Product engineering and sustainability

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Abstract. Chemical engineering has made a substantial contribution to the improvement of the environment during the last decades. Many processes have become more sustainable and harmful waste streams are minimised. However, considerable improvement of sustainability can still be obtained in product engineering and design. Especially the aspects that are important at the end of the life cycle of the product can be improved considerably. A priority list for the design of more sustainable products is presented and illustrated with examples of daily chemical engineering practice.

1. Introduction

During the last decades the awareness of sustainability has induced several changes in chemical engineering practice. In recent years, however, the emphasis in sustainable chemical engineering has been lying mainly in the field of process improvement. Judicious optimization of individual process steps and improved process integration have led to significant minimisation or even to the complete prevention of undesired waste streams in process industry. Significant further contributions from chemical engineering to a more sustainable world can also be achieved in the area of product design and product engineering.

In order to design for optimal product sustainability it is important to consider the total life cycle of a product and to distinguish clearly between the three life cycle steps of a product: production, utilisation and disposal. The requirements for production and utilisation are generally well considered in the concepts of basic product engineering and they are also directly related to marketing and product economics\cite{1}. However, the end of use conditions still need more emphasis in order to come to a real ‘green’ product design.

These end of use requirements contradict often to the properties that are desired during the actual utilisation of the product. For example, in biodegradable packaging hydrophobicity is important for good product stability but for a well-controlled and swift degradation after use a certain degree of hydrophilicity of the product is indispensable. A complicating factor in the acceptance of a sustainable design is the fact that higher quality during the utilisation step can directly result in a higher price where the willingness the pay more for the sustainability of a products is only very moderate. As a rule of thumb it is often assumed that the customer is not willing to pay more than 10% extra for a more sustainable product.

Sustainability considerations are currently not taken into account sufficiently. The focus seems to be on the development phase of a product. First we discuss shortly this development phase. Consequently, we discuss some sustainability considerations. Finally a set of illustrations is given how the sustainability of a product can be improved so that its impact at the end of use is less severe to the environment.
2. The development phase.
During the design of a product two distinct steps can be distinguished (figure 1). In the first step, the diverging step, as many new ideas as possible are generated while in the second step, the converging step, the new ideas are tested and evaluated. The objective of the diverging step is to obtain as many new alternatives for the product and process as possible without too much concern about any possible constraints. It is clear that in this brain storming step of the product development not too much consideration is generally given to the sustainability of the product and the process.

This will mainly occur in the second step, the evaluation phase of the product. Here the process converges by critically scrapping many alternatives to come to the final design. In this step emphasis lies on the interactions between product, process, marketing and sustainability. In this step special attention must be given to the following considerations:
- existing know-how and experience,
- considering financial and time constraints
- environmental impact of the product.

In a normal development path the converging and diverging step will be passed in an alternating way many times. However, the more the final product concept is approached, the more important the converging step becomes and the more emphasis has to be given to the sustainability of the final product.

![Figure 1: Two steps in product design: idea generation (diverging) and evaluation (converging)](image)

3. Sustainability considerations.
In order to decrease the impact of a product at the end of its use, more attention needs to be paid to the disposal and the recycling in the development phase of the product. When considering the end of use alternatives for a general product several different alternatives can be distinguished. These alternatives can be ordered according to their sustainability hierarchy or environmental preference. Two additional effects should be taken into consideration when designing a product:
- environmentally undesired components should be avoided (like Volatile Organic Solvents (VOS) and certain heavy metals)
- preferably very limited amounts of components with a limited availability should be used (like for instance Lithium or Lanthanum)

Although the relative importance of the different environmental considerations strongly depends on the product considered they can be put in a generalized order of preference:
- avoid the use of hazardous components
- make the product re-usable
- avoid depleting feed stocks
- design the product for easy ‘back to feedstock’
- re-use the product as filler
- re-use the recycle for lower quality products
- facilitate clean pyrolysis
- avoid hazardous smoke at incineration
- avoid tailings in case of land fill
4. Illustrations

Examples of the list above can be found in many all-day products. This list is not extensive but serves as an illustration of the possibilities and challenges in sustainable product engineering.

1. Hazardous components should already in the design phase of the product be avoided as much as possible. VOS can sometimes be substituted by more benign solvents like ionic liquids[2,3] or supercritical carbon dioxide[4]. A very well-known example of VOS substitution is water based paint, where the irreversible solidification of the binder occurs by a chemical reaction after the water has evaporated. Another possibility to avoid hazardous materials is the use of modern organic pigments that make it possible to eliminate heavy metals for colored products.

2. Re-usable products, like deposited packaging are preferred if possible. Although this seems to be an obvious conclusion it can only be applied in a very limited way. Too often plastic bottles are used for storage of other materials like gasoline or organic solvents. These components can diffuse into the bottle material and therefore form severe restrictions to re-use. Special care has to be taken with food packaging because these pollutions can form a serious health hazard on re-use.

3. Avoiding depleting feed stocks is especially important if the materials are scarce and have a limited availability. Lithium and Lanthanium are examples of elements that are widely used in electronics and for batteries and indispensable for the present electric car technology. The total minable amount of these elements is limited which implies that prices and availability can change quickly. Moreover most of these elements are concentrated in limited areas in the world and therefore subject to geopolitical tensions. The threat of a delivery stop of Li for electrical cars by P.R. China to the Japanese car industry has recently increased the research in other types of batteries. But also if the base materials are not scarce the use of renewable resources is important for avoiding depletion. Several new bioplastic products have been introduced in de last decade using common materials like celluloses and starches[5]. Also the production of fuels and platform chemicals from biomass contributes to the avoiding of depletion[6].

4. Re-use the product as a filler is only scarcely applied in plastics and rubber industry but it forms an economically attractive way of re-using old materials. Co-injection molding techniques allow to form an object which inside consists of reused polymers while the outside consists of virgin material[7]. Another example of re-use as filler can be found in the tire industry where the objective is to substitute a few percent of the virgin rubber in car tires by partly devulcanized rubber from old tires. Research of this application looks promising.

5. Back to feed stock can form an alternative for the reuse of plastic products. Because of this possibility thermoset materials should be avoided in the design as much as possible. When using thermoplastics, the returned products can be regranulized and the polymer can be devolatized to remove traces of impurities. Successively the granules can be extruded or injection molded to be formed into new products. Care has to be taken that no mixing of different types of polymers occurs. Due to the bad miscibility of (high molecular weight) polymers in general, traces of impurities will result in very poor product quality. During the design of a product it is preferential to use only one type of polymer or to have easily separable units each consisting of one single material.

6. Re-use for lower quality can be an alternative for the use of the recycle for the same product. It is particularly attractive if the possibility to purify the recycle stream is limited like in food packaging. A rather recent new technique is the use of devulcanized tire rubber to reinforce bitumen roof coverings[8]. This technique can also be used instead of back to feed stock. A typical other example is the production of large sheets of PET (poly ethylene terephthalate) for agricultural use. Plants are protected against winter conditions and against
pests by these sheets made of PET bottles.

7. Pyrolysis of waste streams is often considered if the alternatives above are technically or economically not feasible. Many of our waste streams still possess a large amount of useful components that can be obtained by cracking or pyrolysis. Relatively clean biomass can be used to obtain syngas. Another product from the pyrolysis of organic waste is biochar that can be used as fertilizers. Cracking of plastic waste streams can produced an oily substance with a slightly higher certain number than conventional diesel oil[9]. The pyrolysis of tires is reported to produce methane gas, combustible fluids and carbon black.

8. Incineration can occur in a controlled way in large incineration ovens or uncontrolled by small local fires. Controlled incineration can sometimes be used to obtain part of the formation energy that is still available in the waste stream and it is sometimes called thermal recycling. If the product is likely to be burned in an uncontrolled way (open fires at a country side) it is important that during the design of the product such materials are chosen, that the smoke from the fires does not contain harmful components.

9. Land fill as a way of disposal should in general be considered to be a last resort. If land fill is likely, the product should not contain components that can be leached out easily and come into contact with the soil and the water. This can result in serious pollution of the drinking water[10].

5. Conclusions

After the development in process engineering product engineering forms an area with interesting new possibilities in chemical engineering. Whereas many efforts have been successful to make processes more environmental friendly, improving the sustainability of products still forms a challenge. Although different products require different measures to improve their sustainability it is possible to present a generalized list of considerations and to order these measures in an order of urgency or desirability.

6. References

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