Lupranol Balance – Eco-Efficiency-Analysis

1. From castor oil to the polyol

In the past there have been numerous attempts to use natural raw materials in the manufacture of polyetherols. The disadvantages of these products were poor processability, high odor and emission. The main reasons for this lack of performance are usually the anionic and acidic reaction conditions during the production of polyols.

For the first time BASF and Elastogran research and development experts have succeeded in the development of a polyetherol on the basis of the oil of the castor-oil plant which does not display any of these disadvantages.

For some time polyurethane experts have been researching into a completely new type of catalysts, double metal cyanide (DMC) catalysts. The main components of the DMC catalyst are commonly zinc and cobalt. This catalyst is many times more reactive than potassium hydroxide. Traces of the catalyst are sufficient to start a reaction between castor oil and ethylene and propylene oxide **(fig. 1).** The distinct advantage is that the solid catalyst is neutral and therefore saponification can not occur. As a direct result, it is not possible to detect any cycles of the ricinoleic acid cycle in the polyol and/or the foam (< 1 ppm) which renders the latter nearly odourless.

2. Lupranol Balance 50 and its use in flexible slabstock foam

Lupranol Balance 50 is a natural oil polyol (NOP) based on castor oil. It is the only NOP that can be used as a 100 % drop-in for any other conventional slab polyol. Changes to the slabstock foam formulations are usually not necessary. A main point where NOP usually fail are emissions and odour – factors who have become increasingly important in past years. Emission measurements show that the Balance 50 can easily compete even with the low-emission slab polyol Lupranol 2084.

This has been proven by the chamber test for mattresses conducted by the LGA (Landesgewerbeanstalt Bayern – trade institute of the state of Bavaria). The limit value for total emissions after 7 days is 500 µg/m^3 and can easily be achieved with values far below. With respect to this also CertiPUR standards can be accomplished with foams based on Balance 50.

Foams based on Lupranol Balance 50 have also been comprehensively tested for their mechanical properties. Whereas the mechanics show no difference towards standard slab foams, the hydrophobic structure of the Balance-polyol leads to slightly better ageing properties.

Lupranol Balance 50 is based on a content of 31 % castor-oil. This means that up to 25 per cent of the weight in the polyurethane slabstock foam can be replaced with renewable resources **(fig. 2).**

3. Eco-Efficiency Analysis

3.1 Method

3.1.1 What is eco-efficiency?

The purpose of Eco-Efficiency Analysis is to harmonise economy and ecology. BASF SE in Ludwigshafen, Germany, is one of the first chemical companies to develop this method

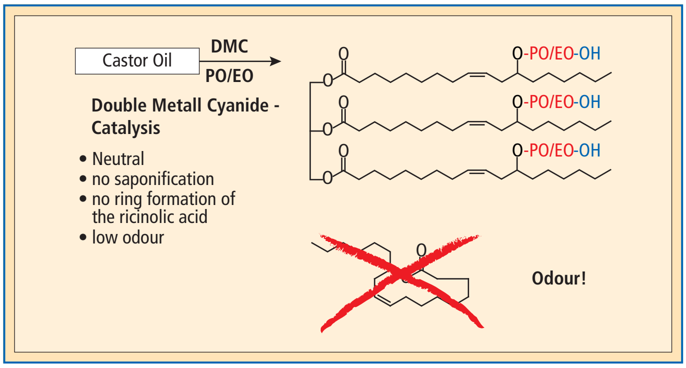
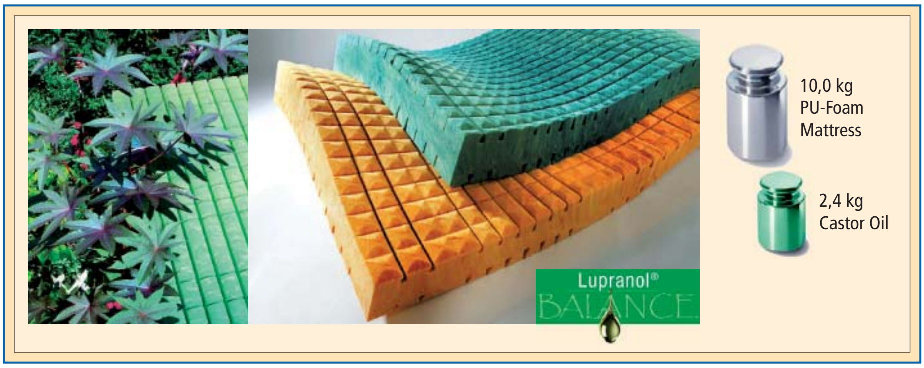


Fig. 1: *Alkoxylation of castor oil with BASF "DMC"-catalyst polyol production technology*

Fig. 2: *Lupranol Balance 50 used in high quality flexible foam mattresses*



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for use in its business activities. BASF employs this approach to determine which products and processes it will pursue in the future. This in-house tool was developed in 1996. To date, about 300 different products and manufacturing processes have been analyzed using the new method. BASF applies the Eco-Efficiency Analysis in order to use as few materials and energy as possible in producing products and to keep emissions as low as possible. Additionally , in many cases BASF also help our customers to conserve resources.

3.1.2 From the cradle to the grave

Eco-Efficiency Analysis assesses the life cycle of a product or manufacturing process from the "cradle to the grave." For example, it includes the environmental impact of products used by BASF as well as of starting materials manufactured by others. The analysis also takes the consumption behavior of end-users into account, as well as various recycling and disposal options.

First, the environmental impact is described based on six categories:

- Raw materials consumption
- Energy consumption
- Land use
- Air and water emissions and disposal methods
- Potential toxicity
- Potential risks.

Fig. 3: *Label of the Eco-Efficiency Analysis*

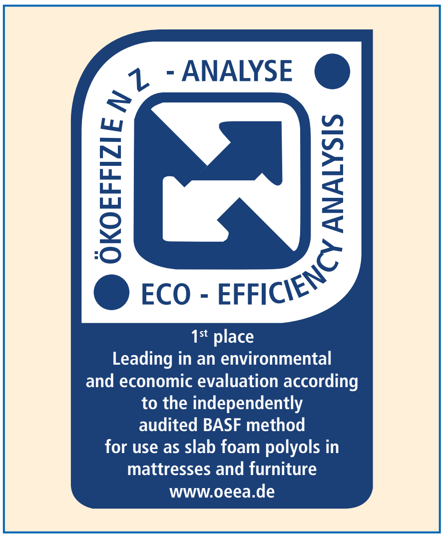


Fig. 4: *Certification by the TÜV Rheinland/Berlin-Brandenburg, Germany*

Combining these individual data gives the total environmental impact of a product or process. Furthermore, as described below recent analysis based on BASF market data provides quantification of environmental benefits along consumer relevant measures such as electricity consumption, barrels of crude oil saved, deforestation, smog creation, acid rain emissions, water pollution, waste and landfill reduction.

3.2 Label Eco-Efficiency Analysis

BASF SE has developed a new label **(fig. 3)** for products that have been evaluated by an Eco-Efficiency Analysis. The methodology of this analysis is certified by the TÜV Rheinland/Berlin-Brandenburg, Germany (www.tuv.com/ID5711150561) **(fig. 4).** After realization of the analysis a third party evaluation (critical review) is performed. Furthermore, publication of the results of the analysis will be undertaken via internet (www.oeea.de).

The label can be carried on for three years. After that period, a revision of the analysis is required due to cover market developments and product diversity.

3.3 Eco-Efficiency Analysis of Lupranol Balance 50

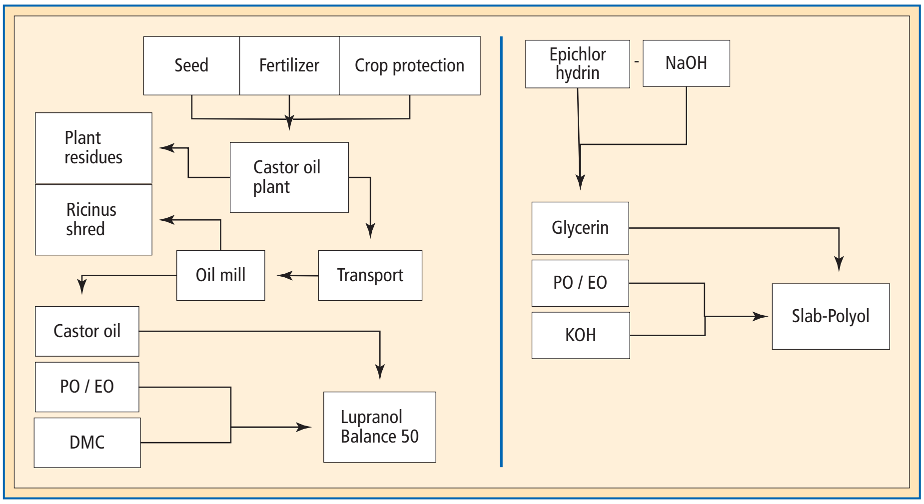
3.3.1 Definition of System Boundaries

Lupranol Balance 50 can be directly used as a drop-in for standard slab polyols in the production of polyurethane flexible slabstock foam. Therefore a standard slab polyol was chosen as a direct alternative in the eco-efficiency scenario. As foam production, phase of value (utilization) and disposal are considered to be the same, only the polyol production needs to be taken into account for the eco-efficiency analysis **(fig. 5).**

3.3.1.1 Determination of environmental impact

The environmental impact is determined on the basis of six main categories: toxicity potential, risk potential, resource consumption, land use, energy consumption and emissions. Weaknesses and potentials driving environmental impacts can easily be identi-

Fig. 5: *System boundaries for the production of Lupranol Balance 50 (left) and a conventional slab-polyol (right)*



fied and described in this way. Data acquisition and calculation is done according to ISO 14040.

3.3.1.2 Toxicity potential

The toxicity potential is calculated using the R-phrases (safety classification) of the chemicals and components being used defined by the system boundaries. Each R-phrase and combinations of it are linked to calculation values between 0 – 1000. E.g. R26/27, toxic, is linked to the value 750 and a less critical category R35, acidly, is linked to the value 300. The balance and addition of the calculated values along the defined life-cycle multiplied by the amount of the components being used results into the overall assessment of the toxicity potential.

Taking into account the above mentioned system boundaries of the production of Lupranol Balance 50 and a standard slab-polyol the tox potential is as depicted in **figure 6.**

The much better performance of the natural oil polyol Lupranol Balance 50 is remarkable. The main reason for this is the large amount of the castor oil which is used for the production.

3.3.1.3 Risk potential

The risk potential reflects the danger of accidents in the manufacture, use and recycling of the polyol. The values used for the individual products are comparative. The assessment is based on statistical data taken from employers' accident insurance on workplace accidents, transportation accidents, plant safety, fire behavior etc.

The use of castor oil derived from agricultural production mainly from India leads to an impact of potential workplace accidents due to a high share of manual labor and lower occupational safety conditions compared to US or EU standards. Nevertheless castor oil has a positive impact in fire and plant safety. The reason for this is the substitution of propylene- and especially ethylene-oxide.

3.3.1.4 Resource consumption

Under resource consumption, the mass of raw materials needed by the polyol production process is determined. The individual materials are weighted according to their reserves according to the statistical calculations of the USGS (US Geological Survey, Mineral Commodity Summaries (1997)). They predict for how long a particular raw material will still be producible with today's economical methods assuming consumption stays the same. Renewable raw materials are considered to have infinite resources as long as they are sustainable managed. If not, because e.g. of rainforest logging, the appropriate resource factor is applied.

Figure 7 shows the weighted consumption of raw materials being used. Especially oil and gas reserves are preserved when using castor oil in the production of Lupranol Balance 50. Based on a theoretical BASF Corp. analysis, annually more than 320,000 metric tons of fossil fuels could be saved by using Balance 50 compared to conventional, petroleum-based polyol, which in turn translates into 20,000 barrels of crude oil saved. Based on 100 percent replacement of conventional polyols in the manufacturing of all NAFTA flexible foam demand (2007 market data).

3.3.1.5 Energy consumption

Energy consumption is determined over the entire life cycle and describes the consumption of primary energy. Fossil energy media are included before production and renewable energy media before harvest or use. In case of BASF processes specific BASF data is used otherwise UCTE (Union for the Coordination of Transmission of Electricity) data is taken into account.

The 12 % savings in energy consumption is due to the fact that castor oil partly substi-

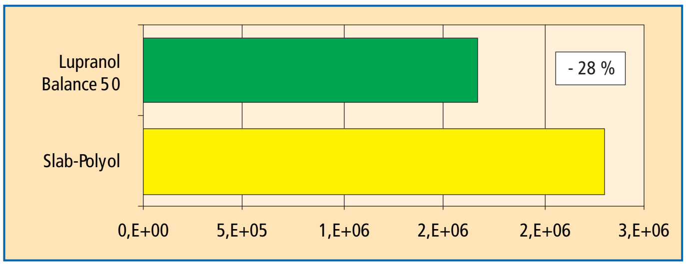


Fig. 6:
Toxicity potential assessment unit [-]

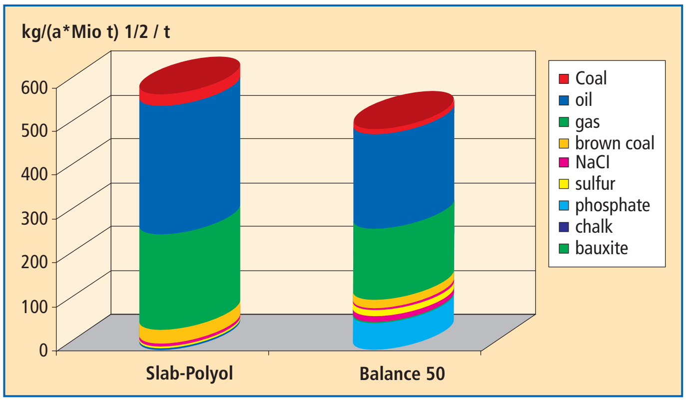


Fig. 7:
Resource consumption

Tab. 1:
Emissions: conventional slab-polyol versus Lupranol Balance 50

Emissions		Slab-polyol	Lupranol Balance 50
air:	Global Warming Potential (CO_2 equivalents t/t polyol)	2,99	2,18
	Ozone Depletion Potential (CFC equivalents g/t polyol)	7	4
	Acidification "Acid rain" (SO_2 equivalents kg/t polyol)	19	17,6
water:	Critical water volume (norm. m³/t polyol)	1239	929
Soil:	Solid waste (norm. t/t polyol)	0,22	0,11

tutes propylene oxide in the production process of Lupranol Balance 50 **(fig. 8).** Castor oil derived from the renewable resource the castor-oil plant is much less energy consuming than the propylene oxide production process which is used as a feedstock in polyol production. In the US, annual energy savings realised through Balance substitution of conventional polyols would be sufficient to provide enough electricity to more than 98,000 homes, assuming energy consumption per house of 3,000 kWh/month.

3.3.1.6 Emissions

Emission values are initially calculated separately as air, water and soil emissions (waste). The calculation includes not only values, e.g. from electricity and steam production and transport, but also values directly from the production processes. The individual values are subsequently aggregated via a weighting scheme to form the overall value for the emission category **(tab. 1).**

The emissions to air, water and soil can be reduced significantly when using castor-oil in the BASF production process of Lupranol Balance 50. Especially the GWP is reduced by nearly 30 %. Normalised to the annual NAFTA flexible foam demand, the reduction is equivalent to the amount of CO_2 sequestered by 4,200 acres of forest preserved from deforestation. (Based on 143.37 metric tons CO_2/acre converted. Source: Inventory of US Greenhouse Gas Emissions and Sinks. US EPA, Washington, 2005. http://www/epa.gov/cleanenergy/energy-resources/refs.html#deforestation)

Furthermore the emissions with respect to solid waste (normalised mass) can be reduced by 50 %. Government sources indicate that in 2005 US residents, businesses and institutions produced more than 245 million tons of solid waste, or approximately 4.5 pounds of waste per person per day. Using Balance 50 as complete replacement of conventional polyol in the annual foam production would save the amount of trash from 127,000 people. (Source: Municipal solid waste in the United States. 2005 Facts and Figures, USEPA. http://www.epa.gov/epaoswer/non-hw/muncpl/facts.htm).

In terms of reducing SO_2 emissions, or acid rain, the use of Balance 50 polyols in lieu of conventional, petroleum-based polyols is equivalent to turning off 300,000 central air-conditioning units for a year, assuming 7.77 kg SO_2 emitted by a 36,000 BTU air-conditioning unit per year. (Source: Air Conditioning Comparison Calculator.)

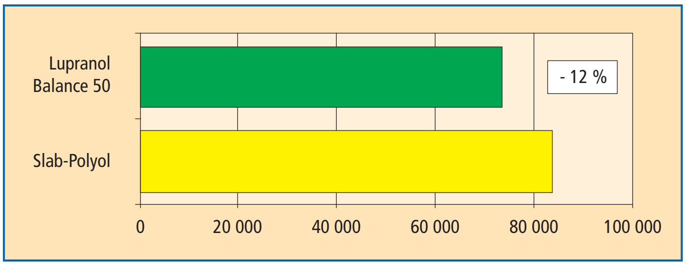


Fig. 8:
Energy consumption [MJ/t_{Polyol}]

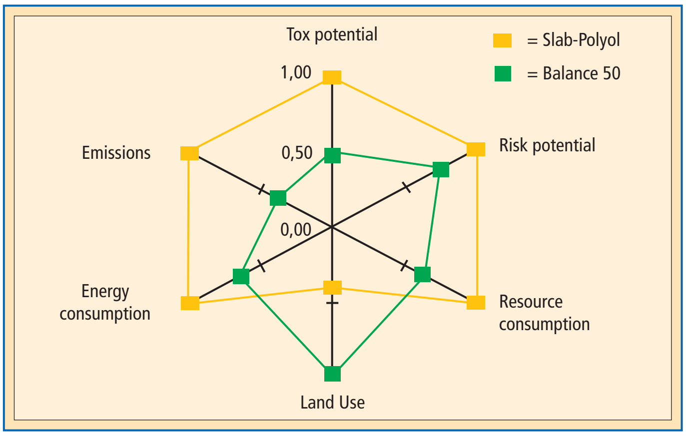


Fig. 9:
Plot of environmental fingerprint

4. Environmental Fingerprint

The environmental fingerprint by BASF is summarised in a special plot. The plot represents a graphic depiction of the relative ecological pros and cons of the alternatives Balance 50 and a conventional slab-polyol. The outermost alternative, bearing a value of 1, is the least favorable alternative, in that the further inward an alternative is located, the better it is.

Figure 9 shows that Lupranol Balance 50 in comparison to a conventional slab-polyol shows much less environmental impact in all categories except land use. With castor oil as a renewable and sustainable resource this result regarding land use is not surprising. The castor plant has an average harvest of 480 kg/ha castor oil. This relates to an use per metric ton of Balance 50, which is roughly the size of a soccer-field. It is also important to mention that castor oil is inedible and therefore not directly competing for its use as human food stock.

5. Summary

In line with the procedure, an independent critical review of this analysis was performed by the TÜV-Rheinland. This critical review report underlined the statements of the BASF analysis:

- "… The Lupranol Balance product portfolio on the basis of the renewable resource castor oil shows significant ecological advantages e.g. in terms of energy and resource consumption, global warming, acidification, ozone depletion potential and waste assessment."

With this positive result of the critical review the eco-efficiency label was awarded to the natural oil polyol Lupranol Balance 50. Lupranol Balance is an innovative natural oil polyol for the slab foam production. It combines excellent processability and foam properties as well as high biomass content and proven eco-efficiency.