Environmental aspects of energy input of chemical reaction

Summary

The environmental loads resulting from serving electric or thermic energy are particularly important. Often the total environmental impact of products and processes is dominated by them. To decrease environmental loads, energy must be employed very efficiently. In chemical-technical plants this requirement is considered, whereas in laboratory experiments the reduction of energy gets less attention.

All techniques for inserting the reaction energy required for syntheses consume electric energy. The efficiency of serveral heating techniques differ in a very wide range. An investigation indicated that for a specific conversion the energy required differs clearly depending on the method used for inserting energy. For example, using a heating mantle only 70% of the electric energy is requireed as by an oil bath in the same reaction. Only 20% of the consumed energy of an oil bath was used by a reaction in a microwave field. These differences can be explained by different losses of energy into the environment, i.e. different efficiency of energy transfer from the heating medium to the reaction medium. The importance of this aspect is emphasised by the amount of these differences. The efficiency supplying energy has a large influence on chemical reactions and should therefore be discussed equally with chosing the chemicals.

If it is possible to use heating-mantles they should be prefered to using an oil bath. Furthermore the use of non-classical methods of supplying energy like microwaves can also lead to reduction of energy consumption. Furthermore it is important to ensure good isolation of the reaction plant to minimize the energy loss and thereby reducing the energy which has to be reinserted.

The recommendations given are effective only if neither safety aspects like local overheating by using heating-mantles nor issues of practical feasibility prohibit them.

The aim of the investigations and experiments is not to decrease the insignificant energy consumption in the laboratory. Rather students should be sensitized for the energy

consumption and loss within chemical reactions. On a larger scale these factors determine the efficiency of a reaction.

Introduction

The environmental impacts resulting from spending energy, e.g. the emissons from the production of electric or thermal energy by combustion of fossil fuels, dominate in many cases the ecological balance ([1] Beck *et al.*, 2000), i.e. the amount of environmental load of a process is in large part determined by this.

Often within chemical reactions thermical energy is required to be added or led off. For reactions in laboratory the energy required is provided mostly by devices like a heating mantle or a heating bath (oil or water). Additional methods of the energy supply, as for example the reaction in the microwave field, the application of ultrasonics or mechanical energy are currently used less frequently and are often only usable for very special reactions. Even though different methods use different principles for supplying energy, essentially there is no difference: they all convert electric energy taken from the electricity network to the desired form of energy.

Investigation

Which method of supplying energy requires the least energy?

Which of the possible methods for supplying energy is the most favorable from an ecological point of view? In other words, which method requires the smallest amount of electricity for a specific reaction and has therefore the highest efficiency? In order to investigate this question, a reaction was carried out once by using a heating mantle, then by using a heating stage with an oil bath and finally in a microwave field; the energy consumption was determined by an energy counter.

Fig. 1 - Energy counter

The results of the measurements furnished that a heating mantle required only 70% of the electricity used for the reaction when utilizing an oil bath. Even 80% of the energy could be saved if the reaction was carried out in a microwave field ([2] Diehlmann, 2002).

What are the reasons for these differences?

There were significant differences in the energy consumption of the different methods of supplying energy. What are the reasons for these differences? In comparison to the classical procedures (heating mantle, oil bath) the microwave synthesis has a shorter reaction time which can be important (reaction duration approx. 30 minutes). There is no difference in reaction time when using a heating stage with an oil bath or a heating mantle as energy source (in both cases approximately 2 hours). Therefore the differences have another cause.

The experimental set up under an IR-camera

With the help of thermography (Fig. 2, Fig. 3) the differences between the variants compared can be shown.

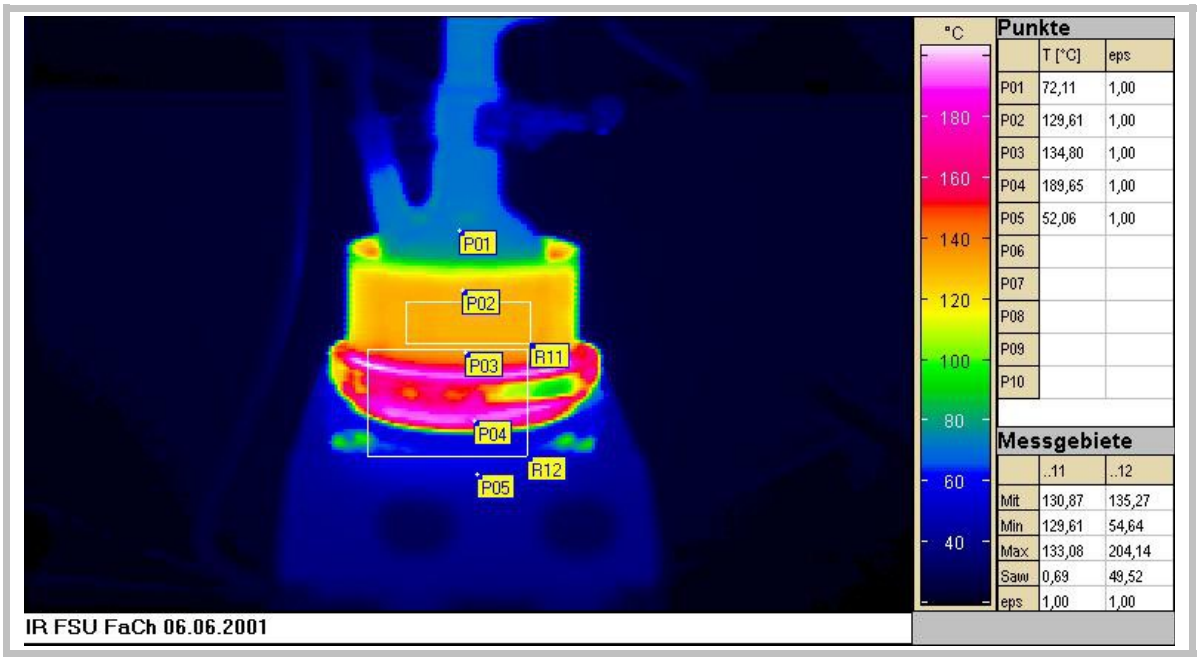

Fig. 2: IR-photo – heating stage with oil bath

The surface temperature of the experimental set up is increased up to 190 °C when the heating stage is used. The surface of the oil bath hull was still approximately 130 °C. In comparison, using a heating mantle leads to significantly lower temperatures. Thus the highest surface temperature measured is only approximately 50°C when using a heating mantle and is thereby well below the temperature of the heating stage with oil bath.

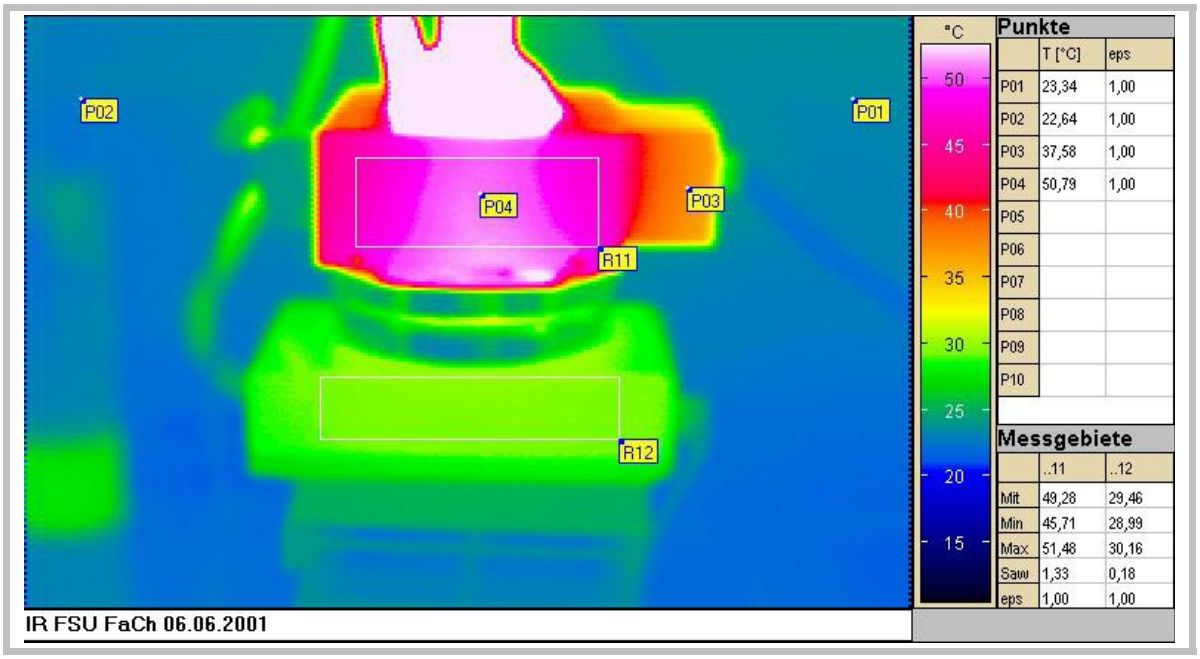

Fig. 3: IR-photo – heating mantle

The surface temperature has an impact on the energy transfer

The energy loss of a body to the environment is mainly due to convective processes. Heat radiation is much less important in the reaction examined. According to the equation for heat transfer the convectively emitted energy Q increases with rising temperature differences between laboratory apparatus and surrounding medium.

$$Q_K = \alpha \cdot F \cdot (T_{body} - T_{environment}) \cdot \Delta t$$

Qk = convectively emitted energy by the experimental setup

α = heat-transfer coefficient

F = surface of the experimental setup

T_{body} = Surface temperature of the experimental setup

$T_{environment}$ = temperature of the surrounding medium

Δt = time for the heat transfer

Isolation and reaction time swich the balance

Against this background it is obvious that the advantage of "microwave synthesis" is caused by the shorter reaction time compared to the classical reaction variants. The loss of energy due to convection is quite smaller with shorter reaction time. The differences in the energy consumption between heating mantle and oil bath can be explained as well with the equation given above. Due to different temperatures of the heaters surfaces different amounts of energy are transferred into the environment. In order to replace this "loss energy" more electric energy has to be taken from the net. From the results of the measurement of the IR-photographs the loss of energy of the two experimental setups were determined approximately. Using a heating mantle approximately 50 %, utilizing a heating stage with an oil bath approximately 85 % of the electric energy taken out of the net is transfered to the environment. The differences in the loss of energy of the two classical experimental setups and the different surface temperatures of the heating media can both be explained by the better isolation of the heating hood used.

Recommendations due to the results

General:

In the discussion of the environmental impact of a reaction the aspect of energy input underrepresented up to now. Our investigations show that a large part of the environmental impact of a synthesis is due to preliminary processes. For instance, a large part of the total environmental effects come from the production of electricity in power plants. Against this background it will be important in the future to regard the aspect of energy on an equal footing with the different aspects of the reaction. For a reaction it is not sufficient that "chemistry" is right, but the reaction time (kinetics), reaction temperature or the insulation play an important role as well.

Concrete:

In view of the research results recommendations can be given concerning the selection of equipment for the implementation of chemical reactions in the laboratory in a concrete case. If possible a heating mantle is to be preferred to the use of a heating stage with an oil bath. The efficiency of heating mantles is just as high as the one of a heating stage with an oil bath. However, the efficiency of heat transfer of the heating medium to the reaction mixture is due to better isolation and smaller surface far more favorable than those of the oil bath. The use of newer methods (e.g. reaction in the microwave field) also affects the energy consumption of chemical reactions on the laboratory scale. However, the time saving has to be significant in comparison to the reaction using classical heating media. The efficiency of the microwave is only about 50%, but the output is predominantly transfered to the reaction medium.
Furthermore, isolating the equipment affects the energy consumption very favorably.

It is important to observe that the recommendations given are effective only if neither safety aspects like local overheating by the use of heating mantles nor causes of the practical feasibility prohibit them.

References

[1] Beck, A., Schering, M. and Hungerbühler, K. (2000). Fate modelling within LCA. *The International Journal of Life Cycle Assessment,* 5(2000), 1-10.

[2] Diehlmann, A. (2002). *Beitrag zur Implementierung des Leitbildes "Nachhaltige Entwicklung" in der Chemieausbildung.* Dissertation. Friedrich-Schiller-Universität Jena, Institut für Technische Chemie und Umweltchemie.