Mass and Energy Flow Management in the Sector of Surface Treatment

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Summary: Vehicle refinishing body shops are concerned by the environmental policy against photochemical air pollution caused by VOC emissions. For supporting these small enterprises the mass and energy flow model IMPROVE has been developed. Based on an LCA-approach, the process steps of vehicle refinishing are modelled. The model IMPROVE helps to disseminate the consequences of product substitution in comparison to so far used products and techniques in the body shop. For the dissemination of experiences practical guidelines have been developed. Moreover, a comprehensible tool for the Solvent Balance is being offered. Thus, various means are available for consulting and also for strategic production planning for the SME in the sector.

Keywords: Mass and energy flow management, VOC (Volatile Organic Compounds), SME (Small and Medium sized Enterprises), LCA (Life Cycle Assessment), Decision Support

Introduction

The Solvent Directive of the European Union (99/13/EC) lays down emission limits for twenty different categories of installations using solvents. Companies have to fulfil the requirements set by the Solvent directive from 2001 (new installations) respective 2005 (existing installations). Therefore, the companies are obliged to take measures in the near future. In comparison to larger companies, small and medium-sized enterprises (SME) are generally not very well informed about the measures which could help them to reduce their costs and emissions, because of their limited personal size and cash flow. Consequently, the diffusion of environmentally sound products and technologies is often insufficient. With the help of a suitable mass and energy model, geared to the special needs of small and medium-sized enterprises in the vehicle refinishing sector, the different process steps can be analysed, and the influence of product or process modifications on other process steps, can be evaluated, in order to reduce the costs and emissions caused by coating activities in body shops.

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The Individual computer aided mass and energy flow model for the vehicle refinishing sector IMPROVE

Since the vehicle refinishing sector is characterised by a large number of small companies, their activities have not yet been subject to detailed research. Therefore, a practical tool for the mass and energy flow management should investigate the overall changes of emission and of costs for individual body shops, based on an integrated analysis of all processes from surface cleaning to final finishing and polishing, comprising all materials with VOC content (as gunwash, precleaner, stopper and body filler, wash primer, precoat, primer, plastics, topcoat, basecoat, clearcoat and several special coatings).

Consequently, a representative model of a typical vehicle refinishing shop has been defined in close co-operation with branch experts from manufacturers of paints and equipment and from professional associations. This model is representative for the majority of vehicle refinishing firms in Germany as regards the working structure, spraying processes and corresponding technological equipment [2; 6].

A large part of the basic data (e.g. consumption figures related to area, components and vehicles, structure of orders, working times and capacity data of the technologies, such as thermal and electrical capacity) was collected in two reference body shops. Based on these intense analyses, the mass and energy flow model IMPROVE 1.0 (**i**ndividual co**mp**uter aided mass and ene**r**gy flow m**o**del for the **ve**hicle refinishing sector) has been designed and implemented. The model includes 15 different spraying processes each with a maximum of 55 stages from receiving the car to handing it over to the customer and a large variety of products and technologies for each stage. The mass and energy flow model IMPROVE is implemented with the commercial software UMBERTO. The LCA software UMBERTO is based on the so-called material flow networks [4; 5]. The formal basis rests on Petri-net theory, a special type of network from theoretical informatics which with its strict systematic (see Figure 1) not only allows the setup of complex systems, but also a combined material and inventory calculation.

Figure 2 gives a screenshot of the Petri-net representing all 430 process steps in a modelled vehicle refinishing body shop. The assessment of the mass and energy flows can then be printed out, be further worked on by means of a chart editor, or be exported to following modules, e.g. spreadsheet programmes or databases, for further processing.

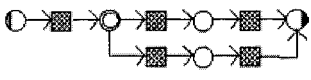
Transitions are locations in the material flow network, where transformation processes occur and can be described mathematically.

Storage places are elements in the network, where no transformation of materials occurs, but materials can be stored.

Arrows link places and transitions, and thus create the actual network structure. They show in which direction the energy and substances flow. It is not possible to link components of same type with an arrow.

Input and Output places represent the boundaries of the balance and act as bridges to the environment.

Connections can only distribute flows and not act as storages, i.e. their inventories are always zero or constant.



The ***material flow network formalism*** consists inter alia in the fact that places and transitions always alternate in the network. Thus a transition can never be directly linked to another transition; a place has to be interposed. If no storage occurs between two processes, the transitions can be linked by a connection place.

Figure 1. Components of the Material Flow Network [4; 5]

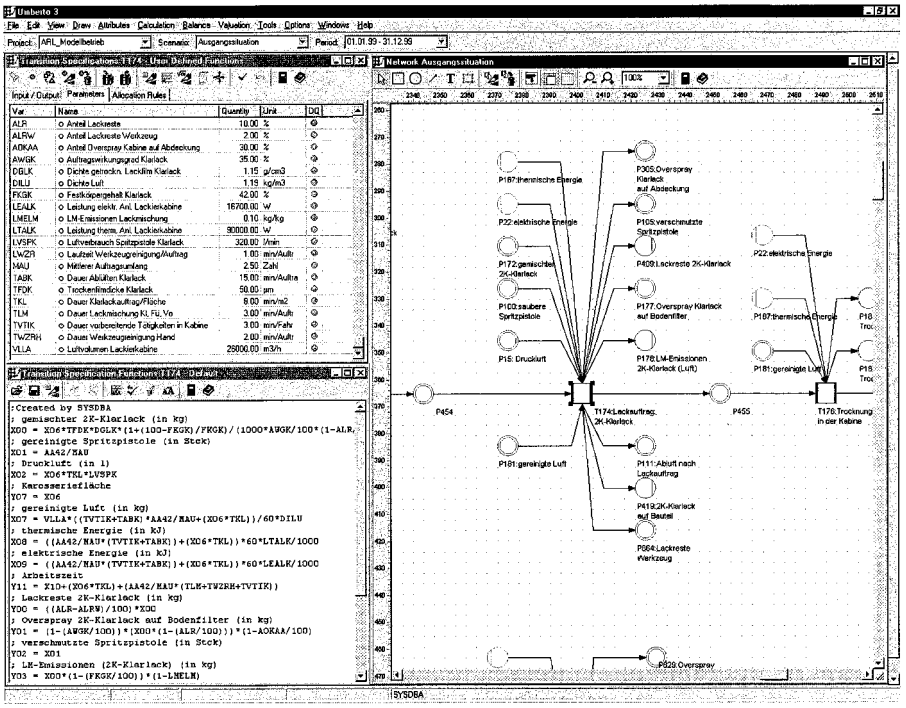


Figure 2. Screenshot of IMPROVE

For the economic and ecological analysis of the mass and energy flows, an evaluation programme has been especially designed within IMPROVE based on MS- EXCEL. Here on the one hand the individual mass and energy consumption quantities are listed according to special product groups (e.g. quantity of waste which has to be particularly monitored), and on the other they are multiplied with specific material prices, which are based on price lists from manufacturers, suppliers' invoices and billing rates. With the evaluation programme it is possible to determine the share of costs of certain product groups and the economic advantage of particular measures for reducing emissions compared to the initial situation. Figure 3 gives an example for an evaluation of the implications of material substitution and change of techniques. The results can be taken as a basis for investment decisions.

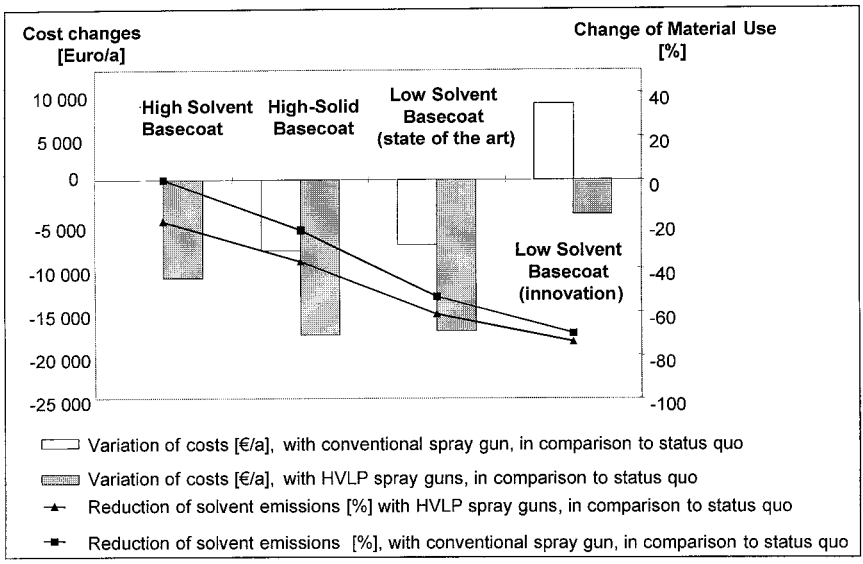


Figure 3. Implications of the use of low overspray application techniques in combination with different coating systems for the model body shop with 1 875 vehicle parts per year

The ratio of incoming and outgoing materials at each individual stage is described by a multitude of mathematical equations and parameters. The spraying processes are centrally controlled by approx. 200 parameters, such as material consumption, working time, performance characteristics, machine times and paint mixture ratios. Thus every vehicle refinishing enterprise can be depicted relatively simple and quick with regard to the individual structure of orders, working methods and the products and technologies applied, and the economic and ecological effects of measures to reduce emissions, integrated into production, can be determined in absolute figures. With this model also loops of materials, such as the reuse of distilled cleaning agents, can be taken into consideration.

Thus, IMPROVE simulates the procedure of vehicle refinishing and enables the flows of materials and energy to be determined and to be more efficiently organised in small and medium-sized vehicle refinishing firms. As the experiences from the practical use of IMPROVE in several body shops show, the concept is well accepted by practitioners, because it makes the process steps transparent with regard to cost savings and emission reduction.

While IMPROVE is conceived for the in-depths-investigation of single firms, some insights on the consequences of the introduction of emission reduction measures can be generalised.

Therefore, based on the findings of the use of IMPROVE, easy-to-use diagrams have been developed for an approximate judgements of the benefits or consequences of certain options for a specific firm. Figure 4 gives an example for the easily understood investigation about the economic consequences of the investment for a body shop, where the amortisation (payback period) for automatic cleaning devices for spray guns is derived depending on the number of painted parts per year in the considered body shop.

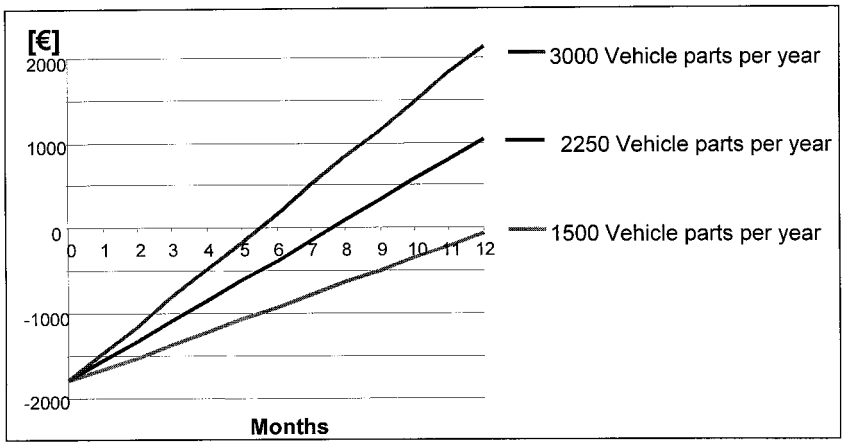


Figure 4. Diagram for simple evaluations: Determination of the amortisation for automatic cleaning devices for spray guns

Development of practical guidelines

Basically, the use of the mass and energy flow model IMPROVE is designed for the consultation of individual body shops. For immediate support for the SME affected by the new environmental legislation, a practical guideline for an improved use of water-based coating systems and other solvent reduced / free coating products (also auxiliary products) has been developed [7].

In close co-operation with nine body shops and national professional associations for vehicle refinishing, a practical changeover concept has been conceived, based on the results of IMPROVE. In addition, interviews and tests after the introduction of water-based coating systems permitted the evaluation of advantages, disadvantages and difficulties of the new introduced system. Based on these broad experiences, the elaborated guideline points out critical points, offers solution possibilities and comprehensible check-lists and names contact persons in case of difficulties.

As another further development of the IMPROVE-Approach, a tool for deriving the Solvent Management Plan according to the EU-Solvent Directive (1999/13/EC) has been conceived [8]. Based on the data contained in the mass and energy flow model IMPROVE, product information of paint producers has been analysed and revised. The developed calculation program for drawing up the solvent balance is based on the standard software MS-EXCEL for spreadsheet calculation. Also a paper based version is being offered to the firms for manual use. In addition, if a body shop uses IMPROVE, the calculated mass and energy flows can be taken as data input for the establishment of the solvent management plan.

In this comprehensive manner, specific decision support is provided for the concerned SME, as the overall concept in Figure 5 illustrates.

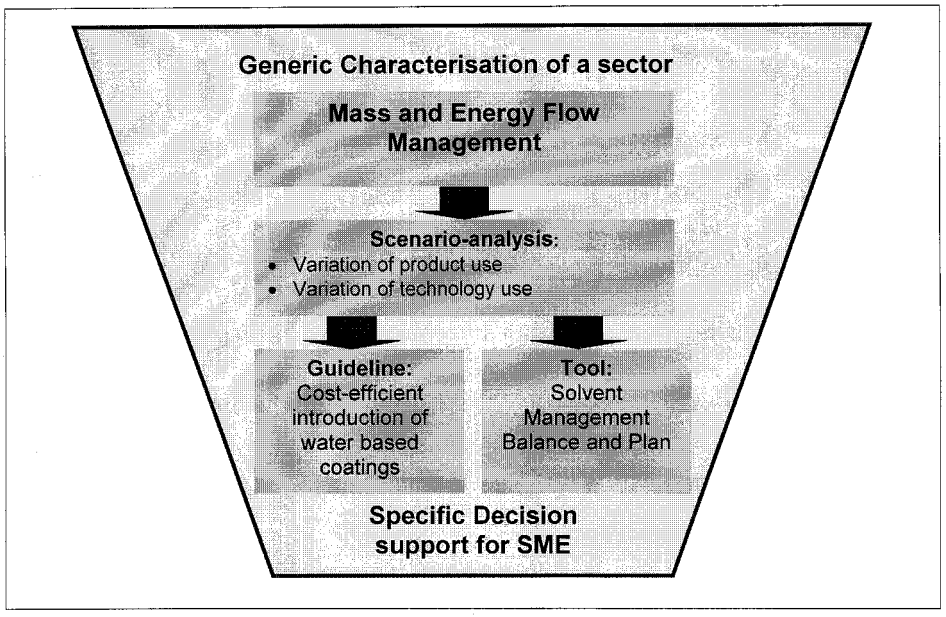


Figure 5. Comprehensive mass and energy flow management in the sector of surface treatment in SME

Conclusions

By describing the way of operating and the technological environment as well as by a complete view of shop internal material and energy flows, the mass and energy flow model IMPROVE helps to disseminate the consequences of product substitution (e.g. costs incurred, emissions caused) in comparison to so far used products and techniques in the specific body

shop. Thereby possible environmental and economic reduction respectively saving potentials can be identified.

For the broader dissemination of the achieved results, practical guidelines with checklists and market analyses foster the introduction of waterborne coatings in the sector. Moreover, a calculation model for drawing up the Solvent Balance - as requested from the SME in the sector of vehicle refinishing - uses in simplified terms the data stored in IMPROVE.

The conducted research projects demonstrate, that the use of mass and energy flow models can not only support larger companies in their environmental management, but also SME. While IMPROVE was developed specifically for the processes of vehicle refinishing, further fields of application may be industrial and general commercial spraying (cf. [9]), car body construction work (e.g. welding), or lorry refinishing. In addition to the ecological and economic aspects, organisational issues can be investigated with IMPROVE, like the investigation of work time, ergonomics and capacity planning [10].

Not only the body shops will profit from the guidance notes, but also the paint manufacturers can use the mass and energy flow model IMPROVE and the guidelines for their Customer Relationship Management (CRM). Some paint producers use IMPROVE for their customer service, in order to simulate the necessary changes in the enterprises of their customers when changing the processes from conventional to waterborne products. Moreover, the results gained with IMPROVE are a valuable data source for decision support on strategic planning for future paint production and improvements in surface treatment [1].

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