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Process Design and Evaluation of Biobased Polyhydroxyalkanoates (PHA) Production

Karl-Heinz Kettl[1*], Michaela Titz[1], Martin Koller[2], Khurram Shahzad[1], Hans Schnitzer[1], Michael Narodoslawsky[1]

[1] Graz University of Technology, Institute for Process and Particle Engineering Inffeldgasse 21a, 8010 Graz, Austria, kettl@tugraz.at
[2] Graz University of Technology, Institute for Biotechnology and Biochemical Engineering, Petersgasse 12, 8010 Graz, Austria

Conventional plastic products are made of crude oil components through polymerization. Aim of the project ANIMPOL is to convert lipids into polyhydroxyalkanoates (PHA) which constitute a group of biobased and biodegradable polyesters. Replacing fossil based plastics with biobased alternatives can help reducing dependence on crude oil and decrease greenhouse gas emissions.
As substrate material waste streams from slaughtering cattle, pig or poultry are taken into account. Lipids from rendering site are used for biodiesel production. Slaughtering waste streams may also be hydrolyzed to achieve higher lipid yield. Biodiesel can be separated into a high and low quality fraction. High quality meets requirements for market sale as fuel and low quality can be used for PHA production. This provides the carbon source for PHA production. Nitrogen source for bacteria reproduction is available from hydrolyzed waste streams or can be added separately. Selected microbial strains are used to produce PHA from this substrate.
An optimized process design will minimize waste streams and energy losses through recycling. Ecological evaluation of the process design will be done through footprint calculation according to Sustainable Process Index methodology (Sandholzer et. al, 2005; Narodoslawsky and Krotscheck, 1995).

1. Introduction

Plastics are very frequently used products which are produced from crude oil. Many products are based on plastic and therefore are also fossil based. Polyhydroxyalkanoates (PHA) or Poly-β-hydroxybutyric acid (PHB) are biologically based polymers which are now produced mostly from sugar cane or molasses (Harding et. al., 2007). Aim of the ANIMPOL project ("Biotechnological conversion of carbon containing wastes for eco-efficient production of high added value products"), funded by the European Commission within the 7th Framework program, is to produce biobased plastics (PHA) out of animal waste streams.
Especially waste from slaughtering industry can be used as source for lipids and nitrogen. Both are needed for PHA production. Starting from rendering products like tallow, biodiesel can be produced chemically via transesterification. Two different

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qualities of biodiesel are available. A high quality unsaturated biodiesel fraction for the fuel market and a low quality biodiesel fraction containing mainly saturated fatty acids. Low quality biodiesel can be used for PHA production.

2. Process Design and Assessment

To get the highest efficiency for the PHA production, Cleaner Production Studies will be done to build a process design. Through Process Intensification (PI) technologies, energy demands will be decreased to a minimum level. The design also implements the objectives of cleaner production. After optimizing the design in terms of specific technologies, an ecological footprint will be calculated according to the Sustainable Process Index (SPI) methodology.

2.1 Process Intensification (PI)

PI is a paradigm shift in process design. The focus concretes on minimization of the plant size and the reduction of energy intensive structures, as well as the use of internal gains. In the 1970s Colin Ramshaw and his co-workers at The Imperial Chemical Industries lead the development of this concept. Process Intensification was defined as a "reduction in plant size by at least several orders of magnitude" (Doble and Kruthiventi, 2007).

There aren't any clear boundaries between the concepts of Process Intensification and the general approaches of process optimization. Only the way on how the main goals of reduction - energy as well as resources and consequently also Greenhouse gas emissions- could be achieved, is different. Unlike process optimization, which focuses on the improvement of established systems, Process Intensification creates new processes and structures. Therefore, reachable efficiency potentials, especially in concepts with Gordian process structures, are not only geared on the development of new technologies, but on the development of new processes and structures using existing technologies. Solutions which are accomplished by Process Intensification are tailored to particular needs. Because of the given reason, it is possible to improve the energy efficiency in a sustainable way by setting objectives (Moulijn et. al., 2008).

2.2 Sustainable Process Index (SPI)

To measure the ecological impact of the PHA production an ecological footprint is used. This value allows comparing different products in terms of their environmental burden. Production processes for conventional fossil based plastics can be compared with the ANIMPOL PHA production process via the ecological footprint methodology.

SPI methodology (Sandholzer et. al, 2005; Narodoslawsky and Krotscheck, 1995) uses areas as references and is part of the ecological footprint family. Material and energy consumption is taken into account and expressed in an equivalent area of different categories (area for infrastructure, area for renewables, area for non-renewables and area for fossil carbon). Also emissions into the three ecological compartments air, water and soil are part of the overall ecological footprint for the final product. This methodology is well known and already used in other publications (e.g. Eder et. al., 2009, Gwehenberger et. al., 2007).

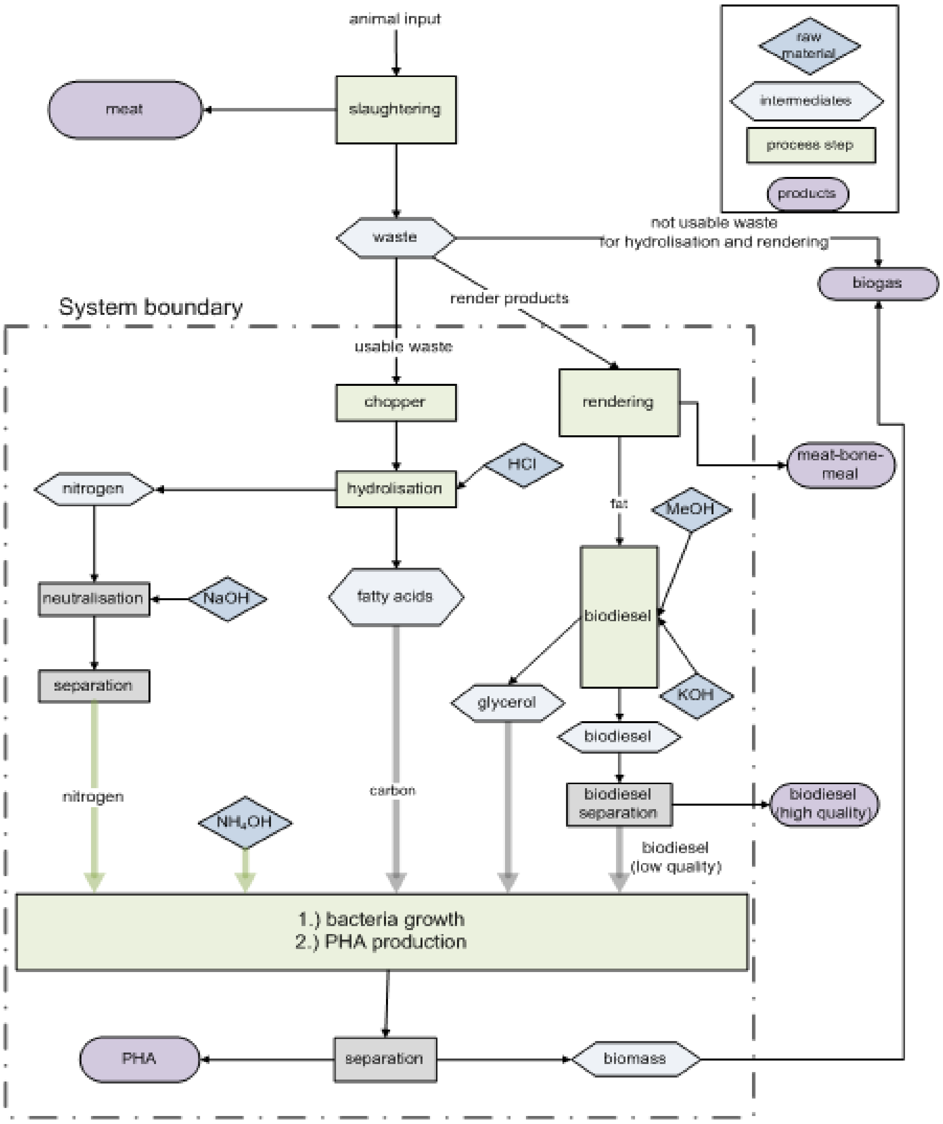

Figure 1: Process flowchart

3. Slaughtering Waste Utilization for Biobased Polyester Production

Meat production is an energy and material intensive process. Fertilizer and fodder production are using much of energy, regarding to the fact that only 36 wt% from a

cattle are sold on the food market in Austria (Niederl and Narodoslawsky, 2004). Waste streams (excluding inwards) from slaughterhouses are used now for rendering to produce meat and bone meal and tallow. Meat and bone meal is sold to the market and tallow can be used as substrate for biodiesel production.
Figure 1 illustrates a flow sheet how waste stream could be utilized in an alternative, value-creating way. There are some key process steps which are described in detail.

3.1 Rendering

Waste fat undergoes rendering which produces meat and bone meal and tallow for biodiesel production. The conventional way of rendering uses every waste stream with the exception of hides and inwards. In our approach a part of the slaughterhouse waste (e.g. hearts, livers, lungs) can be used for hydrolysis instead of rendering.

3.2 Hydrolysis

Hydrolysis can be done using a strong acid like hydrochloric acid. This step produces nitrogen compounds (amino acids and their low molecular mass oligomers) from the proteins which can easily be used for microbial growth prior to the PHA production step. The carbon fraction (mainly odd-numbered fatty acids) will also be used for the growth of bacteria in the first step of the bioprocess and as carbon source in the second step, where the intracellular carbon flux is directed towards PHA accumulation due to the limitation of an essential growth component such as nitrogen- or phosphate source.

3.3 Biodiesel

Biodiesel or in that case TME (tallow methyl ester) is made out of the tallow stream from the rendering process. Methanol is used for transesterification which is catalyzed by KOH. Biodiesel as main product contains a mixture of saturated and unsaturated fatty acids. A higher content of unsaturated fatty acids results in a higher quality of biodiesel. Therefore high quality biodiesel is sold to the market and low quality biodiesel (which contains a high amount of saturated fatty acids) is a substrate for PHA production.

3.4 PHA Production

Nitrogen from the hydrolysis step and carbon is used to produce high concentrations of catalytically active microbial biomass. After the desired concentration of biomass is reached, the nutritional conditions in the bioreactor are changed towards surplus of carbon source. Together with the limitation of another essential growth component the bacteria are performing the intracellular accumulation of the final product polyhydroxyalkanoate. This polyester is biodegradable and can be used to substitute plastics out of crude oil. After the downstream processing, PHA- free biomass components remain as side-product.

3.5 Biogas

To reduce waste stream for the whole process and to supply energy a biogas power plant could be part of the whole process flow sheet. In Figure 1 the biogas unit is outside of the system boundary because it is not a key technology for the PHA production itself. As option the utilization of the PHA-free biomass waste stream after the PHA isolation step is taken into account. Heat from a combined heat and power unit could be used internally for the PHA production and electricity for selling to the market. This can improve economical feasibility and reduce the ecological impact.

4. Conclusions

Taking into account the possible enhancement of each process step in the production of PHA starting from animal-derived residues, one can make considerable progress towards the designing of a cost-efficient and ecologically benign technology. Modern tools of Life cycle assessment and Cleaner production studies provide precious tools to quantify the sustainability and efficiency of the novel bioprocess to be developed. What is needed for an industrial implementation of the promising research results is the narrow cooperation of the experts in the special scientific fields of microbiology, genetic engineering, biotechnology, chemical engineering and polymer science. The successful translation of the project into industry will provide benefit for the industrial sectors of rendering, slaughtering, biodiesel and polymer industry.

References

Doble M. and Kruthiventi A. K., 2007, Green Chemistry and Engineering, Academic Press. California, USA.

Eder M., Sandor N., Kettl K.-H. and Narodoslawsky M., 2009, Ecological impact of renewable resource based energy technologies, Chemical Engineering Transactions, 18, 611-616.

Gwehenberger G., Narodoslawsky M., Liebmann B. and Friedl A., 2007, Ecology of scale versus economy of scale for bioethanol production, Biofuels, Bioproducts and Biorefining, 1(4), 264-269.

Harding K.G., Dennis J.S., von Blottnitz H. and Harrison S.T.L., 2007, Environmental analysis of plastic production processes: Comparing petroleum-based polypropylene and polyethylene with biologically-based poly-β-hydroxybutyric acid using life cycle analysis, Journal of Biotechnology, 130, 57-66.

Koller M., Salerno A., Dias M., Reiterer A. and Braunegg G., 2010, Modern Biotechnological Polymer Synthesis: A Review, Food Tech. Biot, 48 (3), 255–269.

Narodoslawsky M. and Krotscheck Ch., 1995, The sustainable process index (SPI): evaluating processes according to environmental compatibility, Journal of Hazardous Materials, 41, 383-397.