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REVIEW PAPER

THE MANY FACETS OF PRODUCT TECHNOLOGY

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This overview is an attempt to position product technology as a scientific discipline that covers the area of product design and engineering. In industry a distinct difference can be observed between large-scale bulk or specification products and performance products that show a large variety and that are produced because of the specific functionality requirements of the market. In this review, first the main elements of product technology are structured. Then production plant design and operation are discussed, followed by strategies for product development, product technology R&D and teaching of product technology. In the Appendix a number of typical product technology R&D results are summarized. In our view product technology comprises more than chemical products only. Further, an important difference with process engineering is that the entire production chain is taken into account. At a first glance, the product development processes of various products are distinctly different. However, when examined in more detail, many similarities are present and a broader approach is considered appropriate. By studying the similarities and the differences the methodology of developing new products can be improved. In this way inspiring innovative products and processes can be developed and at the same time the time to market can be shortened. Further the relation with process engineering is clear; products are made by processes. In the twentieth century chemical engineering research and application was developed substantially leading to the growth of a very large industry. The recognition of the underlying physical principles of the unit operations can be called the first paradigm. The second is how the role of the physical transport phenomena in obtaining physical and chemical thermodynamic equilibrium. Will product technology become the third paradigm of chemical engineering? An outline of the challenges to be met in the first part of the twenty-first century is given at the end. They comprise, for example, the generics of product technology, process–product relations and defining performance. The authors intend to formulate a number of answers to some of these challenges in a subsequent paper.

Keywords: product technology; market; education; product development; strategy.

INTRODUCTION

Product technology and its approximate synonym product design and engineering are increasingly receiving attention from the chemical engineering environment. This can be attributed to an ever-increasing demand from customers for high performance products with a high functionality. This is also clearly reflected when analysing the marketplace. The production of performance products such as food and health care products, detergents, lubricants, pharmaceuticals and bio-materials is often considered more profitable than the traditional production of commodities and bulk chemicals.

In chemical engineering circles it is now generally accepted that there is a difference between process engineering for the production of bulk products and the production of a large variety of all kinds of products for the food consumer, and the pharmaceutical and chemical specialty market. This distinction can also be made by calling the bulk products, such as gasoline, ammonia, and ethylene, specification products. These products are made by production companies or by others, per required specification. On the other hand, the many small-scale products, which can vary from bread additives to special polymer coatings or drugs, may be called performance products. The latter are primarily produced and marketed because of their specific performance, e.g. colour, taste, stability and other requirements. Performance products often comprise a large number of different chemicals that all have a specific function in the formulation.

Chemical engineers are well aware of the important role of the process in producing bulk chemical products. Major innovations have occurred in the past and will be necessary to meet the difficult goal of the society of a sustainable future. Process technology for bulk products can be considered as mature and it is observed that the increase in
efficiency will primarily be achieved by innovation in mechanical and construction improvements and in data handling and control.

In contrast to classical process technology for bulk products, the supply and demand aspects and the related logistics play a very important and sometimes decisive role in the economics of production of performance products. In addition, the required performance of the products requires a close relation with the market, definitions of what the market wants and translating that into attributes of the product. Hence, product engineering covers a much larger part of the production chain and is not limited to the production plant only.

Thus the challenge for chemical engineering is shifting from process improvement orientation to product development and improvement that may be called the ‘birth’ of product technology. The shift from process-oriented chemical engineering to product orientation implies that the resemblance to related technologies becomes more apparent. Product technology in a broader sense also comprises mechanical or ‘discrete’ products and ‘software products’ traditionally belonging to the IC technology. The analogy is not based on their specific appearance or performance, but on the similarity with the product development and production processes.

In this overview many different facets of product technology are briefly reviewed in order to demonstrate the broad field of product technology. Chemical engineers will be confronted in the near future with many new challenges. Examples are the selection of the fastest instead of the cheapest production process steps in order to meet the ever-shortening time to market. For expensive products the process costs are often small compared with other costs. Moreover the products itself show increasing complexity in order to meet the client requirements. In the academic research environment this shift is often not yet sufficiently recognized.

Objectives

The objectives of this article are 4-fold:

- to provide an outline of product technology in a broad sense—the development of chemical, pharmaceutical, food and biomedical and other products shows so many similarities that a combined overview is warranted; the differences are sometimes less than is recognized at first sight;
- to provide a concept for categorizing and structuring product technology;
- to show the interaction of product engineering and design and process design;
- to present some views on how to teach product technology to young students and engineers.

The field is broad and at the same time developing in many directions. A classification of product technology is still in its infancy. However, it can be argued that such classification is essential for developing product technology as a dedicated branch of science.

Product Technology: the Third Paradigm of Chemical Engineering?

Wei (2001) and more extensively Cussler and Wei (2003) discussed the history of the scientific framework of chemical engineering and recognized three paradigms:

- the unit operations in the 1920s and 1930s;
- the transport phenomena in the late 1950s; and
- product technology at the turn of the century.

A paradigm is the general framework of theory formulated in a given period.

Looking back to the development of chemical engineering as a science, it can be observed that the concept of unit operations was a substantial step forward. Before this concept was developed chemical engineering was a large set of data resulting from small-scale experiments and industrial experience, but the binding element was missing. Prediction of performance of equipment and operations was difficult and often based upon intuition, until the corresponding physical aspects of the unit operations were recognized.

The second major step forward, the second paradigm, is the concept of transport phenomena. The recognition of the importance of these phenomena occurred in the late 1940s and became the basis for many inspiring researches. The late 1950s and the 1960s were characterized by a large number of publications, recording the new concepts and their application. Of these should be mentioned the penetration theory, the description of the flow, heat transfer and diffusion physical processes in equipment items and the application to the physical phenomena in chemical reactors. Books on chemical reactor design of Levenspiel and of Kramers and Westerterp contributed to the development of the understanding of chemical reactors and added to the basis of the spectacular increase in plant size and more sophisticated design of more efficient reactors and up-scaling of process equipment. In the 1970s, 1980s and 1990s the chemical engineering research expanded, leading to numerous models and increasingly detailed insight. Major new insights were not developed and the technology became mature.

The life cycle concept for products, i.e. introduction, growth, maturity and decline, can also be applied to chemical engineering science. This implies that the technology is facing a less pronounced growth compared with the previous period.

From a business viewpoint a mature technology does not lead to spectacular commercial results, and the return on investment decreases. As a consequence the engineering and construction of chemical process plants shifts from application of the latest technology insights in chemical engineering to cost reduction by cheaper mechanical design and reduction of personnel cost by extensive process control and data monitoring. As recently pointed out by Westerberg, the profit of one crude tanker exceeds that of many technological innovations in the oil industry, which demonstrates the comparative importance of process innovations for bulk products.

The maturity of chemical engineering technology is also reflected in the staff reductions and the shift in research in the 1990s of major research laboratories of most of the main oil, gas and chemical companies.

The challenge for chemical engineering is shifting from process improvement orientation to product development and improvement, which may called the ‘birth’ of product technology.

The required performance of the products requires a close relation to the market, definitions of what the market wants and translating that into attributes of the product. At the same time, because of the nature of the products, there are many relations to other sciences, such
as physical chemistry, interfacial engineering, health, pharmaceutical and medical sciences.

Moreover functionality of modern products stems not only from its ingredients, but more and more also from its product structure. Typical examples are modern products comprising a structure polymer blend, but also in food many examples exist in which control over product structure is the key element of success.

What is Product Technology?

There are different views about the definition of product technology, as is understandable since for many years process engineering studied the processes to produce products. Cussler and Moggridge (2001) pointed out that there are four steps in chemical product design: needs, ideas, selection and manufacture. The reality is of course more complex. The needs reflect the increasing importance of the market. The ideas show the importance of creativity and imagination. The selection represents the essential structuring of the development process. The manufacture is related to classical process design, but with an important difference: minimizing production costs is not an important drive, but flexibility and time to bring the product to the market are decisive. Cussler and Wei (2003) restated this, remarking that both in research and teaching major changes will take place.

In our view product technology comprises more than chemical product design. A possible definition is product technology is the science and art of developing and producing performance products to meet the demands and requirements of society and achieves this by adding value to materials by improving existing and designing new products.

When this definition is accepted, it becomes understandable that product technology is not limited to the development of new chemical products, but that food, bio-medical, specialist mechanical products and even certain software belong to product technology. Market, imagination and structured innovation are the key elements in the steps required to develop new products.

The difference between product technology and process technology is that the latter focuses on a limited part of the total production chain, but this difference is more than a ‘nuance’, a small diversity of the present state of knowledge. It is an essential difference when you look at the total chain. Product engineering thus includes supply and demand and the associated logistics. Primarily looking at the process production steps is not sufficient any more. This approach does not reduce the importance of process technology, but underlines it. Consumer wishes, quality demands and legislation lead to more complex products that are more difficult to produce and require innovative process steps.

STRUCTURING THE MAIN ELEMENTS OF PRODUCT TECHNOLOGY

Classifying Product Technology According to Underlying Discipline

Product technology can be subdivided according to the science that plays the major role in the product design. A useful classification is:

- chemical/biochemical;
- food;
- pharmaceutical;
- physical–mechanical (also called discrete or fine-mechanical);
- biomedical;
- software.

There are similarities and differences between each of these technologies. These are discussed below.

Market orientation

Product design and development is strongly market-oriented and the relation to the market is usually much more direct and intensive than with specification or bulk products. In the latter the off-take is of course the capacity-determining factor, but only with respect to the volume of production. The specification of the product, for example gasoline is not or only to a small extent influenced by the buyer. Performance products usually have a much shorter lifetime than specification products. The latter are sometimes the feedstock for derived products. The intensive relation between product design and the consumer is quite apparent from the examples given below in the overview at the end of this review.

Food products

The product technology principles of interdisciplinarity and looking at the overall production chain and not only at the process, have been applied in food science for some time. Many food-oriented universities possess product-oriented departments, such as meat sciences, dairy sciences and cereal sciences. Food products should always be evaluated by various disciplines. A food product should not only have the right nutritional value and the right structure, but it should also be safe from a microbial point of view. As a result of this, food product technology has always recognized the role of other disciplines.

Food products comprise bulk products such as milk and yoghurt. Here the characteristics of bulk production can be recognized, like improving the business economics by investment and operating cost reduction by larger scale production, standardization and a shift to cheaper construction cost and more automation. For a dairy product such as milk there is a strong supply drive from the farmers, as milk deteriorates rapidly.

On the other hand, when comparing food products in the supermarket of 10 years ago and nowadays, the difference is impressive. The number and variety of products have increased considerably, while the life cycle of many new products is short.

The consumer market directly influences food products. It is extremely important for the success of the product that the requirements of consumers are met. Yet what does the customer want? The food consumers make their decisions based on a mix of rational and emotional considerations that they themselves only partly realize. Thus for food products the insight into the market is of extreme importance. Therefore, research into the requirements of the consumer is of pivotal importance in food product technology.

**Pharmaceutical and biomedical products**

These, on the other hand, also have consumers, but their motivation to buy is quite different. They are primarily interested in whether their rather sharply defined needs are fulfilled by the product. Concern about your own health opens the purse.

Slow release medicines are medicines which are released into the human body over an extended period of time. Thus the number of times that the medicine has to be taken becomes less and the ‘medicine level’ in the body is more constant. The technicalities of the physical release system are not of interest for the patient and only to a certain extent for the doctor. He or she is primarily interested in results, in the benefits or the patient. For illustration, two examples are given:

- Drug delivery to the lung can be achieved by aerosol particles. Large particles get stuck in the tortuous and narrow lung passages and small particles are too quickly absorbed. Aerosols of high porosity and large diameter that penetrate far enough into the lung and can release the drug slowly are nowadays being developed.
- A voice-producing element to be used by a patient whose larynx has been surgically removed is highly specialized equipment that improves the quality of life of the patient considerably as otherwise he or she cannot speak. No wonder that the consumer is extremely willing to buy, provided that the product meets their requirements with respect to the bio-compatibility of the voice-producing element and to the resemblance to a normal human voice.

**Chemical products** like polymers and inorganic salts are often intermediates and are not used as such by consumers. For example, an inorganic salt like CaCO3 is an important ingredient in an end-product like tooth paste. The manufacturer of the end product is the one that takes the decision to buy the intermediate. Again, meeting the requirements is the most important decision factor to buy or not to buy.

**Various physical-mechanical products** produced by so-called ‘jobbing’ follow the same product technology laws as chemical or pharmaceutical products. Examples of physical–mechanical production technology are the development and the small-scale manufacture of speciality products as a measuring device for a ship frame and a probe to gather physical data in an oil or gas stream.

**Requirements and attributes**

The need for a product starts usually with a rather undefined feeling and consequently a vague definition of what the customer actually wants. In the beginning the product developer often does not know what is really required. The definition of the requirements and of the attributes of any product starts vague and is a process in itself. Consumers and users often do not define their requirements in such a way that the engineer can start with product development immediately. A sequence of conceptual, basic and detailed design may be recognized in the various steps leading to a new product. The development process is as the Echternach procession, three steps forward, two steps backwards. Side steps and circles are also not uncommon.

There is a great variety of characteristic requirements and attributes of products. A classification would be supportive of the development of product technology as a science. Kind (1999) addressed the importance of systematizing the product quality factors.

**Shortening the time to market**

Products are developed in a competitive environment and the company that is the first to market a new product has a certain advantage. However, the company that follows the ‘me too’ principle has the advantage of recognizing the errors made by the first manufacturer. In the near future it can be expected that the complex process of new product development, combined with the process design procedures to adapt or design and construct the production facilities, will be subject to much management science research.

Many of the new products that are developed are failures, and these failures are expensive. Highly qualified people, market researchers, process engineers, designers, etc. are involved in the product development. From an organizational and managerial viewpoint the challenge is to form an effective team consisting of many different disciplines. Interdisciplinarity is very typical for product technology. Therefore, in this review some managerial and organizational aspects of product technology are also discussed.

**The Differences**

Many differences can be observed in the scientific literature about product technology. This could be attributed to researchers focusing on the specific research objective and not taking the broader framework of product technology into account.

This becomes apparent from the summaries in the Appendix of a number of articles. In an attempt to categorize the differences between the various technologies and products the following classification may be observed:

- performance characteristics (the performance of the products is market- and application-oriented);
- shape and structure (the shape and structure are particularly related to the preferences of the client and customer, as is particularly apparent in the food industry);
- complexity of composition—the complexity of composition relates in a complex manner to performance; research into the relation between composition, for example of polymers, and performance may lead to a certain predictability of performance of new products;
- process(es) to produce the product (for bulk products there are many generic design rules, but for the production of performance products these have not yet been developed; product-process relations are important for the shortening of the time to market products).

Reference is also made to the overview of the presentations at the first European symposium of product technology, as given in the Appendix.

**The Product—Process Engineer**

It is expected that in the near future a new type of engineer will develop. He/she has a thorough knowledge of the...
basics of process technology, i.e. thermodynamics and transport phenomena. An additional requirement is the awareness of the engineer regarding the importance of product performance. Thus he/she must know about process–product relations and ask him/herself the question what process steps are required to obtain a certain specific performance. Sometimes physical chemistry and chemistry are involved and sometimes there are biological or mechanical requirements.

This requires from the product–process engineer a broad knowledge and an application-oriented and business attitude. University education will have to meet these requirements of the present time.

**PRODUCTION PLANT DESIGN AND OPERATION**

Products are manufactured in production plants. The design of such plants is a multidisciplinary and creative professional effort, with time schedule, cost and co-ordination between disciplines as its main parameters for achievement and success. Therefore a project approach is commonly used. The project manager is the focal point in the design process, and is primarily interested in the three parameters time, cost and co-ordination. He/she guides and motivates the members of the project team. He/she reports to management that primarily is interested in cost: time schedule is of course also cost and lack of co-ordination results in extra cost.

As explained in the Introduction, a distinction in production processes can be made for ‘specification products’ and ‘performance products’. A valid question is therefore what is the difference in the design of plants for these two types of products?

**Design of Plants for Bulk or Specification Products**

Most of the plants producing bulk products, are large and usually show several hundred equipment items, of which only one is the chemical reactor. The design procedures show distinctions between three project phases:

- conceptual design;
- basic design;
- detailed design, procurement and construction.

In the conceptual design the main process steps are defined, the mass and heat balances are established and the main process control is determined. During the basic design the conceptual design is further detailed, equipment specifications are prepared and drawings, the so-called P&IDs (piping and instrument diagrams) are prepared resulting at the end of the project phase in drawings and data sheets marked ‘approved for detailed design’. So far the costs are limited to ‘engineering man-hours’. Process engineers play a major role in these two phases. At the beginning of the third phase (engineering, procurement, construction, EPC), major commitments to equipment and material suppliers, contractors and subcontractors are made. Therefore, ‘board approval’ is required just before the EPC phase starts. The so-called ‘phased approach’ has proved to be very effective, particularly its rational and systematic underlying philosophy. Attempts to shorten the associated decision time, such as ‘parallel engineering’, inevitably lead to a more chaotic engineering process and more engineering man-hours. This may nevertheless be acceptable in some cases from an overall business viewpoint, for example if the time to finish the project is of great and financial importance. However, managers should be aware that in engineering and day-to-day life, you cannot have your cake and eat it.

Smith and Linhoff (1988) compared the chemical bulk production plant with an onion, the nucleus being the chemical reactor, with sequencing layers of separation and recycle systems, heat exchanger networks and utilities. Voncken (1995) added another layer, the offsites, representing the relation with the environment, and two cloves, the economics and the safety as penetrating and essential parameters into the onion. These two not very exact parameters flavour the design. Just like when cooking a dish, the flavour is also important.

Design for the bulk production plant follows reasonably well established procedures, developed over the years by the major oil, gas and chemical companies and the large engineering contractors. Computer programs are readily available, most flows are liquid or gaseous mixtures and their physical properties can be defined, based upon well-known thermodynamic calculations. Boiling points, density, viscosity of mixtures, and many other physical data are quickly calculated. Process technology innovation plays a less dominant role, the conceptual design is primarily based on experience and major breakthroughs are rather unlikely and cannot be expected for most processes.

Technological improvements will be found in the near future primarily in mechanical and civil engineering, and in automation but most likely not in process technology. Researchers are often insufficiently aware of the large risks involved with a process change or a new process. At the same time they often do not know nor realize the consequences of the fact that the bare cost of equipment is only a small portion of the total installed cost of that equipment, only 25–30%. The rest of the cost is in piping, civil foundations, mechanical supporting structures, instrumentation, process control etc. As a consequence small reductions in the size of equipment are often rather irrelevant for the capital cost of the plant. Process improvement is nowadays more directed to channel information flows, to improve warning systems against production deviations and to prevent potential breakdowns and calamities.

**Design of Plants for Performance Products**

The situation is rather different when designing plants for the production of performance products. Product driven process engineering (Bruin, 2003) is based on intensive engineering effort to produce products to meet performance criteria which are often not very well defined in physical terms and in any case the relation of the performance requirements with the various production steps is mostly unknown. At the same time the commercial pressure to meet these requirements and to bring a newly developed product as quickly as possible to the market is quite high. The success of a new product is difficult to predict—market saturation sometimes occurs quickly, and new products are sometimes rapidly pushed out by slightly better look-a-likes developed at the same time by competitors. In general the failure rate of new products is high.
Some 80% of new products in the food consumer markets have disappeared after a few years.

Obviously the phased project approach that is well accepted for the design of production plants for bulk products is not really applicable to the design of production plants for performance products.

The short time-to-market requirements are in conflict with the time needed to specify new equipment and the associated relatively long delivery time. Plants consist of fewer equipment items, but handling of solids, pastes and slurries is less susceptible to rigorous calculation procedures as physical properties cannot easily be predicted and the effects of the equipment operation on the physical properties are even less known. Consequently there is a lot of trial and error in the design and the testing of the production, requiring a different working relationship between the R&D department, the engineering and the production department. In order to meet the short time-to-market requirements, use often is made of sections of an existing plant. Sometimes second-hand equipment is used. New equipment is sometimes developed and tested in close co-operation with the supplier. Sometimes certain production steps are assigned to outside production firms that have production capacity for semi-manufactured products.

The future plant will therefore be a highly flexible, multi-purpose plant. This will probably lead to substantial changes in plant design. Highly intensive processes are needed to increase safety and to reduce off-spec material as a result of product switches in the factory, which will occur more and more. Advanced techniques, such as micro-technology, will most likely playa crucial role in tomorrow’s plant. Batch processing is much more common than continuous processing and leads to different process control. Equipment loading differs because of cleaning procedures and in general operational philosophy.

Summarizing there are many differences with the design and production of bulk products. The keywords for the production facilities of performance products are flexibility, small-sized equipment and relatively small production rates.

**Strategic and Organizational Aspects of Product Technology**

The fundamentals of chemical engineering, unit operations, transport phenomena and chemical reactor design are the scientific basis for bulk production of both specification products and performance products. Physical chemistry, thermodynamics, chemistry, biochemistry etc. are the connection with science. Society requires scientists and engineers to apply the enormous available 'database of knowledge' in practice to justify the billions it spends on research.

There are strategic and organizational differences between the 'bulk production organizations' and the 'performance production' organizations. Bulk production is focused on producing as large quantities as possible at the lowest investment and operating cost. As applied chemical engineering is a mature technology, the primary focus is on capital cost reduction by cheaper construction and on personnel reduction by improved process control and data acquisition. Strict protocols, standards and guidelines to meet safety and environmental requirements are typical for the organization.

For the small-scale production the strategic and organizational requirements are quite different. Many of these products rapidly become obsolete and the production and development of these products require a much more flexible attitude to organization than the typical bulk producer. Meeting the short time-to-market requirements does not correspond easily with strict protocols. At the same time society, represented by the government, requires particularly for food and pharmaceuticals that strict rules be adhered to. Global companies are often conglomerates of a mix of bulk production and performance product production companies. This implies that the ownership of major parts of companies sometimes changes suddenly because of the overall company strategy. The effect on the workforce is however, rather small.

Many medium-sized companies are facing a similar business process, but as they are relatively small the impact of change of ownership is larger. At the same time the real challenge for the company as a whole is to transform the company into an organization wherein product innovation is the aim of the R&D department and the production facilities. Forced by the market changes, this often requires substantial adaptation of the workforce to the new strategy.

**STRATEGIES FOR PRODUCT DEVELOPMENT**

**The Market and the Engineer**

The key question is to structure the technological strategy and the product development in a company in order to meet the demands of the market, particularly shortening the time to market of a new product. The marketing manager asks 'why this product?' He is particularly concerned about:

- profit analysis;
- market potential;
- client requirements;
- competition;
- protection by patents.

The engineer asks 'how do I make this product as efficient as possible and with the required product properties?' This question cannot be answered by a relatively short list of points of attention, as outlined above. Knowledge and ideas are enormously varied and are not easily put into an overseable framework. On the other hand it may help to look back to the early days of recognizing the importance of transport phenomena and chemical reactor engineering principles. Kramers (1962, private conversation) remarked in those days: 'Science can be seen as a systematic arrangement of facts preferably in the form of models'. That remark is applicable to the present situation of product technology and product development. In the days when the remark was made, chemical engineers were in the middle of developing concepts such as the penetration theory, residence time distribution, similarity of transport phenomena, etc., and their application. Product technology is nowadays a vast number of data and facts and practical principles and know how. Structuring that unstructured database is the challenge to the process–product engineers of the early twenty-first century. The coming decade it will become clear whether product technology will really develop into the third paradigm of chemical engineering.
How can R&D be Structured?

In ‘Third generation R&D’, Roussel et al. (1991) outlined the development of R&D by distinguishing between three generations of R&D after 1945. First the view was that, when you put a number of intelligent and creative engineers together in one rather loose organization, the new products would show up by themselves. This approach led to very good ideas but also to a substantial waste of time, money and talent. In the 1970s the project approach was developed. The discrete, project nature of R&D is recognized, cost and benefits can be monitored for individual projects and progress can be measured against project objectives. However, these projects sometimes do not fit adequately into the strategy of the company, even when they are successful. It should be remarked that the project approach has proved very effective in engineering and construction of major process plants. In that case the project objectives are straight and clear: design and construct a plant meeting predefined objectives of investment, operating costs and quality.

In the concept of third-generation R&D, the effort is compared with the strategic goals of the company. The portfolio shows dimensions such as probability of success, technological competitive strength of the company in a given science field, project attractiveness, time to completion and of course cost of R&D. This leads to a ranking of projects.

From a business viewpoint R&D is an investment that has to meet criteria, just like other investments in new or improved production facilities.

Product Market Technology (PMT)

Development of new products has interfaces with industrial engineering and management and its views on PMT. ‘Market pull’ is sometimes considered as the most effective road to success, but that is not always the case. ‘Technology push’ creates its own opportunities. The marketing man has difficulty in understanding what is driving the technologist, and can probably not really understand the feeling of joy when a technologist has discovered a solution for a certain problem. Nevertheless, the engineer should realize that the market is an essential condition for success.

R&D AND TEACHING OF PRODUCT TECHNOLOGY

The Social Shift in 2000+

To state that our society is changing rapidly is a platitude. However it is remarkable that many think that the changes are occurring elsewhere and not in our own backyard. Bruin (2003) pointed out that changes in society and industry have shifted the potential work fields for chemical engineers. However, many university curricula are still based on classical chemical engineering and insufficiently recognize the shift in demand of the employment market. The focus has stayed on the classical separation and transformation processes that are typical for the oil, gas and bulk petrochemical industry. Of course chemical engineers are and will be employed in this industry. Major innovations are not expected. The innovation in the bulk industry is shifting to mechanical and ICT applications. At the same time many medium-sized and smaller companies recognize the importance of product orientation of their production facilities and of novel product design, associated with the increasing importance of market demand.

Product design and engineering is an interdisciplinary effort, the involvement of several disciplines is required to meet the goal. Research and development of new products is an interdisciplinary effort and requires working in teams consisting of different disciplines.

Another major social effect is the invention and development of ICT. By the invention of printing, sources of information became available in a short time to thousands and later millions of people. The Renaissance and Enlightenment were the social and cultural consequences of the invention of printing. ICT may play in the next decades a similar role by making available to hundreds of millions of people the enormous database of scientific knowledge and information on a global scale. This is rapidly affecting the structure of the global economy and society.

From Process Engineering to Product Engineering

Fundamental research in chemical engineering occurred for decades in both the research laboratories of the large companies and the universities. The fundamental research by industry was at the end of the twentieth century strongly reduced, and also the total research effort was reduced. What was left became much more directly application-oriented. At the universities, however, the research still continues, leading to refinements of fluid bed models, more extensive calculation methods for separation processes and the like. Our calculation power exceeds our real knowledge of the chemical and physical processes of chemical engineering. Also, the calculation power is usually more than sufficient to meet the requirements in practice. Mass and heat balances for a 100 million Euro oil and gas plant are set up in a couple of days using flow sheeting programs that can extract information from large thermodynamic databases, fixing the basis for the process design. Process engineering requires the solution of many problems that cannot be tackled by a computer program. Further refinement and increase of the computing power will not contribute much to the efficiency. Process engineering, particularly for hydrocarbons, has become a mature science.

The development of new products is much less susceptible to calculation by computers. Thermodynamic data of solids and mixtures of solids are much less available than the data of hydrocarbon liquids and gases. Many physical–chemical characteristics cannot be predicted with a reasonable degree of accuracy.

Product design and engineering is an art more than a science and its scientific status can be compared with the situation of chemical engineering at the time that the first paradigm, unit operations, was developed.

In industry new products are mostly developed by teams of specialists of different disciplines in a project structure. Research at the university is still often performed by individuals or by a group of mono-disciplinary individuals. In addition, science students are mostly studying and working as individuals during their first years at the university.

Educational Aspects of Product Engineering

Present education at most universities is based upon the philosophy that scientists and engineers should become knowledgeable in detail of mathematics, physics and chemistry by following stacked study objects like maths 1, 2, 3, 4 etc., physics 1, 2, 3, 4 etc. The reasoning is that the student has to develop a thorough and detailed knowledge in the beginning that expands into slowly broadening knowledge in the later years. Little attention in the beginning is given to the interconnection and interdependence of knowledge. And even less to how problems are solved in practice.

However, in industry and engineering the actual problems are tackled just the other way around. For new plants, processes and products, first broad objectives are defined, often in the form of projects. A project is split up into sub-projects, each with their own definition. Specialist solutions are found for sub-sub projects. The overall co-ordination is maintained by the project management structure.

To work with others in a project team has to be learned, preferably in practice—learning by doing. Wesselingh (2004, personal communication) was one of the first in The Netherlands to recognize product technology as being different from classical technology. He started several research groups of students with different backgrounds, such as chemistry, biochemistry, chemical engineering and technical management science. The students worked as a project team, with a project execution plan and cost and scheduling exercises. Regular progress reporting is part of the training in several cases in cooperation with an interested industrial partner. The students worked hard and with great enthusiasm, which was an excellent training for the real world. Wesselingh (2004, personal communication) further developed the original set-up of his lectures by numerous training examples and an original approach based on ‘learning by doing’.

By introducing an overall course in the first year of study, in which the approach in practice, i.e. from broad to deep, from concept to basic design to detailed specialist solutions, is taught, the students become aware of the methods that are common in practice: define the problem, then find the tools in the vast database of knowledge available. The carpenter has to know how to use a hammer or a screwdriver, not how these instruments are developed or manufactured.

Parallel to this education, the product engineer of the future has to acquire the basic knowledge of the chemical engineering fundamentals. Further, he/she has to develop the attitude that only by deepening your knowledge in a specialized field will you contribute, together with others, to the development of new products meeting the requirements outlined in the conceptual phase.

The first book dedicated to chemical product design has appeared (Cussler and Moggridge, 2001). Previously books on mechanical product development and design appeared, such as Cross (2000) and Ulrich and Eppinger (2000), while the book on process design principles of Seider et al. (2003) was expanded with a chapter on product design. Jonker et al. (2005) worked out seven steps to teach product engineering based on an outline of the research areas and requirements in product engineering, the product-environment-related aspects and working in interdisciplinary groups. Teaching product technology increasingly receives attention.

University Research in Product Technology

A major difference between industrial and university research is the sense of urgency between the two. It is the age-old conflict between the attitude in practice of ‘if it works and sells it is good enough’ and the ‘search for understanding and truth’. Can these two different cultures work together in developing new products and develop some synergy?

A short SWOT analysis leads to the following observations for product technology research:

- The Strengths of the university are the intellectual potential and the availability of young, enthusiastic and imaginative students.
- The Weaknesses are the individualism, the not-market-oriented attitude, leading to diversions.
- The Opportunities are the potential development of improved and perhaps new products, as insight into the physics and chemistry of the product together with imagination are often the basis for improvement and innovation.
- The Threats are, for the university, confidentiality, which may delay publication in scientific journals, and, in the case of a patent, the difficulty of defining ownership between the industrial and the university partner.

THE CHALLENGE OF THE NEAR FUTURE

Process–Product Relations

Process–product engineering and design is an interactive process with loops and recycles. How to achieve results which meet the market demand in a shorter time has been object of substantial study and application in the manufacture of discrete products. The insights obtained through this discipline can be applied to the development of chemical, pharmaceutical and biomedical products as outlined above. It should be realized that the complexity of these production processes is an order of magnitude greater because of the process, thermodynamic, chemical and physical–chemical interactions. Generic rules for the design and development of these products should be developed in order to reflect this additional complexity.

Innovation is a key factor in survival for companies that produce performance products. Simple products are easily copied, and often at lower cost: the ‘me too’ principle. This means that not only should new products be developed, but also smarter products with advanced product structures. The product should contain advanced ingredients and is often structured in a specific way. Improved strength and controlled release are typical examples of functionalities obtained by product structure and the use of advanced ingredients. In this respect, the producers of chemical speciality products can learn from the principles used in the food and pharmaceutical industry.

Potential Research Objectives

Four generic objectives may be mentioned, where scientific relations have to be developed:

- performance characteristics;
- shape and structure;
Further, there may be many science fields where product engineering concepts may be used for the development of new products. A few examples are:

- complexity of composition and its relation to performance;
- process–product relations.

Product technology can develop into the third paradigm of chemical engineering.

(3) Product technology provides many technological challenges for chemical engineers. Interaction with other disciplines is a key success factor.

(4) Teaching product technology should preferably start at the very beginning of academic study. Of course fundamentals of physics and chemistry are an essential and an indispensable toolkit and should be taught in parallel. In the Master’s phase of the education, actual product development should be a part of the curriculum and executed preferably in close co-operation with industry.

(5) A second paper to attempt to contribute to the four main research objectives of the near future will follow this overview and outline:

- performance characteristics;
- shape and structure;
- complexity of composition;
- process–product relations.

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ACKNOWLEDGEMENT

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APPENDIX

Literature Overview

This literature overview is not an overview to provide the reader a complete overview of the state of the art, the most relevant papers published and to give him/her a relatively complete picture of the achievements in the last 5 years or decade. Its purpose is to underline the main texts, and to demonstrate that product technology is a new discipline, using the chemical engineering achievements and those in associated sciences. Therefore, in this Appendix we limit...
ourselves to technologies that are not well-known to classical chemical engineers, but that are close.

We have, for the time being limited ourselves to food product technology and to biomedical technology while purposely skipping chemical technology, pharmaceutical technology, physical–mechanical (also called discrete or fine mechanical) and software product technology.

In the subsequent paper we will add examples of the mentioned technologies and attempt to structure the large amount of data into a set of overseeable parameters, describing the performance of this great variety of products.

The variety of products and applications is great in the following examples:

- cheese analogues are widely used on pizzas because of their similarity to mozzarella and their much lower cost;
- control of dehydra†ion and rehydration processes is very complex;
- consumers are not rational decision-makers, human factors play a role;
- replacement of the voice of patients who have lost their larynx because of an operation

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**Food Product Technology**

*Cheese analogues*

By blending constituents such as non-dairy fats and proteins, cheese-like products can be produced that can be used as a replacement for real cheese. They are cost-effective, relatively simply to manufacture and replace selected milk ingredients by cheaper vegetable products. Moreover the interests of food consumers are shifting to food products with less fat, saturated fat, cholesterol and calories.

Cheese analogues may be considered as engineered products and provide an example of the complexity of product development.

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**Market considerations**

Bachmann (2001) presented an overview of the product development of cheese analogues. The market demand for cheese analogues increased because of the enormous growth in popularity of the pizza. Cheese is among the costliest components of a pizza. An imitation cheese allows the pizza manufacturers to manipulate constituents to meet nutritional, textural and low cost requirements. Imitation cheeses consisting of caseinates and vegetable oils are particularly available in the USA. Further, the price of cheese is rapidly rising and can be expected to rise further. Lower income groups are consuming cheese-like products instead of the higher-priced milk ingredients. Savings can be obtained by the manufacturers as the raw materials and also the production costs are considerably cheaper.

In developing countries milk production is insufficient to meet the demand, dairy products are expensive and substitutes form an adequate nutritious alternative. In the developed countries there is an ever-increasing interest in products which contain less total fat, particularly less saturated fat, cholesterol and calories because of the relation to body weight, heart and artery diseases.

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**Basic process aspects**

There are two basic processes for the manufacture of cheese substitutes. In the first a liquid ‘milk’ is used and the conventional cheese-making method is followed. This leads to a product that is often called ‘filled cheese’. The second process is based on mixing various raw materials together and using techniques similar to those for processed cheese manufacture. The first process has the disadvantage that relatively large volumes of streams with low solid content are required. Cheese substitutes are mainly produced by the blending process.

Cheese analogues offer in principle an excellent opportunity for substituting a traditional product with a new one with the same or better nutritional and textural characteristics with caseinates as protein source and polyunsaturated vegetable fats and oils providing a cholesterol-free product.

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**Raw materials—protein sources**

The water-soluble phosphates of calcium caseinates are located at one end of the protein, while the other end carries non-polar fat-soluble groups. Calcium caseinates are widely used in the manufacture of cheese analogues.

Functional properties of caseinates for imitation cheese production in general show different performance characteristics, e.g. pH, firmness, degree of emulsification and degree of casein dissociation. Often blends of different caseins and/or caseinates are used. Vegetable proteins, such as isolates of soybean and peanut proteins, are used in partial or total replacement of milk proteins.

Soybean products play an important role as low-cost substitutes for milk protein. Cheese analogue products can be developed by blends of soymilk, diary whey and caseinates, providing low-cost protein sources. However the functionality of the substitution is affected by the fact that soy proteins are much larger than the milk proteins.

From the middle of the twentieth century, substitutes of protein and milk fat have been tried out and used by the public. Its main acceptance factor is the low cost. In the last decade the awareness of the public of the dangers of cholesterol has meant that synthetic cheese products have increased in popularity.

On the other hand, soybean vegetable fat can influence hardness, adhesives, cohesion and springiness. By adding other analogues such as butyric acid and soybean oil, significant changes in texture may be obtained. Stretchy characteristics are required for mozzarella cheese, much used in pizzas. Texture depends upon the physicochemical properties of the mixture of the constituents. Small and numerous fat droplets influence the texture, as does the disruption of the protein matrix.

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**Food ingredients**

Dietary fibre, seasonings, flavouring agents, binding agents, edible gums, hydrocolloids and mixtures thereof are often added. As emulsification plays a key role in cheese analogues, emulsifying agents are utilized. Mixtures of natural diary cheese and cheese analogues are also possible, but are more costly than the cheese analogues themselves. An important negative property of imitation cheese is its flavour difference with real cheese. However,
with mozzarella on pizza the average consumer is not able to distinguish between real cheese and analogue cheese.

Processing of cheese analogues
Careful selection of raw materials, ingredients and the method of manufacture can control the functionality of the final product. Requirements for shredding and slicing, melting or straining influence the manufacture of cheese analogues. Processed cheese equipment can be used, such as the batch cooker mixer or the continuous scraped surface cooker. Extruders are widely used.

The driving force for cheese analogues to meet the increased mozzarella consumption is related to the popularity of the pizza. Functional requirements are the ability to shred cleanly, melt sufficiently quickly, and show the desired degrees of flow, stretchability, chewiness, oiling-off and browning while baking. Recent research has focused on the relationship between compositional and processing factors.

Market considerations
The combination of raw materials, ingredients, particularly flavour systems, and processing is not yet sufficiently developed for it be used as an inexpensive replacement for real cheese. The market is limited to a small group, including vegetarians. The unnatural image, but also regulations, are at present drawbacks and therefore it represents little threat to the natural cheese market. The major market demand stems from the pizza manufacturers. However in the future these products will find their way into the consumer market.

Molecular weight reduction of starch by shearing and heating
In many food products starch is the major carbohydrate component and therefore plays an important role in product properties. Crispiness, brittleness, stringiness and fracturability are important product properties, presenting requirements that have to be attained by careful process design. However, there is still much trial and error when developing food products. Van den Einde et al. (2003) reviewed the molecular weight reduction of starch during heat and shearing, the relation between molecular weight ($M_w$), size and distribution, and the breakdown mechanisms and their relation to the extrusion process.

Macromolecular degradation and product properties
Lower $M_w$ decreases the cold paste viscosity, and influences pasting and geling properties and the degree of retrogradation. The average $M_w$, the polydispersity and the average chain length govern extrudate expansion.

Thermal and shear-induced mechanisms
Heating with or without shear can induce breakdown. Heating of dry starch leads to extensive depolymerization and provides ‘British gums’ (Tomasik and Wiejak, 1989). When small amounts of water are present, hydrolysis reactions may take place.

When low-moisture starch is subjected to combined heating and shearing treatment, a variety of physical and chemical changes occur. The granular structure is lost, native crystals are partially molten and macromolecules can be disrupted. Amylopectin is more sensitive than amylase, probably because of its branched structure.

Van den Einde et al. (2003) showed that the peak stress during heating and shearing determines the degree of starch degradation, provided that there are no significant thermal effects. This may be attributed to covalent bond breakage by mechanical stress along the polymer chain. The time-dependency of the bond-breakage is, however, a matter of discussion because of conflicting results. Moreover, there seems to be a certain selectivity and probably only the larger molecules are broken down.

Extrusion and macromolecular degradation
Screw speed and temperature, re-extruding, the specific mechanical energy and the amylase content all affect on the molecular degradation as its occurs along the extruder screw. Control of the degradation is important to ensure specific product characteristics. The physical processes in the extruder are a combination of thermal and shear mechanisms; advances in numerical flow calculations are observed, but the very complex patterns in the extruder are not yet fully understood. Moreover several different types of extruders exist, each with its own characteristics.

Process, equipment and product design
Selective, energy-efficient processes that produce products with specific characteristics are the objective of much product development. The main disadvantage of the extruder is the inhomogeneous shear and elongation rate, causing non-selective breakdown. As selective starch breakdown may be possible as long as no thermal breakdown occurs, there is an opportunity for equipment that provides a better-defined flow and a homogenous high shear or elongation stress for a short time period. Such equipment will provide a wider window for product-driven process engineering and for new products.

Use of consumer collages to define consumer preference
Consumer choices are partly based on feelings, emotions and experiences. In order to define guidelines for product design in home meal replacements, as well as relevant product attributes, Costa et al. (2003) used consumer collages to determine the underlying considerations of consumer choice. Most of the current research into identification of consumers is verbo-centric, but recent insights in psychology and neurobiology show that the decisions are not so rational, as can be concluded from these studies.

Home meal replacements (HMR), in particular ready meals, are a growth market and the needs and the consumer decision-making are of particular interest for product development. When it is assumed that consumers are rational decision-makers, it is assumed that they are objectively evaluating available products, the benefits thereof and the combination of maximum satisfaction and lowest cost. When emotions play a certain role, investigations based upon reason are incomplete and do not provide a sound basis for product design. In verbo-centric investigations consumer test panels
have a tendency to show that their choice is more rational than actually is the case. A research into customer need identification should take this human factor into account.

A method to counteract these drawbacks is the use of collage studies. In such a study consumers are given magazines, scissors, paste and paper and asked to cut out pictures that represent their feelings, emotions and experiences regarding the product category under study. They are requested to make meaningful collages from magazine clippings. From a reasonably wide selection of magazines contemporary issues were provided to two panel groups, that each prepared a collage from clippings. The groups presented their collages to each other and then a discussion followed. Probing questions were asked about the collage of the other group, to start a group discussion.

In spite of the appreciation of convenience in home meal replacements, the participants did not always see ready meals as the ideal solution. Cooking can be an inspiring, restful and pleasurable event, but it can also be an efficiency-driven, stressful experience. Home-made meals should be simultaneously tasty, healthy, i.e. contain plenty of fresh vegetables, and simple and quick to prepare. Nevertheless, ready meals were not always seen as the ideal solution to replace or speed up home-made meals. Criticism of the HMR's was that they are too fatty and salty and that the amount of vegetables is too small. An interesting element was that there was also certain guilt when using ready meals. The good few vs the bad many aspects of using ready meals became apparent from the collages regarding using ready meals. The study defined a number of concrete consumer needs, as well as direct and indirect suggestions for product improvement. Image-based consumer research tools for product design may help reduce development costs, bridge the gap between design and actual product development and provide the high degree of customer involvement considered essential for food product development.

As food-related consumption behaviour is to a great extent based on oversimplified and irrational decision-making processes, emotional aspects also play an important role.

**Food matrix engineering**

Dehydration and rehydration processes concern heat and mass transport phenomena coupled with macro- and micro-structural changes in structured food systems. Control of these changes is a major aspect of food engineering, because of the effects of the processes of food functionality and the interactions with the consumers.

The objective of food matrix engineering is to apply the knowledge of composition, structure and physical-chemical properties to control the changes during dehydration and rehydration in order to improve the sensorial and functional properties of the food. Many phenomena can be observed, such as heat and mass transfer, vaporization-condensation, internal gas or liquid release and internal gas or liquid release. Often several of the occurring phenomena are coupled during the drying and rehydration process.

Fito and Chiralt (2003) provided an overview of the food dehydration fundamentals by drying or osmosis, particularly for structured foods cellular issues and food colloids. The major characteristic of food systems is their high degree of complexity. Food can usually be considered as soft condensed matter, with a cellular-based structure. Other foods may be considered as colloidal systems. The chemical composition of foods shows a large number of components, some of them biopolymers. The structure of food shows often compartment cellular tissues or colloids. From the thermodynamic point of view, food is a multi-component polyphasic system.

Dehydration–hydration modelling is complex. Different mass transfer mechanisms occur in cellular tissues and the hydromechanic systems are usually coupled with deformation relaxation phenomena. Fick’s diffusion mechanism alone is not sufficient to properly describe the mass transfer phenomena in such complex systems, wherein the porosity is also affected by time and distance.

The mechanical stress stored in the food matrix during drying due to shrinking is released as sample swelling. This causes pressure gradients in the food matrix, which promote the flow of external liquid into the structure. Heat generated by microwaves can be used to create final products that differ greatly in structure, texture and shape.

New products with improved composition and sensorial properties may be developed by applying microwaves generating high heat fluxes, osmotic dehydration, vacuum impregnation and common air-drying or combinations thereof.

**Bio-Medical Product Technology**

**A voice-producing element for laryngectomized patients**

Surgical removal of the larynx may be necessary as the ultimate treatment for laryngeal cancer. Such an operation leads to a severe handicap in human verbal communication—the loss of voice. A substitute can be obtained by vibration of the mucosal tissue at the entrance of the oesophagus. Air is brought into the oesophagus by a silicone rubber shunt valve, placed in a fistula, intentionally created in the tissue wall. The voice has a low frequency, which is embarrassing for women, as it leads to confusion as to the gender of the speaker, particularly over the phone.

De Vries et al. (2000) developed a voice-producing element with the possibility of varying the mean speaking frequency. In the product development two approaches were used: numerical modelling and in vitro testing, thus creating a feedback loop by providing guidance from the testing to improve the numerical model.

**Geometry**

The voice-producing element is at best placed at the same location as the original vocal folds, i.e. at the shunt valve between the trachea and the oesophagus. The voice-producing element has a diameter of 5 mm and a length of 10 mm, depending upon the type of shunt valve.

**Energy supply**

The airflow supplies the energy for the vibration of the voice-producing element. The ranges of pressure and mean flow are determined by the patient, while the aerodynamic properties of the shunt valve largely determine the relation between flow, pressure and the voice-producing element.
Voice sound characteristics

In order to avoid monotonous speech, the frequency should variable. Semitones and harmonics are important for the intelligibility of speech produced by the user of the voice-producing element. The lip principle was selected for further development and numerical models based on a finite element method were developed.

Testing

Prototypes were tested in vitro and later in vivo on patients and showed that an acceptable speaking fundamental frequency could be obtained, although the resulting speech is rather soft. Development is being continued, for example, the combination with commonly used shunt valves.

Fixation

Geertsema et al. (2001) studied the fixation of laryngeal prostheses in a subsequent study. The tissue connector consists of a titanium ring penetrating the tracheal epithelium. It is fixed to a propylene mesh that allows the ingrowth of soft tissue, thus anchoring the titanium rings to the trachea. The biocompatibility was tested by implanting the tissue.

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**Table A1. Presentations of the process route to obtain specific products.**

<table>
<thead>
<tr>
<th>Author</th>
<th>Remarks</th>
<th>Product</th>
<th>Process</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>L.B.P.M. Janssen</td>
<td>Mixing with polystyrene (starch + polyoles) to increase water resistance</td>
<td>Thermoplastic starches</td>
<td>1. Mixing and 2. Re-extrusion</td>
<td>Biodegradability Mechanical properties</td>
</tr>
<tr>
<td>Chyi-Cheng Chen</td>
<td></td>
<td>Vitamin E nanoparticles</td>
<td>Ultrahigh-pressure homogenization</td>
<td>Particle size reduction and stabilization</td>
</tr>
<tr>
<td>H. Schubert</td>
<td></td>
<td>Carotenoids</td>
<td>1. Premix to coarse emulsion 2. Homogenization nozzle</td>
<td>Homogenization pressure</td>
</tr>
<tr>
<td>K. Jorgensen</td>
<td>Impact resistance improvement</td>
<td>Enzyme granules</td>
<td>Layer coating or homogeneous high shear granulation</td>
<td>Impact resistance</td>
</tr>
<tr>
<td>H.P. Schuchmann</td>
<td></td>
<td>Cereals</td>
<td>Cooking extrusion (intermeshing co-rotating twin extruder)</td>
<td>Texture and mouth-feel</td>
</tr>
<tr>
<td>M.J. Steinbeck</td>
<td>Penetration rate</td>
<td>Crop protection, aromas, baking mixes</td>
<td>Encapsulation, granulation</td>
<td>Controlled release</td>
</tr>
<tr>
<td>U. Broeckel</td>
<td></td>
<td>Stabilized fertilizer</td>
<td>Coating of granules</td>
<td>Controlled release</td>
</tr>
<tr>
<td>F. Vilasca</td>
<td></td>
<td>Polystyrene reinforced lignocellulosic fibres to fibres</td>
<td>Extrusion into pellets, injection moulding</td>
<td>Mechanical properties (fraction resistance, flexion hardness)</td>
</tr>
<tr>
<td>S. Kill</td>
<td></td>
<td>Anti-fouling paints Math modelling, testing</td>
<td>Paint testing</td>
<td>Adherence</td>
</tr>
<tr>
<td>A.A. Broekhuis</td>
<td></td>
<td>Inuline strength</td>
<td>Spraying, lubrication</td>
<td>Binding hollow particles that fracture during tableting operations, not before Defect-free films</td>
</tr>
<tr>
<td>A.B. Jarebski</td>
<td></td>
<td>Sol–gel films</td>
<td>Dip-coating of different supports</td>
<td></td>
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<tr>
<td>G. Schmidt-Nahe</td>
<td></td>
<td>Stable oxalinium salts</td>
<td>Cationic grafting of oxazolyl copolymers</td>
<td>H-NMR spectra</td>
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<tr>
<td>J. Abildskov</td>
<td></td>
<td>Thermopane windows</td>
<td>Sealing</td>
<td>Thermal insulation, permeability of light sealing and prevention of gas leaks</td>
</tr>
<tr>
<td>M.A. Pètach</td>
<td></td>
<td>Eucalyptus pulp</td>
<td>Refining by valley beater</td>
<td>Cationic demand</td>
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<td>H.J. Heeres</td>
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<td>Lactite-based micropores</td>
<td>Water–oil–water emulsion evaporation</td>
<td>Drug release</td>
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<td>A. Gnatowski</td>
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<td>PA–PP blends with PVA (polvinylamide)</td>
<td>Injection moulding</td>
<td>Mechanical properties</td>
</tr>
<tr>
<td>T. Johannessen</td>
<td></td>
<td>Composite metal oxides</td>
<td>High-temperature flame synthesis</td>
<td>Coating stability</td>
</tr>
</tbody>
</table>

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**Table A2. Product stability and product testing.**

<table>
<thead>
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<th>Author</th>
<th>Product</th>
<th>Test</th>
<th>Characteristic</th>
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</thead>
<tbody>
<tr>
<td>A.R. Zarubica</td>
<td>Polyurethane, epoxy and alkyd varnishes</td>
<td>UV radiation</td>
<td>Mechanical features, resistance to UV</td>
</tr>
<tr>
<td>A.R. Zarubica</td>
<td>PVC, chlorinated</td>
<td>UV radiation</td>
<td>Colour differences</td>
</tr>
<tr>
<td>S. Chemki</td>
<td>Potatoes</td>
<td>Humidification</td>
<td>Moisture sorption</td>
</tr>
</tbody>
</table>
connector in rats and goats. The future for human use looks promising.

Overview of the Presentations at the First European Symposium on Product Engineering

From 21 to 25 September the First European Congress on Product Engineering was held as part of the Fourth European Congress (ECCE-4) in Granada, Spain. From this overview (Voncken, 2003) it is apparent that there are many processing routes to obtain a specific product meeting its performance requirements (Tables A1–A3).

APPENDIX REFERENCES


