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New Challenges in Food Process Engineering

With changing attitudes to food becoming ever clearer, responding to those changes in market requirements now and in the future will become an increasingly important part of the role of the process engineer in the food industry. Process engineering is not an end in itself, it is an activity to support the requirements of the market and often an exercise in adapting what we *have* to provide what we *need*.

The correct interpretation of scientific and general research data to provide the correct equipment and process conditions to produce the product the market wants rather than merely what the process equipment will most easily produce is central to industrial development.

Added to these imperatives regarding the product, it is vitally important to design for optimum use of all resources, including capital, labour, raw materials, energy, effluent, etc. if we are to achieve minimum cost manufacturing operations.

It is clear that in addition to low cost and long shelf life, consumers, at least in Europe, are becoming more and more interested (perhaps preoccupied) with foods embodying traditional values and with lower levels of preservatives and processing and what they perceive as traditional flavours and textures.

Whilst events which reduce disposable income certainly affect attitudes and push people back towards cost rather than value, there is still an observable and genuine trend towards what are perceived as "healthier" foods both for the individual and the environment. Some of this is tied to aspirations for "Organic" and "Welfare" but this does not need to (and indeed on a large scale cannot) conflict with the need to process raw materials efficiently into foodstuffs which the consumer wants and can afford.

Reproducing traditional flavours and textures can be a real challenge for modern high efficiency plants designed initially for primary purpose, high throughput and maximum efficiency. Many of the "traditional" components of flavour and texture derive, more or less by accident, from the historical limitations of the original process machinery and techniques and simply removing these limitations often results in the loss of the desirable flavour and textural components.

Key elements of "low cost" in the future will be reduced energy, raw material and other resource inputs and reduced environmental impact. This will be expressed in terms of maximum utilisation of capital and ingredients whilst minimising effluent, waste and, in the near future, water consumption both in agriculture and processing.

Whilst there will continue to be growth in the "local" sector and for the foods often associated with this, it is simply not possible to feed large urban populations with fresh, locally produced, unprocessed foods. In addition the dominance of the major multiple food retailers in the market place will not be broken, they simply provide too good value for money, excellent control of quality, supply chain capability and shopping convenience to be significantly threatened by local and small retailers in any but niche markets and/or people with high disposable income. It is very fashionable to berate Tesco etc. and call for the return to the high street, but how many people are really willing to do so for high volume shopping, accepting parking problems, higher prices, limited choice, carrying heavy bags long distances, etc. compared with the convenience of a major out of town store.

Large scale food process engineering is certainly here to stay, but will have to adapt its approaches to the new requirements of the marketplace and of consumers. This review considers the importance of traditional flavours and textures in retaining the identity of food products and later some of the key cost drivers which need new approaches to ensure that foods are not only acceptable but profitable to produce.

Traditional Foods and Flavours

Current market movements have strong elements of history and nostalgia but most traditional food flavours and textures are a complete accident and frequently the byproduct of an old food preservation technique. For example, people did not set out to create cheese, they merely wanted a method for preserving the nutritional value of surplus milk. Similarly excesses of fish and meat were dried and smoked to preserve them for leaner times, fruit juices were fermented to wine to avoid spoilage and early canning techniques were developed to help feed expeditionary armies and navies.

Preserving food was, until comparatively recently, a significant and important "cottage" industry in most countries and continues to be so in many. Historically, few if any food sources were constant in supply and many are highly perishable. Thus preserving food was initially a key to survival through leaner times and then facilitated the growth of urban populations, industrialisation and the ability to put large armies into the field. Techniques for preserving and facilitating the transport of foods which have resulted in flavour and texture changes which have in turn become valued in their own right include:-

- Salting (Fish, Meat, some Vegetables)
- Pickling (Vegetables, Meat, Fish)
- Preserving with Sugars (mainly Fruit, but also Milk)
- Smoking (Fish, Meat) (likely to have originally been a byproduct or enhancement of drying)
- Canning (All foods)
- Drying
    - Evaporation (Milk)
    - Air Drying (Fish, Meat, Milk, also Cocoa, Coffee, Tea, Spices)
    - Vacuum Drying (Milk and Cocoa Products)
    - Removal of Water by other means to stabilise a foodstuff (eg producing Butter and Cheese from Milk)
- Fermenting (Vegetables, Fruit Juices, Milk (yoghurt))

In virtually all of these cases the fundamental aim historically was to preserve food, often by changing the composition of the water phase such that it would not support the growth of undesirable spoilage bacteria, yeasts and moulds. (Yoghurt is probably an exception where a driver was the elimination of lactose to which a high proportion of non Caucasians are intolerant) The other changes were incidental and of little interest at the time to populations seeking to preserve foods for times of famine or to make it possible to transport food to urban populations or military campaigns. Whilst the success of the process literally meant the difference between life and death in early times, it later facilitated the growth of urban populations and industrialisation fed by the farming activities of relatively remote rural populations.

However, modern process technology can now carry out the fundamentals of many preservation processes quickly and much more efficiently than our predecessors were able, and in many cases the absolute need for these historical techniques has been displaced by more modern techniques such as freezing, cold chain, vacuum packing, aseptic packing etc. as well as the developments in agriculture which give us such as a more or less constant supply of liquid milk, meat and fish and global continuous cropping of otherwise locally seasonal fruit and vegetables.

There are many instances where the flavour and texture changes which resulted from traditional processing techniques have become a key element in the identity of a food. Whilst food preservation by most traditional techniques is no longer necessary to supply nutrition, most of the products of those preservation techniques have become valuable (even fashionable) foods in their own right and so have to continue to be produced. Trying to do so in an efficient manner using modern process technology is the point at which process science and design becomes both challenging and interesting.

Food materials are by their very nature complex and contain a massive variety of components which can be altered by the conditions during process operations to result in different flavours and textures from the original. A few outstanding examples include:-

- The massive variety of different cheeses which can be produced by slightly altering processing and storage conditions.
- The differing flavours which can be induced in meat and fish during drying processes tuned to different local environments
- The range of flavours which the Maillard reaction(s) between reducing sugars and milk proteins can produce under even slightly different process conditions

If we are to produce foods with traditional flavours and textures whilst using modern processing techniques it is essential to look beyond the fundamental process and to consider the other changes which are taking place as a result of the process conditions in the original methods. It is then often possible to modify the process to reproduce the required product, although in many cases the chemistry we are trying to reproduce is extremely complex and can only be monitored by tasting, so there is a certain amount of guess work involved. It is also extremely difficult in most cases to identify the precise conditions under which reactions are taking place, because although the "macro" conditions may be measurable the "micro" conditions at the actual reaction sites may be affected by differential solubilities, release of heat of crystallisation, rates of molecular diffusion, byproduct volatility and a whole host of other issues. Many natural flavour development reactions result in massively complex flavour chemistry which will defeat even the best modern analytical techniques and it is important to deploy effective but credible taste testing systems for any degree of certainty.

Typical process conditions which need to be considered on both a macro and micro scale include:-

- Time/Temperature/Moisture profiles
- Process temperatures affected by evaporation pressure

- Diffusion of major and minor components in and out of foodstuffs during processing
- Addition of traditional materials which may appear to have little purpose but which may alter flavour chemistry significantly
- Effect of physical processing on flavour and texture development
- Mix effects where a traditional process may in reality have a mix of process conditions and new processes a single set.

In many cases the flavours and textures arising from early process techniques became the signature of a particular product or company and have dictated the path of technical change in those businesses ever since.

<u>Time/Temperature/Moisture Profiles in Drying</u>

Many early drying techniques are “fixed bed” where a bed of material is heated and moisture is carried away either by an air stream or vacuum system. This type of process results in an extremely complex (and very difficult to measure) set of time/temperature/moisture profiles and a high degree of heterogeneity in the mass of material. As a result a very wide range of levels and types of flavour development take place during drying, none of which are deliberate but all of which contribute to the characteristics of the final product.

Modern continuous and batch drying processes focussed mainly on efficient water removal produce extremely homogeneous products which can make flavour matching very difficult In addition the physical conditions of the original process can affect issues such as the degree and rate of crystallisation of sugars which may also affect downstream processing and final product characteristics.

Even the fine structure of a material can be affected when different drying processes are applied, such as the effect of localised heat of crystallisation which may not be removed as effectively when drying conditions move from evaporative drying and consequent cooling caused by vacuum to convective drying and cooling using air.

Drying meat and fish in different environments often results in radically different products because of the drying process being controlled by different elements. Where fish is dried in cold, dry conditions the process is slow as it it controlled by the availability of heat energy to evaporate water, even where the partial pressure of water vapour in the air is low. This results in a bland but very dry product such as the dried cod produced in the far north. Although the process is very slow, the low temperature and slow diffusion of moisture from the centre to the exterior of the product prevents microbiological activity.

However, much fish is also dried in the tropical regions where the temperature and humidity are much higher. In this case there is plenty of energy and drying is controlled by the humidity of the air and its ability to absorb moisture from the product. Drying is much faster but there is some microbiological activity due to the higher temperatures resulting in very strongly flavoured dried fish products.

Almost every drying process and the food associated with it has a unique set of conditions which dictate the characteristics of the final product and which are difficult to achieve in a different, perhaps more efficient drying process.

<u>Process Temperatures in Evaporation</u>

Evaporation temperatures in processes such as sugar cooking for high boiled confectionery products can vary significantly as processes and materials are changed. Newer plants often use lower pressures to evaporate at lower temperatures but in addition the use of alternative ingredients such as Palatinat requires higher temperatures to achieve the required lower moisture levels. As well as affecting the ways in which flavours added at the end of the cooking process react to higher or lower temperatures, the viscosity of the mass can require modifications to the handling and forming systems and can affect clarity, colour, etc.

Similarly the move from roller drying milk to spray drying, where the evaporation temperature is significantly lower, has a significant effect both on the flavours developed in the milk during processing and the way in which fat is trapped in the finished product. Together these differences significantly affect chocolate manufacture, for example, and consequently many higher quality products continue to use roller dried milk powders.

Diffusion

Diffusion is a process not often considered in food processing but it can have an absolutely fundamental effect on the characteristics of products by affecting the transport into and out of a mass of material of important components. It also affects the degree and way in which components in foods are able to react together to create flavour entities and other effects.

A similar effect is zonal crystallisation, where components can be removed from a reactive mass by crystallisation resulting in changes in the concentration of the remaining syrup phase and the release of heat in a potentially critical location.

The effect of diffusion can be illustrated by reference to the drying of raw cocoa. Where wet fermented cocoa is dried in the sun the shell of the bean remains hydrated and moisture and acetic acid from the fermentation process pass through it by liquid diffusion. The hydration of the shell also delays the counter diffusion of air until late in the drying process. Where artificial drying is used the shell dehydrates rapidly and whilst moisture vapour can still diffuse out the much less volatile acetic acid cannot and remains trapped in the product. Furthermore air is able to enter the bean at an early stage of drying through the dry shell.

The result of this is an acidic product (which is less desirable) and oxidation of the anthrocyanins present in the cocoa which are important to later colour development in some cocoas.

By altering the drying process and conditions it was possible to continue to use hot air but to avoid shell dehydration and to produce the desired cocoa quality.

Added Materials

In traditional manufacturing processes there are often cases of ingredients being added for no very clear reason and frequently these additions are called into question when new processes are introduced. Whilst in some cases these additions are historical and play no part in the product (they may, for example, have been added as a processing aid for the original process) there are cases where added materials have an important role in the finished product. This can be particularly the case where there is a recycle stream in the process due to scrap or other reasons in the original process. A new process with greater efficiency which eliminates the recycle stream can easily loose important contributions from material which has passed through the process more than once.

The Mix Issue

Many traditional foods were originally processed in small batches which were often then blended together. Frequently there were variations in the process and raw materials which meant that individual batches (or even different parts of individual batches) tasted quite different, but when blended together a fairly consistent product was obtained. It can be extremely difficult to match a blended product with a single identity produced from a modern highly consistent process because it will lack the small quantities of “extremes” arising from the small batches.

In one experiment 100 different batches of a (raw) material were converted into individual finished product samples. None of these was considered to be acceptable in flavour terms, yet when the 100 samples were properly blended and sampled the resulting product was considered to be entirely acceptable. There are many other similar cases in the food process industry.

This is an extremely difficult problem to overcome because very small amounts of the extreme materials may have a large effect on the flavour of the finished product. If the modernised process is still a batch process it may be possible to cycle conditions during the process cycle to produce the required flavour components, but with continuous processes it may require the identification of and addition of specific flavour compounds to combat this problem.

Low Cost Processing - The Cost Drivers

Whilst there is justified emphasis on “cost” as a central issue in food processing, it is perhaps more useful to consider the phrase “resource utilisation” because in design. construction and operation it is resource utilisation which the process engineer is in reality most able to control and optimise. Whilst this is often seen as equivalent to cost, in reality it provides the opportunity for consideration of a longer timescale, different locations and the modelling of the effects of changes in resource availability and cost.

In confectionery manufacture the following broad cost allocation is typical for western European factories:-

- Ingredients 57%
- Waste 2.6%
- Labour 24%
- Overheads 16%

Other sections of the food industry will differ in emphasis but as the above is taken across all forms of confectionery manufacture on a large scale it is reasonably representative. However for factories located in Eastern Europe, the Far East or Russia there is a change in that the labour component reduces by anything up to 80% with a coincident increase in the contribution of overheads and other costs. This illustrates the importance of looking beyond the immediate cost and location effects when considering process design.

Whilst efficient processes can sometimes use lower cost ingredients, a much more important attribute is to make more efficient use of existing raw materials by reducing waste and scrap levels. Similarly, whilst efficient processes with lower scrap and recycle rates can reduce labour costs a much potential bigger contribution comes from reducing overheads by obvious (energy, effluent, etc) and less obvious (process integration, efficient use of capital, maximising utilisation etc) methods. In addition the initial process design of a production unit needs to consider carefully the product cycle and run length to optimise manufacturing operations

The Targets

Scrap and Waste

Food companies fail to convert a surprising amount of their raw materials into good finished product through losses in the manufacturing process. In addition poor weight control can result in substantial losses through "give away" making accurate design and control of piece weight and bag weight essential. Another potential loss is the discarding of unwanted components of raw materials or the failure to maximise the value inherent in potentially valuable materials present in but not important to the final product under direct consideration. A positive example of this is the extraction of lecithin from vegetable oils during processing – a high value material obtained at zero raw material cost

Whilst 2.6% of total cost (above) for waste may seem a relatively small target, if this is thought of as wasting about 5% of purchased ingredients (or more brutally simply throwing away one bag in 20, one tanker load in 20, or running to waste one shift per week) then it is placed into sharper relief. When the cost of disposing of that wasted material and the labour and energy cost involved in processing it is added, the potential for saving becomes clear. Added to that is the lost production potential – greater plant capacity is needed to compensate for the waste, and if a plant is output limited in supplying the market or has to run additional shifts then the losses multiply.

Often a substantial proportion of waste and ingredient loss is due to washing and cleaning cycles. Whilst food plants do clearly need to be cleaned periodically for hygiene reasons there is also a substantial amount of cleaning in many plants to restore performance, for example due to fouled heat transfer surfaces, build up in pipework, product change over and end of shift or week's operations. In addition it may well be possible to adapt plant and process design to maintain an aseptic environment or to manipulate process conditions to provide an inherent sterilisation cycle.

Another significant reason can be the failure to monitor quality and specification issues throughout the production process and either stop or correct the process at that point. Failure to do so can result in "consequent losses" as value is added to product which is never going to be satisfactory.

Useful approaches to minimise waste, scrap and give away losses include:-

- Careful monitoring of ingredient usage compared to that required for good product output and setting "stretch" targets with incentives
- Optimising product runs to minimise change over losses
- Ensuring that out of specification materials are recognised and removed at the earliest possible point in the process with minimum added value.
- Understand the reasons for and minimise heat transfer surface fouling
- Recover out of specification, scrap and waste materials via an integrated process which has provision for a waste stream to be added back. (Note: the finances of waste recycle are complex and this needs careful study to avoid rework usage becoming an additional cost on the manufacturing unit)
- Design processes such that waste recovery streams are stable and do not in themselves generate wastes
- Hygiene monitoring to optimise cleaning cycles rather than running to a fixed cycle
- Optimising unit weights to make achieving average product weight as easy as possible (a particular issue where packs contain several or many units)
- Maximise plant runs between shut down – it may for example we worth considering continuous operation for 4 days (12 shifts) rather than 2 shift daily operation.

Energy

The food industry has had surprisingly little regard for energy use other than in those processes such as evaporation and spray drying where they have inherited technology from the wider process industry and in which energy consumption has been an important component of design, frequently because of the scale involved.

The food industry probably has six major “bad habits” in the context of energy:-

- Fouling of heat transfer surfaces and poor process design necessitating frequent cleaning of equipment with large energy and water requirements
- Adding water to dissolve or rehydrate ingredients and then removing most of it again
- Poorly thought out air handling and air conditioning systems
- Lack of integration of energy input and energy removal
- Lack of efficient energy recovery
- Continuing use of old, energy inefficient plant and process concepts, and in particular applying these to new materials where alternative solutions are available

In defence of the industry, however, it must be admitted that relatively low margins, inherent conservatism in adopting technology and lack of true innovation on the part of food process equipment suppliers have all contributed to this situation. Furthermore the difficulty of reproducing traditional products with new processes has held back energy efficient processing to a degree in that, as is mentioned above, concentration on the apparent primary purpose for a process often looses essential elements which contribute to the product characteristics. This has lead to a large number of disappointing results where modern, large scale process technology has been introduced with inadequate research and has resulted some very extended and very expensive development programmes.

When designing new plant and process operations it is important to make accurate forward projections on energy cost and availability and to model the effects of major variables. Energy costs will continue to rise and become less predictable going forward and the economics of different sources (eg bought in electrical energy vs in house generation) may change radically over the lifetime of a plant (typically 25 years). It is one of the benefits of true and informed cost modelling that it allows not only a variety of different scenarios to be evaluated but also allows changes with time to be considered, for example the alternatives which may be considered when a boiler or power plant needs to be replaced in five years time.

It is also important to understand thoroughly the process task and conditions and to consider technology from other industries where similar problems may have been encountered and resolved. The food industry has not been at the forefront in adopting the technology of other industries because it has always regarded its technologies and materials as unique. Whilst food materials do present unique challenges and often surprise the wider process industry, there are certainly opportunities and new ideas available.

Effluent

Food processing frequently produces large amounts of (generally liquid) effluent often as a result of cleaning processes or product change over and sometimes in the form of solid waste materials or byproducts.

In addition there is another important form of effluent which is frequently ignored and that is energy “disposal” through cooling and chilling systems. Assuming that most materials enter and leave a factory at more or less the same temperature (the exception being frozen foods of course) then any energy input during processing (either thermal or mechanical) has to be accompanied by an equivalent energy removal. This has quite high capital and energy costs in itself, particularly where chiller systems have to be employed.

Food processing plant design in the future will need to reduce waste and effluent by ensuring that all components of raw materials and byproducts are used to make profitable – or at least contributing – products. This may be by co-operating with processors of similar materials in joint byproduct ventures where neither has the scale needed for individual processing. If the R&D and investment costs can be managed, possibly by joint ventures, then major advances in utilisation might be made, particularly if original thinking can be applied. It may even be possible to extract valuable materials from byproduct streams if sufficient scientific attention can be brought to bear.

Cleaning for hygiene and product separation will always be a major focus for the food industry and is to some extent inescapable. However that is not to say it cannot be reviewed and made to use fewer resources of energy and water by careful plant design such as completely enclosed systems and also basing cycles on the measured level of microbiological activity rather than set routines.

Effluent load due to cleaning plant between different products can be minimised by optimising run length, but there are also new approaches such as disposable liners for process equipment (pioneered in the pharmaceutical industry) which are worthy of consideration. Approaches which eliminate the need for transfer pipework by physically moving plant large items may sound far fetched, but are used in the paint and ink industries to avoid the cleaning of process pipework.

Cleaning to remove surface fouling presents one of the greatest challenges and opportunities. System design to eliminate surface fouling is rare, fouling is frequently regarded as “one of those things which happens” and cleaning to remove it generally involves large amounts of water and chemicals (and high liquid velocities) resulting in expensive systems and effluents from which it is extremely difficult to reclaim value.

Many food materials – particularly those containing proteins - are temperature sensitive and both denature and adhere rapidly to high temperature surfaces, reducing heat transfer efficiency radically. Fouling can also occur where materials are cooled by too low a temperature surface. There are a number of current approaches which can reduce the problem of surface fouling but few which can eliminate it completely,

In order to transfer heat to a fluid system the heat transfer surface, logically, has to be significantly hotter than the fluid being heated. There will always be a more or less static boundary layer of fluid close to the heat transfer surface and this will be at a temperature approaching the heat transfer medium, causing denaturing or degrading of the product and fouling of the surface.

To significantly reduce the problem of surface fouling will require original thinking and some investment in new technologies. Even using very complete models of true cost of cleaning it can be difficult to justify major investment. However most models ignore the fact that effluent disposal in particular will become more expensive at a rate much faster than general inflation as environmental authorities realise that they can charge almost limitless fees for receiving even pre treated effluents – after all what is the alternative? In addition the cost and availability of the large quantities of water involved in cleaning may become a significant issue in some environments.

Technologies which have the potential to significantly reduce heat transfer surface fouling and consequent cleaning include:-

- Mechanical energy input (ultra intense mixing, not suited to all materials but very interesting for producing high solids syrups without evaporation)
- Induction heating (allowing accurate and graduated control of surface temperature and energy input)
- Direct steam injection (only applicable in limited situations and requiring potable steam supply but valuable where water has to beaded to a process)

Note that non stick surface coatings have had little success in reducing the severity of industrial surface fouling in all but a very few cases, not least because applying them to large process equipment is rarely if ever practical.

Process cooling can also present difficulties, particularly where viscous liquids or granular materials are involved because the energy input from mixing can rapidly exceed the very poor heat transfer rates achieved between the solid process materials and a jacketed vessel wall. Sophisticated paddle designs in mixers can overcome this to a degree for viscous liquids and some powders although convective cooling of powders under vacuum is an almost insurmountable problem. Powders can be cooled in purpose designed equipment which has an extended surface area in the form of internal discs, screws or coils although the cost of such equipment is high and it is difficult to clean.

If a granular material is not suitable for an obvious technique such as fluid bed cooling (eg if the particle size distribution is too wide) then it may be possible to employ evaporative cooling in the case of drying processes by reducing the pressure which will remove heat as residual moisture evaporates (water can even be deliberately injected to provide evaporative cooling). This is however only generally effective down to about 50°C. Another interesting technique is to inject liquid nitrogen into the process vessel directly. Although the cost of the liquid gas is relatively high the equipment needed is relatively simple and overall the technique can be highly effective in the right circumstances.

<u>Process Integration</u>

Many food processing operations are multi stage, particularly where a degree of automation is involved. It can be extremely difficult too operate (and in particular to start up and shut down) plant in which materials pass directly from one process to another and a degree of interstage buffering is often utilised to desensitise the operation.

Interstage buffering of process lines, whilst making plant much easier to start up, shut down and run frequently leads to waste as it results in tanks or hoppers which require cleaning and it may be difficult to shut down or start up a process line without having too much or too little of an intermediate at some point. However, complete elimination of buffering can lead to plants being very difficult to operate in practice and being very vulnerable to forced shutdowns due to short term breakdowns or routine maintenance and cleaning. It can also make start up and shut down of processing lines much more difficult and result in it taking longer to achieve full throughput

Greater use needs to be made of process mass flow modelling to allow accurate prediction of routine buffering needs and even of transient needs in special circumstances which may allow production to continue rather than being stopped by even minor problems. This type of modelling can also be used – with accurate information inputs – to help decision making when breakdowns occur and facilitate planned maintenance schedules.

In addition to applying process integration to existing processes there are great opportunities to improve all round plant design by rethinking the manufacturing processes and consequently eliminating intermediate steps. In one example it was possible to take a process requiring nine separate processing operations and considerable WIP and to reduce this to three processing operations with almost no WIP other than the material in process. Furthermore, because the process was self sterilising and totally enclosed the need for cleaning wa significantly reduced.

Capacity and Utilisation

It is extremely instructive to undertake a thorough plant capacity loss analysis from a position or 24/7/365 operation at maximum throughput. Very few plants, even ones which run 24/7, will in reality generate more than about 65% of their theoretical output at a first sight but by understanding the reasons behind capacity loss better plant utilisation can be achieved and lower installed capacity (at lower cost) can be used to give the same output.

Typical factors which can reduce capacity but which are amenable to improvement will include:-

- Annual Shutdowns and Public Holidays
- Cleaning and maintenance cycles
- Product change over
- Speed reduction due to product mix
- Wastage of materials
- Unplanned downtime (breakdowns, lack of raw materials, etc)
- Planned and unplanned speed reductions (for example start up and shut down transitions, shift to shift handover "custom and practice")
- Intermittent operation (ie operating less than three shifts per day thus requiring daily shut down and start up)

This type of capacity and utilisation analysis is very powerful when used to determine the actual capacity of a plant and the factors which are derating it from its nominal or installed capacity. Of course no plant will run continuously at its spot capacity, but when losses can be pinpointed and quantified significant gains can be made.

This type of analysis is also very useful when new investment is requested or is being considered because it provides a modelling tool for deciding whether or not new investment is really justified or whether better operation and utilisation of existing plant – all be it perhaps with some investment – can achieve the required capacity or flexibility.