Bacteria to produce bioplastics

Polyhydroxyalkanoates are storage substances produced and stored by many cells, plants and bacteria only in times when they lack important nutrients. A particular property of these plastics-related biopolymers is that their composition and hence their material properties can be regulated by the fermentation process.

The American companies Archer Daniels Midland and Metabolix are planning to put a commercial scale plant into operation in 2009 in order to start producing Mirel™ through TellesTM, their joint venture. The companies have high expectations of Mirel™, a new plastic that consists entirely of renewable resources and is also completely biodegradable.

Mirel™ is based on polyhydroxyalkanoates (PHA), water-insoluble polymers produced by many bacteria and yeasts, but also by plants such as Arabidopsis, rape, tobacco or maize. In order for the bacteria, yeasts and plants to produce PHA, they need to have sufficiently high quantities of sugar, starch or other carbon sources, at the same time as having low quantities of phosphorous, nitrogen or trace elements.

Metabolic pathways determine the product

PHA refers to polymers that are composed of hydroxy carbonic acids, i.e. carbonic aids with one or several additional OH groups. Some organisms are able to combine hydroxy carbonic acids to polyesters due to their specific chemical structures. Over 150 different PHAs are known, and there are good reasons for such a large variety. Cells produce hydroxy carbonic acids from standard intermediary products of the energy metabolism and fatty acid synthesis. When key components in the food supply are lacking, organisms and cells turn to alternative metabolic pathways and form PHAs. Specific metabolic pathways are chosen on the basis of the carbon source provided to the cells, which leads to the creation of PHAs with different chemical structures.

This principle is almost ideal for controlling the chemical composition and the characteristics of PHAs through biotechnological processes. When long-chain carbon sources such as palm oil are used, microorganisms will produce a larger number of PHAs consisting of short-chain 3-hydroxybutyrate and long-chain 3-hydroxyhexanoate molecules. The use of glucose as substrate decreases the number of long-chain 3-hydroxyhexanoate molecules and the resulting PHA is less flexible.

Weaknesses at the base

PHAs can consist of chains of identical components such as is the case with polyhydroxybutyrate (PHB), a polymer which consists of several hydroxybutyrate monomers. However, other types of PHAs can be polymerised from different monomers, with the result that the material characteristics change. Thus, the PHA with the simplest structure, polyhydroxybutyrate, PHB, has two similarities with the mass plastic polypropylene. The melting point of both PHB and polypropylene is around 180 °C and the polymers also have similar tensile strengths. However, PHB has a considerably reduced tear strength. PHB will break if the polymer is lengthened by only 5 per cent. Polypropylene is far more robust; it tolerates elongations of up to 400 per cent. PHB also has weaknesses with regard to the glass transition temperature. This parameter indicates the temperature at which a plastic becomes increasingly brittle and hence fragile as the ambient temperatures decrease. PHB has a glass transition temperature of 4 °C. A PHB dish would therefore be prone to breakage when it is taken out of a well-cooled fridge and dropped on the floor. A better choice of dishes are those made of polypropylene or certain types of polyethylene, which only start to become brittle at temperatures as low as -10°C or -30°C, respectively.

Natural polymer plasticisers from biological processes
The most important and commonest polyhydroxyalkanoate (PHA): 3-hydroxybutyrate

Despite all these limitations, PHB along with many other PHAs are technically relevant plastics. If 3-hydroxybutyrate, the monomer used to polymerise PHB, is combined with a close relative, 3-hydroxyvalerate, in a polymer, the material's parameters will change considerably. If 20 per cent of the butyrate molecules are replaced by 3-hydroxyvalerate, the polymer's melting point decreases to 145°C, the material becomes a lot more elastic, has a glass transition temperature of -1°C and the tear strength increases ten-fold.

Short – medium - long

There are three major types of PHA. Short-chain PHAs consist of basic molecules with a backbone of between three and five carbon atoms. Medium-chain PHAs consist of hydroxy carbonic acids with a backbone of six to 14 carbon atoms. Long-chain PHA consists of basic units that are more than 14 carbon atoms long. The higher the proportion of medium- and long-chain basic elements they contain, the more polymers take on the properties of elastomers. They develop a rubber-like structure which can be stretched and which then returns into its original shape when the tension is reduced.

Many points of intervention

PHAs can be used in many fields of application. The design parameters used by bio- and plastics technologists to synthesise made-to-measure polymers are process control, the selection of nutrients and organisms. Further design options arise from the possibility of using genetic engineering and systems biology methods to adapt the metabolism of the organisms used to synthesise the required polymer.
The enzyme PHA synthase is the key enzyme for the biosynthesis of PHA. It combines the basic units into a polymer. The PHA synthases of different organisms do not act identically although they have the same tasks, at least in biochemical terms. Some synthases prefer short-chain building blocks while others prefer medium-chain building blocks and still others work best with long-chain building blocks. Using genetic engineering methods, biotechnologists can tailor the synthases exactly to the characteristics of the basic monomers, thereby improving the quantity and homogeneity of the final polymer.

Quality, costs and image

Mirel™, a bioplastic produced on the basis of PHA, will be launched next year. According to the manufacturer, there are already numerous clients interested in using the bioplastic. The polymer chemistry seems to be in place, the plastic is suitable for the production of device casings, tins, dishes and other items used for packaging consumer goods. However, it remains to be seen whether the chemistry between the bioplastic and the consumers is also the right one. Mirel™ will cost about 1.50 euros per kilogram – polypropylene costs about 85 cent. For Metabolix, the price is secondary in the company’s bid for market shares: “We have a premium product with top-class characteristics for the environment,” said a company representative rather optimistically, hoping that the ecofactor will reinforce the image of the plastic.