant numbers and become endemic in a processing plant. Chemical contamination may also result from contact with surfaces, if they are not adequately rinsed after cleaning and disinfection procedures. Lubricants, often unavoidable in equipment with moving parts, may also contribute to chemical contamination (Steenaard, 2002). Non-contact surfaces, such as floors, walls, ceilings, overhead beams and equipment supports, are potential reservoirs of microbial contamination and can also be a source of physical and

[4] Partly based on Lelieveld (2003).

chemical contaminants (e.g. from flaking plaster and its associated chemicals). They need to be designed so that they are durable and can be cleaned effectively.

Production animals are important reservoirs of microorganisms and slaughter animals introduce large numbers of microorganisms into the processing plant. Among them are many so-called zoonotic pathogens that are present on the skin and in the gastro-intestinal and respiratory tracts. Pathogens carried on hands are also a major source of contamination (Taylor and Holah, 2000).

Air can be a significant medium for the transfer (vector) of contaminants to food products (Brown, 1996). Unless the air is filtered, microorganisms will be present, and air may also carry 'light' foreign bodies, such as dust, straw-type debris and insects. Chemical taints can enter the production area through airborne transmission. Water is used in the food industry as an ingredient, a processing aid and for cleaning. Its use as an ingredient or processing aid can give rise to both microbial and chemical contamination, so it is important to use water of a high microbiological and chemical quality (i.e. potable quality). Water used in hand washing facilities poses a potential problem, as does that from condensation of steam or water vapour, leaking pipes and drains, and rainwater. Stagnant water is particularly hazardous, since microbial levels can increase rapidly under favourable conditions. The water used in cleaning programmes also needs to be of adequate quality (Holah, 1997; Dawson, 1998; 2000). Personnel can transfer enteric and respiratory pathogens to food, e.g. via aerosol droplets from coughing near the processing line (Guzewich and Ross, 1999). People can equally be vectors of physical contaminants, such as hair or fingernail fragments, earrings, plasters and small personal belongings.

Pests, such as birds, insects and rodents, are potentially a major contamination problem, and particular care needs to be taken to prevent their entry into food production areas. Buildings must be designed to keep them out. Floors, ceilings and walls should not allow insects and other invertebrates the chance to live and breed.

3.1 Microbial contaminants

Pathogenic microorganisms are the major safety concern for the food industry. The vast majority of outbreaks of food-related illness are due to microbial pathogens, rather than to chemical or physical contaminants. As they are generally undetectable by the unaided human senses (i.e. they do not usually cause colour changes or produce 'off'-flavours or taints in the food) and they are capable of rapid growth under favourable storage conditions, much time and effort is spent in controlling and/or eliminating them. Even if the microbes in a food are ultimately destroyed by cooking, they may have already produced toxins, so it is vital to prevent contamination through the use of hygienic practices. Like microbial pathogens, spoilage organisms can either be present naturally or gain access to food. Whilst not a food-safety concern, increased levels of spoilage organisms will usually mean a reduction in the length of time that the food remains fit to eat. This can affect product quality and thus influence the consumer's perception of the product.

Growth of microorganisms depends on a number of factors, such as temperature, humidity / water activity (a_W), pH, availability of nutrients, presence or absence of oxygen and inhibitory compounds such as preservatives. Different organisms require different conditions for optimal growth (e.g. some grow only in the absence of oxygen, others prefer either warm or cool conditions). Bacterial growth is by the simple division of one cell into two (binary fission), and their number will increase exponentially under favourable conditions. The influence of factors such as temperature, oxygen, pH and a_W on microbial activity may be inter-dependent. Microbes generally become more sensitive to oxygen, pH and a_W at temperatures near growth minima or maxima. Often, bacteria grow at higher pH and $a_{W,}$ and at a lower temperature under anaerobic conditions than they do aerobically. Organisms that grow at lower temperatures are usually aerobic and generally have a high a_W requirement. Lowering a_W by adding salt or excluding oxygen from foods (such as meat) that are held at a chill temperature dramatically reduces the growth-rate of spoilage microbes. Normally, some microbial growth occurs when any one of the factors that controls the growth-rate is at a limiting level. If more than one factor becomes limiting, microbial growth is drastically curtailed or even completely prevented. Effective control of pathogenic and spoilage bacteria thus depends on a thorough understanding of the growth conditions favouring particular organisms. This understanding can be used to minimise contamination of incoming raw materials, to inactivate bacteria during processing and prevent decontaminated food from becoming re-contaminated. It is also important to know where and how microorganisms can become established, if growth conditions are favourable. They are particularly attracted to surfaces that provide a stable environment for survival and growth. Surfaces exposed to the air are always vulnerable unless frequently and effectively cleaned and disinfected. However, surfaces within closed equipment may also be vulnerable. There are usually places in processing lines, even when correctly designed, where some product residues remain longer than is desirable. Even if 'dead' areas have been 'designed out', some product will attach to equipment surfaces, despite the possibility of fast-moving liquids. Microbes may reside on such surfaces long enough to multiply, and contaminate the product. The problem is exacerbated when a process includes dead spaces where product can stagnate. As an example, if a single cell of *Escherichia coli* is trapped in a dead space filled with 5 ml of a slightly viscous low-acid food product at a temperature of approx. 25°C, it could take less than 24 hours for the number of microbial cells to increase to 0.2×10^9 per ml, assuming they double every 40 minutes (Lelieveld, 2000). If one ml per hour is washed out from the dead space by the passing product, then the product would be contaminated with 200 million *E. coli* cells per hour, by the end of the first day's production. If the production capacity of the line is 5 million ml per hour, the average level of *E. coli* contamination would be 200/5=40 per ml. Many traditional process lines have much larger (often very contaminated) dead spaces and growth-rates can be higher if conditions permit.

Microbes may also penetrate through very small leaks. There is considerable evidence that they can pass through microscopic openings very rapidly and that pressure differences may retard, but not prevent, passage, even if the pressure-difference is as high as 0.5 bar. The bacterium *Serratia marcescens,* may move at a speed of 160 mm per hour (Schneider *et al*., 1974). Motile bacteria may propel themselves against the flow of liquid through a leak. Whether motile or not, they may also penetrate by forming a biofilm on the surface. Studies on the migration of microorganisms through microscopic channels show that passage can occur through holes of a few micrometers in diameter in a metal plate of 0.1 mm thickness (Brénot *et al*., 1995).

When attracted to a surface, microbes are deposited, attach and initiate growth. As they grow and multiply, the newly-formed cells attach to each other, as well as to the surface, forming a growing colony. When this mass of cells becomes large enough to entrap debris, nutrients and other microorganisms, a microbial biofilm is established (IFT, 1994). Biofilms form in two stages. First, an electrostatic attraction occurs between the surface and the microbe. The process is reversible at this stage. The next phase occurs when the organism forms an extracellular polysaccharide, which firmly attaches the cell to the surface. The cell then multiplies, forming micro-colonies and, ultimately, the biofilm (Notermans *et al*, 1991). These films are very difficult to remove during cleaning operations (Firstenberg *et al*, 1979. Microorganisms that appear to be more difficult to remove because of biofilm formation include the pathogens, *Staphylococcus aureus* and *Listeria. monocytogenes* (Notermans, 1979). Current information suggests that heat treatment is more effective than the application of chemical sanitizers, and Teflon appears to be easier to clear of biofilm than stainless steel (Marriott, 1999).

Biofilm development may take place on any type of surface and is difficult to prevent, if conditions sustain microbial growth. Many organisms, including a number of pathogens (*Listeria monocytogenes, Salmonella* Typhimurium*, Yersinia enterocolitica, Klebsiella pneumoniae, Legionella pneumophila and Staphylococcus aureus*) form biofilms, even under hostile conditions, such as the presence of disinfectants. Adverse conditions even stimulate microorganisms to grow in biofilms (van der Wende *et al*., 1989; van der Wende and Characklis, 1990). Thermophilic bacteria (such as *Streptococcus thermophilus*) can form a biofilm in the cooling section of a milk pasteurizer, sometimes within five hours, resulting in massive contamination of the pasteurized product (up to 10^6 cells per ml) (Driessen *et al.,* 1979; Langeveld *et al.*, 1995). On metal (including stainless steel) surfaces, biofilms may also enhance corrosion, leading to the development of microscopic holes. Such pinholes allow the passage of microbes and thus may cause contamination of the product. Like other causes of fouling, biofilms will also affect heat-transfer in heat exchangers. On temperature probes, biofilms may seriously affect heat-transfer and thereby the accuracy of the measurement. Reducing the effectiveness of heat treatment may itself help to stimulate further bacterial growth. On conveyor belts and on the surfaces of blanching equipment, for example, biofilms may contaminate cooked or washed products, which are assumed to have been made pathogen-free by the temperature treatment received.

Biofilms may be much more difficult to remove than ordinary soil. If the cleaning procedure used is not capable of removing the biofilm completely, decontamination of the surface by either heat or chemicals may fail, since a biofilm dramatically increases the resistance of the embedded organisms (IFT, 1994). It is therefore imperative that product contact-surfaces are well cleaned before disinfection. Krysinski *et al.* (1992) studied the effects of a variety of cleaning and sanitizing compounds on *L. monocytogenes,* which was allowed to attach to stainless steel and plastic material used in conveyor belts over a period of 24 hours. They found that sanitizers alone had little effect on the attached organisms, even when the exposure time was increased to 10 minutes. Unattached cells, on the other hand, showed a 5-log reduction in numbers within 30 seconds. In general, acidic quaternary ammonium compounds, chlorine dioxide and peracetic acid were the most effective sanitizers for eliminating attached cells. Least effective were chlorine, iodophors and neutral quaternary ammonium compounds. When the attached organisms were exposed to cleaning compounds prior to treatment with sanitizers, the bacteria were readily inactivated.

4. Hygiene control measures in food processing

Hygiene in food processing started with the introduction of general measures, including cleaning and disinfection, prevention of re-contamination and treatment of food products to kill any microbial pathogens present. Heat treatment was introduced into food processing even before the underlying causes of foodborne illness were known. It was Nicholas Appert in France and Peter Durand in England who introduced canning of food and the use of thermal processing around 1800. However, neither Appert nor Durand understood why thermally processed foods did not spoil and remained safe to eat (Hartman, 1997). Then, Louis Pasteur showed that certain bacteria were either associated with food spoilage or caused specific diseases. Based on Pasteur's findings, commercial heat treatment of wine was first used in 1867 to destroy any undesirable microorganisms, and the process was described as 'pasteurization'. This process was also recommended by Escherich (1890) to decontaminate milk.

In the course of time, it became clear that the effects of certain antimicrobial treatments were predictable. Two historical examples were the setting of performance criteria for destroying spores of *Clostridium botulinum* in low-acid, canned foods by Esty and Meyer (1922) and the process criteria for *Coxiëlla burnetii* in milk pasteurization, as determined by Enright *et al*. (1957). Further research resulted in predictions relating to many other processes, such as acidification, drying and the use of curing agents in meat products, on both pathogenic and spoilage organisms. Such knowledge ushered in a new era in safe food production. This era is characterized by the division of hygiene measures into specific practices that are controllable and other general measures, the effects of which are largely unpredictable at present.

4.1 General hygiene practices

One of the first safety systems developed by the food industry was that involving the application of Good Manufacturing Practices (GMP), as a supplement to end-product testing. GMP covers all aspects of production, from starting materials, premises and equipment to the training of staff, and the WHO has established detailed guidelines.
GMP also provide a framework for hygienic food production, which is often referred to as Good Hygienic Practice (GHP). The establishment of GHP is the outcome of long practical experience and major components of the system are:

- **Design of premises and equipment**. This includes the location and layout of the premises to avoid hygiene hazards and facilitate safe food production. Food processing and handling equipment should always be designed with hygiene in mind, including ease of cleaning.

- **Control of the production process.** Control measures are applied throughout the supply chain and cover factors such as raw materials, packaging and process water, as well as the product itself. Key aspects include management and supervision of the process as a whole, as well as appropriate recording systems.

- **Plant maintenance and cleaning.** Both processing equipment and the fabric of the building should be maintained in good order. Suitable programmes need to be developed for plant cleaning and disinfection, and their effectiveness monitored routinely. Systems are also needed for pest control and management of waste.

- **Personal hygiene.** Staff are required to maintain high standards of personal hygiene in relation to wearing of protective clothing, hand washing and general behaviour. Visitors must also be strictly controlled in these respects. The health status of personnel should be monitored regularly and any illness or injuries recorded.

- **Transportation.** Requirements should be established for the use and maintenance of transport vehicles, including their cleaning and disinfection. Vehicle usage should be managed and supervised.

- **Product information and consumer awareness.** It is important that the final product is suitably labelled and that the consumer is provided with all relevant information on product handling and storage, including a 'use-by' date. Labelling should also indicate the batch and origin of the product, so that full traceability is possible.

- **Staff training.** In relation to food hygiene and safety, all personnel should receive appropriate training and be made fully aware of their individual responsibilities. Such training should be repeated and updated as required.

The GHP concept is largely subjective and its benefits tend to be qualitative rather than quantitative. It has no direct relationship to the safety status of the product, but its application is considered to be a necessary preventive measure in producing safe food. Those hygiene measures that have a predictable outcome and are subject to control can be incorporated in the Hazard Analysis Critical Control Point (HACCP) concept. This concept seeks, among other things, to avoid reliance on microbiological testing of the end-product as a means of controlling food safety. Such testing may fail to distinguish between safe and unsafe batches of food and is both time-consuming and relatively costly. However, effective application of the HACCP concept depends upon GHP being used.

4.2 HACCP

The HACCP concept is a systematic approach to the identification, assessment and control of hazards in a particular food operation. It aims to identify problems before they occur and establish measures for their control at stages in production that are critical to ensuring the safety of food. Control is based on scientific knowledge and is proactive, since remedial action is taken in advance of problems occurring. The key aspects fall into four main categories:

1. Quality of the raw materials used.
2. The type of process used, which may include heat treatment, irradiation, high-pressure technology etc.
3. Product composition, including addition of e.g. salt, acids or other preservatives.
4. Storage conditions, involving storage temperature and time, gas packaging etc.

The effects of the last three categories on the hygienic condition of the end product are predictable and relatively easy to determine. Effective management of these categories allows all food-safety requirements to be met. In doing so, it is necessary to define criteria for process performance, product composition and storage conditions. The setting of such criteria is the task of the risk manager, and use of the HACCP concept is the managerial tool which ensures that the criteria will be met in practice.

In a review of the historical background, Barendsz (1995) and Untermann *et al*. (1996) described the development of the HACCP approach, which began in the 1960s. The concept arose from a collaboration between the Pillsbury Company, the US Army Natick Research and Development Laboratories and the US National Aeronautics and Space Administration. The original purpose was to establish a system of safe food production for use in human space travel. At that time, the limitations of end-product testing were already appreciated and therefore more attention was given to controlling the processes involved in food production and handling. When first introduced at a congress on food protection (Department of Health, Education and Welfare, 1972), the concept involved three principles: (*i*) hazard identification and characterization; (*ii*) identification of critical control points (CCPs) and (*iii*) monitoring of the CCPs.

Many large food companies started to apply HACCP principles on a voluntary basis and, in 1985, the US National Academy of Science recommended that the system should be used. Further support came from the ICMSF (1988), which extended the concept to six principles. They added specification of criteria, corrective action and verification. In 1989, the US National Advisory Committee on Microbiological Criteria for Foods added a further principle: the establishment of documentation concerning all procedures and records appropriate to the principles and their application. Use of the HACCP system was given an international dimension by the Codex Alimentarius Commission (CAC), which published details of the principles involved and their practical application (CAC, Committee on Food Hygiene (1991). In 1997, the CAC laid down the 'final' set of principles and clarified the precise meaning of the different terms (CAC, Committee on Food Hygiene,1997):

- General principles of food hygiene (Alinorm 97/13. Appendix II)
- HACCP system and guidelines for its application (Alinorm 97/13A, Appendix II)
- Principles for the establishment and application of microbiological criteria for foods (Alinorm 97/13A, Appendix III)

The full HACCP system, as described in Alinorm 97/13, is shown in Table 4. The document also gives guidelines for practical application of the HACCP system. By 1973, the FDA had made the use of HACCP principles mandatory for the production of low-acid canned foods (FDA, 1973) and, in 1993, the system became a legal requirement for all food products in the European Union (Directive 93/43).

Table 4. The seven principles of the HACCP system, (CAC, Committee on Food Hygiene, 1997)

Principle	**Activity**
1. Conduct a hazard analysis	List all potential hazards associated with each step, conduct a hazard analysis, and consider any measures to control identified hazards
2. Determine the Critical Control Points (CCPs)	Determine Critical Control Points (CCPs)
3. Establish critical limit(s)	Establish critical limits for each CCP
4. Monitoring	Establish a system of monitoring for each CCP
5. Establish corrective actions	Establish the corrective action to be taken when monitoring indicates that a particular CCP is not under control
6. Establish verification procedures	Establish procedures for verification to confirm that the HACCP system is working effectively
7. Establish documentation and record keeping	Establish documentation concerning all procedures and records appropriate to these principles and their application

It was Notermans *et al*. (1995) who first made a plea for the principles of quantitative risk assessment to be used in setting critical limits at the CCPs (process performance, product and storage criteria). It was their opinion that only when the critical limits are defined in quantitative terms can the level of control at CCPs be expressed realistically. At the International Association of Food Protection (IAFP) meeting in 2001, Buchanan (2001) also favoured the use of these principles and suggested that food safety objectives should encompass end-product criteria, which are related to the criteria used in processing. New developments in the HACCP system concern the verification process. These involve verifying the criteria and/or food safety objectives set and use of a probabilistic approach to assessing risk reduction, thus providing information on the degree of control obtained.

5. Future aspects

Improving information on foodborne diseases

As indicated earlier, present information is far from complete and, in 50 – 60% of cases of acute enteritis, a causative agent is not detected (de Wit *et al*., 2001) In order to define better the burden of such diseases, novel techniques should be developed to test for unsuspected pathogens. For this purpose, a multi-factorial approach is advocated and should include a study of the etiology of unsuspected foodborne agents and their epidemiology, the risk factors involved, identification of virulence genes, demographic factors, clinical characteristics, etc. Knowledge of the relevant risk factors and their contribution to the problem is particularly important for the development of appropriate intervention strategies, and this aspect also needs to have an international dimension.

Assessment of process performance

Verification of HACCP involves the establishment of procedures to confirm that the HACCP system is working effectively. However, this stage is still in its infancy. Currently, verification is limited to demonstrating that controls are operating as intended and no proper data are collected. Instead, it is possible to determine the effects of control measures by carrying out a risk assessment. The principles of such an approach are in given in Figure 4. Values to the left of the food safety objective (FSO[5]) are considered to be acceptable and values to the right are unacceptable.

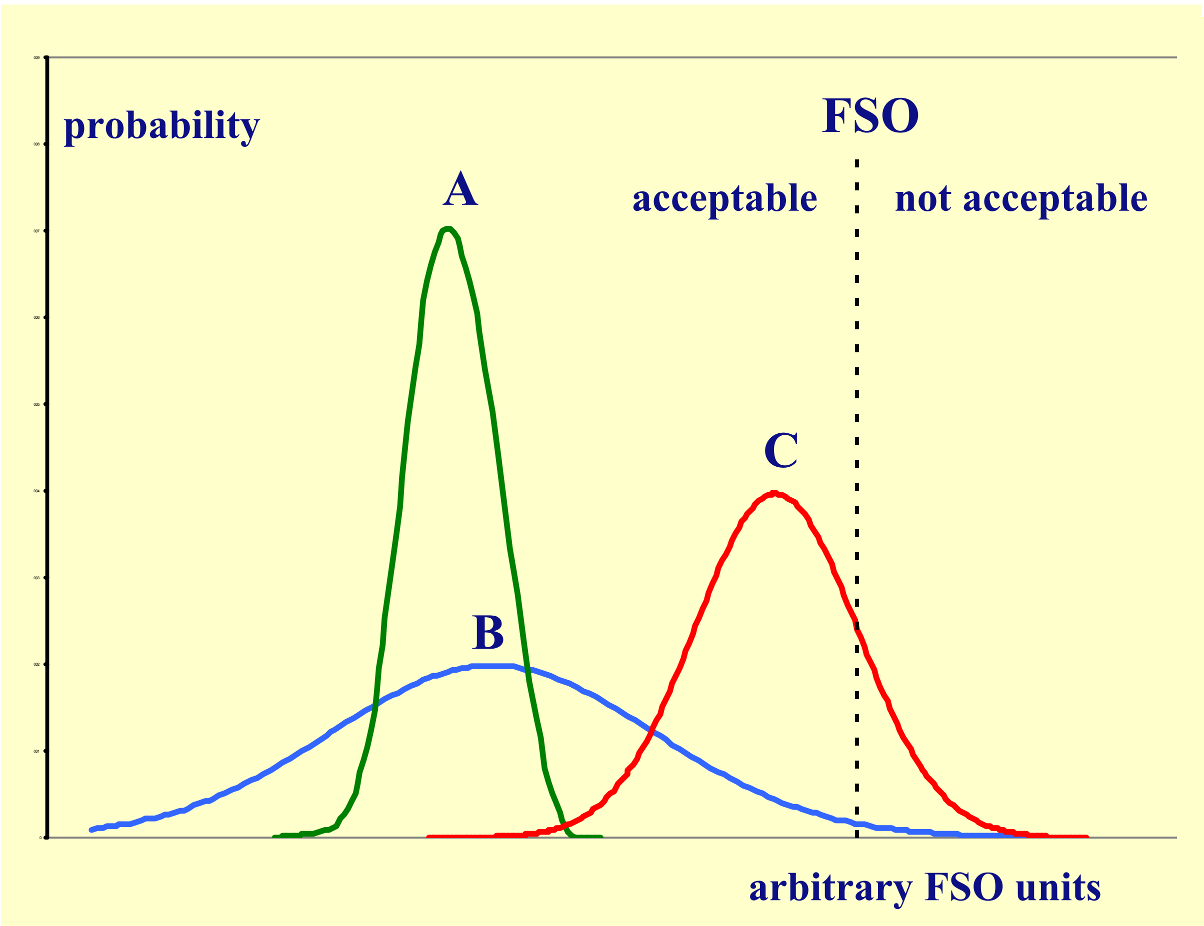
In stead of 'single-point estimates' that result from the performance of a particular process verification data are presented in a probabilistic way. A single point estimate does not provide any information on the probability of exceeding the FSO. The curves A, B and C are so-called 'probability distribution curves' that are based on three levels of process performance. It can now be seen that, in some cases, the FSO is exceeded. The process performance values expressed in curves B and C are unacceptable because a substantial

[5] An FSO may be a criterion or a target. When the criterion or target is met, an appropriate level of protection will be obtained at the time of consumption.

proportion of the product is beyond the FSO. Scenario B shows that the average is well within the target, but because of the large variation in part of the process, the FSO will be exceeded. Curve A is an example of an acceptable curve: the product meets the required FSO and the relatively small standard deviation of the curve indicates that the process is under control while this is not the case for curve B.

Another drawback of the present verification process is that food production is subject to unobserved changes. However, HACCP is based only on existing knowledge and therefore, it is recommended that consumer complaints are also considered in the process of verification.

Figure 4. HACCP-verification based on a probabilistic approach. The Foof Safety Objective (FSO) is set as a criterion that separates 'acceptable' and 'unacceptable' products.



Further development of hygiene control

From long experience, it has become clear that certain hygiene controls are very effective in reducing foodborne disease, and the effects of certain measures, like heating the product, have a predictable outcome. Thus, they have been incorporated eventually in the HACCP system.

However, there are still a large number of important measures that contribute to food safety but their effects are neither quantifiable nor properly understood. Examples include the effects of cleaning and disinfection, steps to prevent cross-contamination in food processing and hand washing and other aspects of personal hygiene. On the other hand, micro-organisms may sometimes become established unexpectedly in processing equipment and food-production facilities, thus increasing contamination of the product. In this case, the usual process parameters are controlled, but other, unknown factors are having an effect. Clearly, more information is needed on the factors that affect product safety and those that have little or no effect.

Changing pattern of microbial hazards

Society is increasingly confronted with microbial problems that are not susceptible to control by traditional measures. This may involve new hazards, including viral contamination of food and the occurrence of bacteria resistant to antibiotics and disinfectants. Many of these problems arise from the introduction of new technologies, new methods of producing raw food-materials and socio-economic changes in society, including overcrowding, increased travelling and global food-production and trade. Foodborne disease continues at a high level, despite increasing attention to food hygiene, and with no alternative strategy available. This situation is an important challenge to modern society and requires a degree of foresight that goes well beyond present concepts of hygiene control. There is a similar problem with the availability of potable water. In developing countries, more than one billion people have no access to a basic water supply and 2.4 billion have no proper sanitation. The developed world has problems too in this respect, with climate change leading to water shortages in many areas. Can all these problems be overcome by technology?

Building hygiene into the system

A new research area that aims to improve general hygiene involves nano-technology. This technology is a promising means of developing processes that are inherently hygienic. For example, coatings based on nano-technology can make the environment more hygienic by preventing bacterial attachment to surfaces (ceilings, floors and walls of processing facilities, conveyor belts etc.) and/or bacterial proliferation on these surfaces. Coatings have already been developed and successfully applied to prevent fouling of , for example, windows, water-closets and tiles.

Another example concerns photocatalytic oxidation technology (www.cuhk.edu.hk/ipro/pressrelease/021007e.htm). The first application was developed by Professor Jimmy Yu Chai-mei of the Department of Chemistry, Hong Kong University, and involves the deposition of a uniform, nanometer-thick titanium dioxide coating on a solid substrate. The coating exhibits strong photocatalytic activity when exposed to visible light that results in the emission of local ultraviolet irradiation. As a result, it can oxidize most organic and inorganic pollutants, and kill bacteria, such as *Escherichia coli* and *Vibrio cholerae,* within seconds. This leads to a very attractive and safe technology for water treatment. The new treatment system has proved to be more effective than conventional UV irradiation, and it is said to be suitable for producing drinking water and treating industrial or agricultural waste-water and sea water. A similar air-purification system can be installed in hospitals, offices, schools, restaurants and homes. Thus, modern technology can do much to protect society from pathogenic agents, but this takes no account of one important factor: natural disease-resistance. Without such resistance, human beings will continue to be highly vulnerable and require ever-more protection from pathogens.

6. References

]ANON. (1993) 'Council directive 93/94.EEC of 14 June 1993 on the hygiene of foodstuffs', *Off. J. Eur. Comm*, **L 157**, 1-11

BAKER A M, *Awaking our self healing body – A solution to the health care crisis*. ISBN 1-883989-25-6.

BARENDSZ A W (1995), 'Kwaliteitsmanagement: HACCP de ontbrekende schakel' in '*HACCP, a practical manual'*, Keesing Noordervliet, ISBN 90 72072 40 5.

BRÉNOT O, DALEBOUT A and ODEN C (1995), personal communication.

BROWN K L (1996), *Guidelines on air quality standards for the food industry,* Guideline No. 12, Campden & Chorleywood Food Research Association.

BUCHANAN R L *et al* (2001), 'Moving byond HACCP – Risk management and food safety objectives' , in Symposium abstracts IAFP 88th Annual Meeting, Minneapolis 2001.

CAC, Committee on Food Hygiene (1991). *Draft principles and applications of the Hazard Analysis Critical Control Point (HACCP) system*. Alinorm 93/13, Appendix VI. Food and Agriculture Organisation, World health Organization, Rome.

CAC, Committee on Food Hygiene (1997), *Hazard Analysis Critical Control Point (HACCP) and guidelines for its application.* Alinorm 97/13. Food and Agriculture Organization, World health Organization, Rome.

DAWSON D (1998), *Water quality for the food industry: an introductory manual,* Campden & Chorleywood Food Research Association.

DAWSON D (2000), *Water quality for the food industry: management and microbiological issues,* Campden & Chorleywood Food Research Association.

Department of Health, Education and Welfare, Proceedings '*National Conference on Food Protection*', Washington, D C US Governmental Printing Office, 1972.

DEWBERRY E B (1959), 'Food Poisoning', *Food-borne infection and Intoxication* (London, 1959, pp 6-7.)

DE WIT M A S KOOPMANS M P G KORTBEEK L M VAN LEEUWEN N J BARTELDS A I M and VAN DUYNHOVEN Y T H P (2001), 'Gastroenteritis in sentinel general practices, The Netherlands', *Emerging Infectious Diseases*, **7**, *No. 1, January–February 2001.*

DRIESSEN F M and BOUMAN S (1979), 'Growth of thermoresistant streptococci in cheese milk pasteurizers – Experiment with a model pasteurizer', *Voedingsmiddelentechnologie,* **12**, 34-37.

DURHAM H E (1898), 'The present knowledge of outbreaks of meat poisoning', *British Medical Journal,* **I**, 1797-1801.

ENRIGHT J B, SADLER W W and THOMAS R C, 'Thermal inactivation of *Coxiella burnetii* and its relation to pasteurisation of milk', Public Health Service Publication No. 517. United States Government Printing Office, Washington, D C, 1957.

ENRIGHT J B, SADLER W W and THOMAS R C (1956) 'Observations on the thermal inactivation of the organism of Q fever in milk', *J Milk Food Technol,* **10**, 313-318.

ESCHERICH T (1890). 'Ueber Milchsterilisirung zum Zwecke der Säuglingsernährung mit Demonstration eines neuen Apparates'. *Berliner klinische Wochenschrift*, **27** 1029-1033.

ESTY J R and MEYER K F (1922) 'The heat resistance of spores of *Bacillus botulinus* and allied anaerobes', *XI J Inf Dis,* **31** 650-663.

FARBER J M and PETERKIN P I (2000), 'Listeria monocytogenes'. In Lund B M, Baird-Parker T C and Gould G W, *The microbiological safety and quality of food* – Vol. I. Aspen Publishers Inc, Gaithersburg, MD.

FDA (1973), '*Acidified foods and low acid foods in hermetically sealed containers*' in Code of US Federal Regulations, Title 21, 1 Parts 113 and 114 (renumbered since 1973) FDA Washington DC.

FIRSTENBERG-EDEN R, NOTERMANS S, THIEL F, HENSTRA S and KAMPELMACHER E H (1979), 'Scanning electron microscopic investigations into attachments of bacteria to teats of cows', *J. Food Prot.* **42**, 305-309.

FITZGERALD M, SCALLAN E, COLLINS C, CROWLEY D, DALY L, DEVINE M, IGOE D, QUIGLEY T and SMYTH B (2004), 'Results of the first population based telephone survey of acute gastroenteritis in Northern Ireland and the Republic of Ireland'. *Eurosurveillance Weekly*, **22** April 2004. Volume 8, Issue 17.

GÄRTNER E (1888), 'Über die Fleischuergiftung in Frankenhausen a. Kyffh. und der Erreger derselben', *Korrespondenzblatt des Allgemeinen arztilchen Vereins von Thuringen*, **1**7, 573-600.

GREENWOOD M (1935), *Epidemics and Crowd diseases, London*, p 157.

GUZEWICH J and ROSS P (1999), *Evaluation of risks related to microbiological contamination of ready-to-eat food by food preparation workers and the effectiveness of interventions to minimise those risks,* Food and Drug Administration White Paper.

HARDY A (1999), 'Food, Hygiene, and the Laboratory. A short history of food poisoning in Britain, circa 1850 – 1950', *Social History of Medicine*, **12**, 293-311.

HARTMAN P A (1997), 'The evolution of food microbiology', in Doyle M P, Beuchat L R and Montville T J, *Food microbiology: Fundamentals and frontiers,* Washington, ASM Press, 3-13.

HOLAH J T (1997), Microbiological control of food industry process waters: Guidelines on the use of chlorine dioxide and bromine as alternatives to chlorine. Guideline No.15, Campden & Chorleywood Food Research Association, Chipping Campden, UK.

HOLLIER J (1623), *Opera omnia practica*, Genevae.

HUCK P (1994), 'Infant mortality in nine industrial parishes in Northern England, 1813-1836', *Population Studies,* **48**, 513-526.

ICMSF, (The International Commission on Microbiological Specifications of Foods) (1988), *Micro-organisms in foods. Application of the hazard analysis critical control point (HACCP) system to ensure microbiological safety and quality*. Oxford, Blackwell Scientific Publications

IFT (1994), 'Microbial attachment and biofilm formation: a new problem for the food industry'?, *Food Technology,* **48**, 107-114.

KOCH R (1876), 'Die Aetiologie der MilzbrandKrankheit, begrundet auf die Entwicklungsgeschichte des Bacillus Anthracis' (The etiology of anthrax, based on the life history of *Bacillus anthracis*), *Beitrage zur Biologie der Phlanzen*, **2**, 277-310.

KOCH R (1883), At the XI German Congress of Physicians in Berlin, Koch introduced a report entitled "New methods for the detection of microorganisms in soil, air and water."

KRAMER J M and GILBERT R J (1989), *Bacillus cereus* and other Bacillus species. In Doyle M P, *Foodborne Bacterial Pathogens*, Marcel Dekker, Inc., New York, NY.

KRYSINSKI E P, BROWN L J and MARCHISELLO T J (1992), 'Effect of cleaners and sanitizers on *Listeria monocytogenes* attached to product contact surfaces', *J Food Protect,* **55**, 246-251.

LANGEVELD L P M, MONTFORT-QUASIG R M G E VAN, WEERKAMP A H *et al.* (1995), 'Adherence, growth and release of bacteria in a tube heat exchanger for milk', *Netherl Milk & Dairy J,* **49**, 207-220.

LELIEVELD H L M (2003), Sources of contamination pp 61 – 75. In Lelieveld H L M, *Hygiene in food processing pp 61-75,* Woodhead Publishing Ltd. Cambridge.

LELIEVELD H L M (2000), 'Hygienic design of factories and equipment', in Lund B M *et al.* (eds), *The Microbiology of Food,* Aspen Publishers Inc, Gaithersburg.

MARRIOT N (1999) *Principles of food sanitation: fourth edition*, Aspen Publishers, Inc, Gaithersburg.

McCLANE B C (1997), *Clostridium perfringens.* In Doyle M P, Beuchat L R and Montville T J., pp 305-326, *Food microbiology: fundamentals and frontiers*. ASM Press, Washington, D.C.

NIVEN J, (1909-1910), 'Summer diarrhoea and enteric fever', *Proceedings of the Royal Society of Medicine*, 3.2, 133.

NOTERMANS S, DORMANS J A M A and MEAD G C (1991), 'Contribution of surface attachment to the establishment of microorganisms in food processing plants - a review', *Biofouling* **5**, 21-36.

NOTERMANS S (1979), 'Attachment of bacteria to meat surfaces'. *Antonie van Leeuwenhoek* **45**, 324-325

NOTERMANS S, GALLHOFF G, ZWIETERING M H and MEAD G C (1995), 'Identification of critical control points in the HACCP system with a quantitative effect on the safety of food products', *Food Microbiology,* **12** 93-98.

ODDY D J and MILLAR S (1985), 'Diet and health in modern Brittain' (London, 1985), pp 148-147.

OSTERTAG R (1902), '*Handbook of meat inspection'*, Washington DC.

PECKHAM K F (1923-24), 'An outbreak of pork pie poisoning at Derby', *Journal of Hygiene*, **22**, 69-76

PORTER C (1924-25), 'Cleanlinnes in food handling: Impression of American methods', *Journal of the Sanitary Institute*, **XLV**, 289.

ROCOURT J and COSSART P (1997), '*Listeria monocytogenes'*. In Doyle M P, Beuchat L R and Montville T *J. Food Microbiology, Fundamentals and Frontiers*. ASM Press Washington, DC.

SAVAGE W G (1909), 'Further report on the presence of Gaertner group of organisms in animal intestines', Medical Officer's Annual Report, Local Government Board, pp XXVIII, p 479.

SAVAGE W H and BRUCE WHITE P (1925), '*Food Poisoning*', Medical Research Council. Special Report Series, no 92.

SCHNEIDER W R and DIETSCH R N (1974), 'Velocity measurements of motile bacteria by use of a videotape recording technique', *Appl. Microbiol,* **27,** 283-284.

SEMMELWEIS I P (1861), 'Die Ätiologie, der Begriff und die Prophylaxis des Kindbettfiebers', Pest-Wien-Leipzig, 1861. Translated into English by Murphy F R (1941), 'The Etiology, the Concept and Prophylaxis of Childbed Fever', *Medical Classics* **5,** 350-773.

STEENAARD P MAAS H VAN DEN BOGAARD J PINCHIN R and DE BOER M (2002),'Production and use of food-grade lubricants, EHEDG Doc. 23, CCFRA Technology, Campden.

TANNAHILL R (1979), *Food in history*, New York, Stein and Day Publishers.

TAYLOR J H and HOLAH J T (2000), *Hand hygiene in the food industry: a review,* Review 18, Campden & Chorleywood Food Research Association.

UNTERMANN F JAKOB P and STEPHAN R (1996), '35 Jahre HACCP-System. Von NASA-Komzept bis zu den Definitionen des Codex Alimentarius'*, Fleischwirtschaft* **76,** 589-594.

VAN DER WENDE E and CHARACKLIS W G (1990), 'Biofilms in potable water distribution systems', in McFeters G A '*Drinking water microbiology: Progress and recent developments, Brock/Springer Series in Contemporary Bioscience*' pp. 249-268. Springer-Verlag, New York.

VAN DER WENDE E CHARACKLIS W G and SMITH D B (1989), 'Biofilms and bacterial drinking water quality', *Water Res*, **23,** 1313-1322.

VAN ERMENGEM E (1897), 'Ueber einem neuen anaeroben Bacillus und seine Beziehungen zum Botulismus', *Z Hyg Infectionskrankh,* **26**, 1-56. English translation (1979), *Rev Infect Dis* **1** 701-719.

WHITEBREAD F G (1926), 'Faecal organisms carriers', *Journal of Safe Medicine*, **34,** 734.

WOODS R I WOODWARD J and WATTERSON P (1988), 'The cause of rapid infant mortality decline in England and Wales, 1861-1921, part 1', *Population Studies* **42,** 343-366.

This process is experimental and the keywords may be updated as the learning algorithm improves. This is a preview of subscription content, log in to check access.Â In proceedings of â€˜Hygiene for the 90â€™sâ€™ November 7â€“8, Campden Food and Drink Research Association, Chipping Campden, Glos., U.K.Google Scholar. Patterson, J.T. (1971) Microbiological assessment of surfaces.Journal of Food Technology 6, 63â€“72CrossRefGoogle Scholar. Pettipher, G.L., Mansell, R. and Mckinnon, C.M. (1980) Rapid membrane filtration epifluorescent microscopy technique for direct enumeration of bacteria in raw milk.