Simulation of Mechanical Processes in Waste Treatment

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Simulation mechanischer Aufbereitungsprozesse in der Abfallbehandlung

Abstract

A critical analysis of mechanical processes in waste treatment plants hints at vulnerable spots in the interaction of plant units and deployed heterogeneous materials. The simulation of mechanical processes in waste treatment may depict the total material flow in a plant and as such, contribute to a better understanding of the behaviour in heterogeneous materials, to identify bottlenecks, to check plant modifications and hence, to support planning and reducing time for implementation period.

The project community, consisting of ARGUS, the Technical University of Berlin and the Fraunhofer FIRST has developed a demonstration model for a simple plant configuration including an air separator, metal separators and comminution aggregates. First encouraging results are available. In a concerted effort with industrial partners a simulation model is gradually developed and customised to real conditions. The system is to support schedulers, manufacturers und operators of waste treatment plants with planning and extensions for existing plants, with quality management, system analysis and development of plant specific simulation models and model adjustments to operation data.

Keywords

Waste treatment, mechanical processing, simulation, process analysis, material flow analysis, air separator, separation processes, comminution processes, waste sampling, mass balancing

1 Problem description and approach

A critical analysis of mechanical processes in waste treatment plants shows first of all vulnerable spots in the interaction of plant units and the heterogeneous raw materials. Unpredictable fluctuations in quality of the charge lead to temporary deviations and exceedings of the admissible quality tolerance of individual treatment aggregates. This then leads to disturbances in the whole treatment sequence and even to idle machines and complex manual intervention. Insufficient throughputs and lacking product quality are the consequence.

So far, the planning and design of complex treatment plants has been to a large extent based on experience. In many cases long and cost-intensive adjustment measures were necessary until the stable commissioning of a plant. The simulation of mechanical processes in waste treatment can contribute to the depiction of the total material flow of a plant, to a better understanding of the behaviour of heterogeneous materials, to the identification of bottlenecks, to the check of plant modifications and thus to the support of the planning and the reduction of implementation periods.

The simulation tool will not replace the skilled and experienced development engineer. It is rather intended to be an effective support in the form of an analysis tool. With the simulation system material data bases, process descriptions in the form of mathematical models as well as simulation techniques are provided on the basis of which an effective tool can be developed. For this purpose a close cooperation with plant operators and development engineers is necessary.

Innovations and advantages for manufacturers and operators of waste treatment plants can be seen in the following domains:

- Implementation of new approaches to the description of material properties of mixed municipal wastes
- Improvement of sampling of heterogeneous material systems as a basis for the evaluation of the efficiency of plants and plant components. (So far, there is a methodical approach for a new sampling procedure (KUYUMCU, H. Z.; ZWISELE, B., 2004/2005) on the basis of which a standard procedure can be applied.)
- Consideration of waste-specific material properties in the description of the process technology (e.g. the selective comminution of mixed wastes, consideration of adherences and agglutinations etc.)
- Use of advanced simulation technology for the description of complex and, regarding the interconnection, complicated technical systems

The project community consisting of ARGUS, the Technical University of Berlin and the Fraunhofer First has developed a demonstration model for a simple plant configuration including an air separator, metal separators and comminution aggregates. The system provides the following functions which may be advanced in cooperation with interested plant operators and development engineers according to the desired intensity of application.

- Material data base for the description of relevant chemical-physical and biological parameters of the raw material
- Computing algorithm for the description of process-related procedures (integrated mathematical simulation model for the description of process-related procedures) in a treatment aggregate
- Calculation of the mechanical processing (individual steps of the procedure and method) in consideration of dynamic fluctuations of the feed flow and further discrete events (commissioning, decommissioning, omission or combination of the waste recovery etc.)

- Quantification of the statistic uncertainty of the simulation model
- Examination and evaluation of different plant configurations by a modularly structured simulation model

2 Modelling of process-related procedures

The example of a simple plant configuration explains the process-related description of the mechanical processes. Figure 1 depicts the formulation of an industrial waste with small proportions of organic constituents into a refuse derived fuel. The processes of classification, sorting, comminution and agglomeration are used.

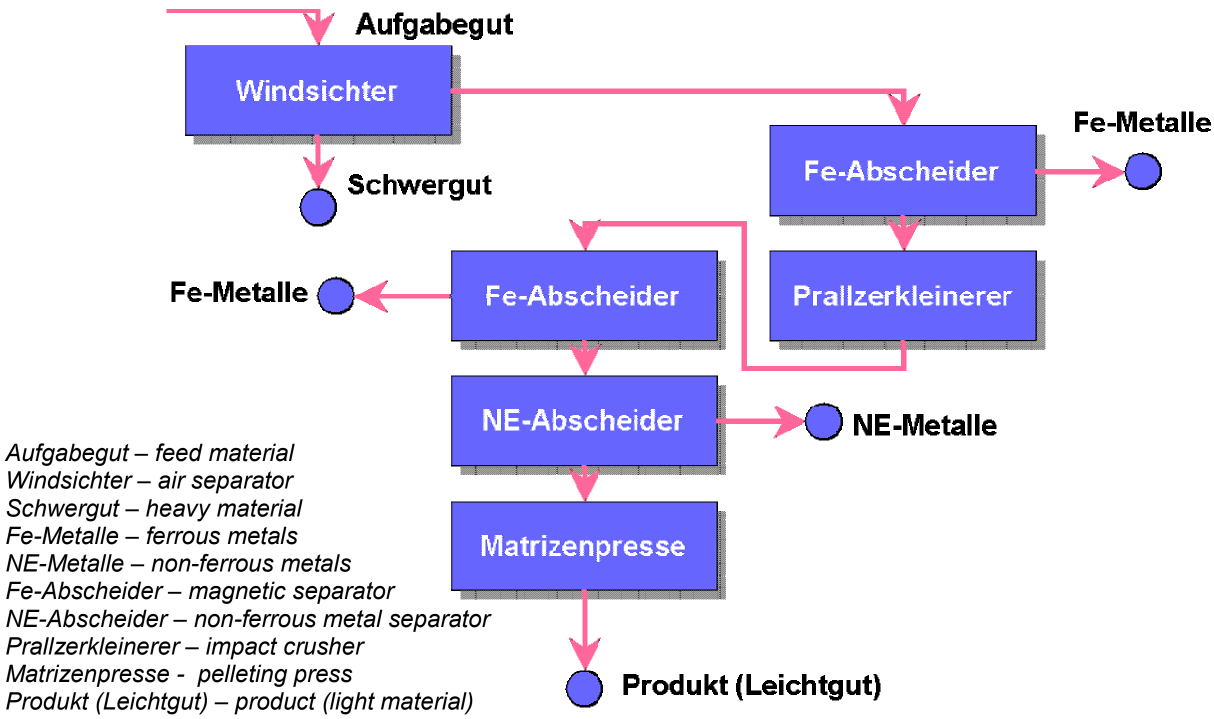


Figure 1 Demonstration example for a plant configuration

Explanation of the German terms contained in the figure:

First of all, an appropriate marking of the material flows is necessary for the process description. For this demonstration example the following flow structure is developed in the first step:

- Division into solid matter flow and fluid flow, considering the multiphasic course
- Subdivision of the solid flow into partial streams for the different substance groups (light solids, high-gravity solids etc.)
- For each substance group indication of mass flow, average material composition and particle size distribution

The flow structure can be expanded flexibly, for example by compositions depending on particle size and other multidimensional distributions. The present case differentiates between the substance groups of light solids, high-gravity solids, minerals, ferrous metals and non-ferrous metals.

For the calculation of the materials conversion, the individual data elements of input flows in a machine or process can be accessed. In the following, the air separator and the magnetic separators are exemplarily presented in a model regarding their process-related function.

Magnetic separator (Sorting)

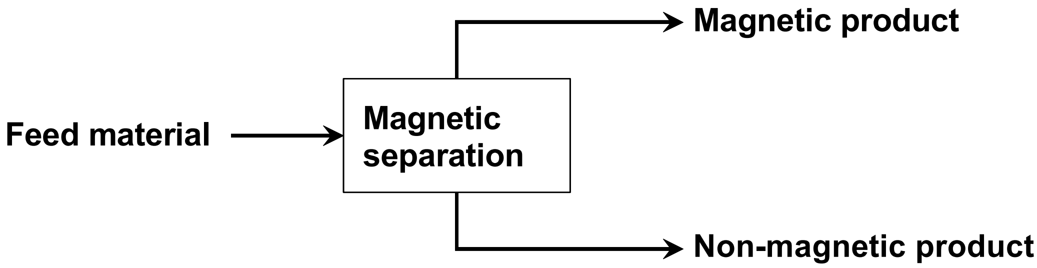


Figure 2 Schematic description of a magnetic separator

The magnetic separator separates interfering metallic components according to the magnetic properties from the material flow in which also non-magnetic particles can be removed. In the simplest case the process behaviour can be described by indicating separation efficiencies for each substance group. The mass fractions of the particle size distribution for each substance group are maintained in this case in both product flows.

With the separation efficiency of the ferrous metals consequently the balance equation applies for the material flows of the substance groups (Equations 1 and 2)

$$\dot{M}_{P1,Fe} = \eta_{Fe} \cdot \dot{M}_{A,Fe}$$ Equation 1

and $$\dot{M}_{P2,Fe} = \dot{M}_{A,Fe} - \dot{M}_{P1,Fe}$$ Equation 2

with:

$\dot{M}$ Mass flow: A (feed), P_1,P_2 (products)
η_{Fe} Separation efficiency of the ferrous metals

Air separator (flow sorting)

In the air separator mainly light and fine material components are separated from heavy coarse material components, which means that besides the classification by particle size a sorting or separation by type of material is carried out due to different material densities and particle shapes. In a waste treatment plant the high calorific materials (mostly fine materials) are separated from the low calorific materials in this process step.

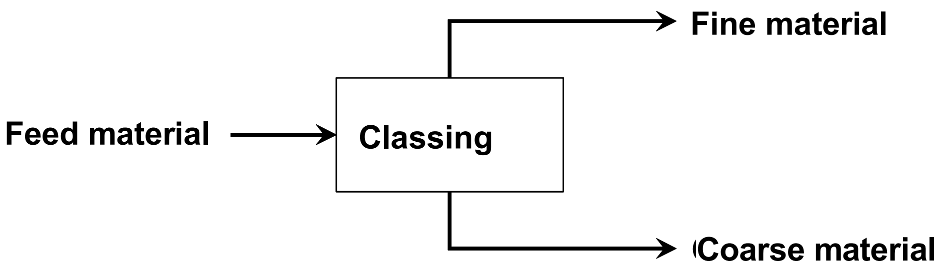


Figure 3 Schematic description of an air separator

In order to describe the classification process, the example uses separation efficiencies which differ from each other in value depending on the type of material and particle size fraction. The influence of the particle shape is for the moment being not taken into account. The separation efficiencies of the fractions can be described in a mathematically consistent way with a so-called separation function. In contrast to the above-mentioned approach for the simulation of magnetic separation hence a greater modelling depth is already achieved.

The process calculation by means of the separation efficiencies is then carried out in the following steps:

- Calculation of the value for the separation function for each substance group and particle size ("diversion ratio in the fractions")
- Division on the level of the fraction mass flows for each substance group
- Recalculation of the mass fraction of the particle size distribution for each substance group referring each to the new partial stream in heavy material/coarse material and light material/fine material

The overall balance is calculated with Equation 3. The fraction balance results in consideration of the fraction separation efficiency as per Equation 4.

$$\dot{M}_A = \dot{M}_{P1} + \dot{M}_{P2}$$ Equation 3

$$\dot{M}_{P1} \cdot p_{1,i} = T_i(x_i) \cdot \dot{M}_A \cdot f_i$$ Equation 4

with

f_i Mass fraction of the fraction i in the feed material

$p_{1,i}$ Mass fraction of the fraction i in the product flow 1 (coarse material)

$T_i(x_i)$ Fraction separation efficiency of the fraction i, calculated with separation function

$\dot{M}$ Mass flow: A (feed), P_1,P_2 (products)

The separation function for the determination of the diversion ratios in the fractions can for example be calculated with Equation 5 (LYNCH, A. J., 1977).

$$T(x) = \frac{e^{\alpha \cdot x/x_T} - 1}{e^{\alpha \cdot x/x_T} + e^{\alpha} - 2}$$

Equation 5

with

α Separation accuracy parameter

x Particle size

x_T Cut diameter

The cut diameter x_T in this case represents the particle size in which the partial stream in the fraction spreads over both products in equal shares. The empirical determination of the cut diameter and the separation accuracy is in the present case carried out with an adaptation calculation to measured flow data.

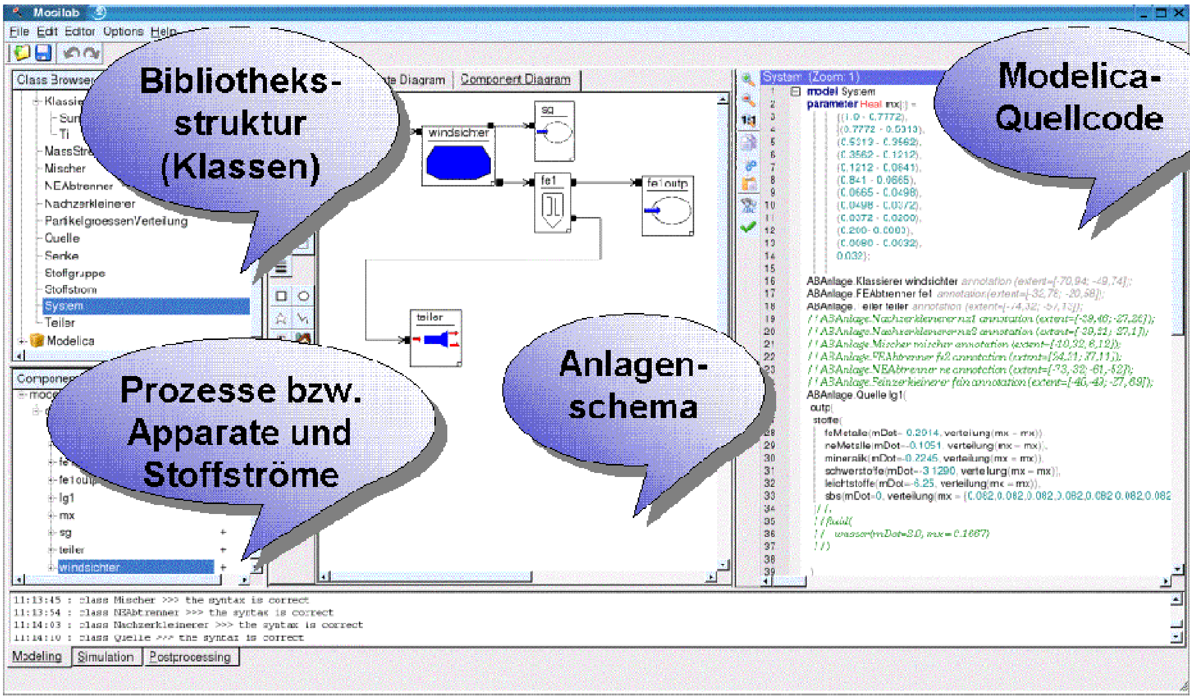
Alternatively, model equations can also be formulated for a calculation of the two separation function parameters. In this case, different modelling depths arise regarding the influent material and process or machine parameters as well as the degree of consideration of physical modes of action. Further improvements of the separation model can be obtained if the process area is subdivided and the herein definable sub-processes are described for these subdivisions.

3 Realization of the simulation task

For the realization of the simulation task the simulation tool MOSILAB (**Mo**delling & **Si**mulation **La**boratory) is used, which is developed under the overall control of the Fraunhofer FIRST (NYTSCH-GEUSEN ET.AL., 2005). The simulation tool is suitable for the development of complex, heterogeneous technical systems. MOSILAB uses a component-oriented, acausal modelling on the basis of the modelling language Modelica® (http://www.modelica.org).

The system consists of an interactive development environment (IDE) for simulation, a simulation kernel system with different exchangeable numerical procedures as well as interfaces for standard simulation software. Due to the open, extendable and scalable software architecture MOSILAB is very suitable as a framework for the development of special-purpose simulators.

Figure 4 shows the user interface for the operation of the simulation system.



Bibliotheksstruktur – library structure
Prozesse bzw. Apparate und Stoffströme – processes or machines and material flows
Anlagenschema – plant scheme
Modelica-Quellcode – Modelica source code

Figure 4 Management of the process elements and plant structure

On top of the left side plant components (e.g. an air separator and a magnetic separator) or mass flow systems (e.g. a heterogeneously composed material flow of varying particle size) can be chosen via drag-and-drop from pre-defined model libraries and can be put together to a plant scheme in a graphical editor. On the right side the corresponding Modelica-model, to which further information can be added in the editor, is automatically generated based on the graphical modelling.

Figure 5 shows the hierarchical modelling of a material flow by means of Modelica. A superordinate model class of the type *material flow* contains besides the total mass flow a solid matter flow which in turn is subdivided into six substance groups (ferrous metals, non-ferrous metals, high-gravity solids, light solids etc.). Each substance group in turn contains an individual particle size distribution. With this modelling process different material flow compositions can be modelled flexibly.

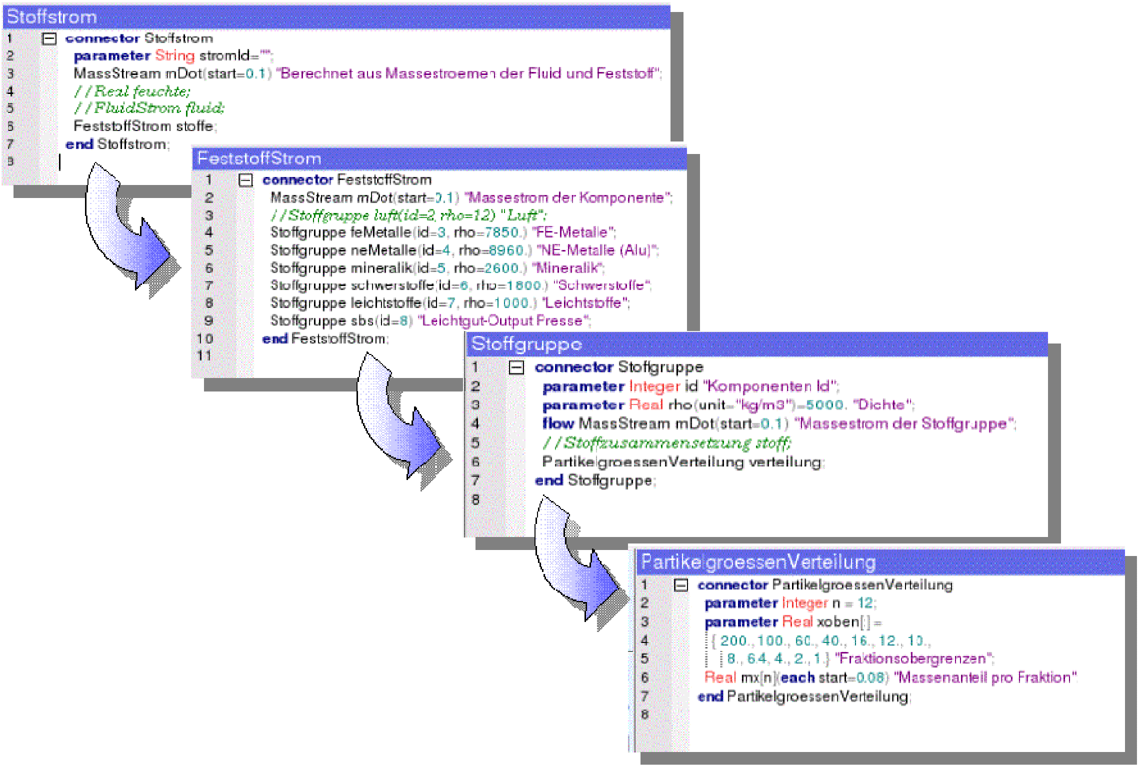


Figure 5 Hierarchical description of the material flows

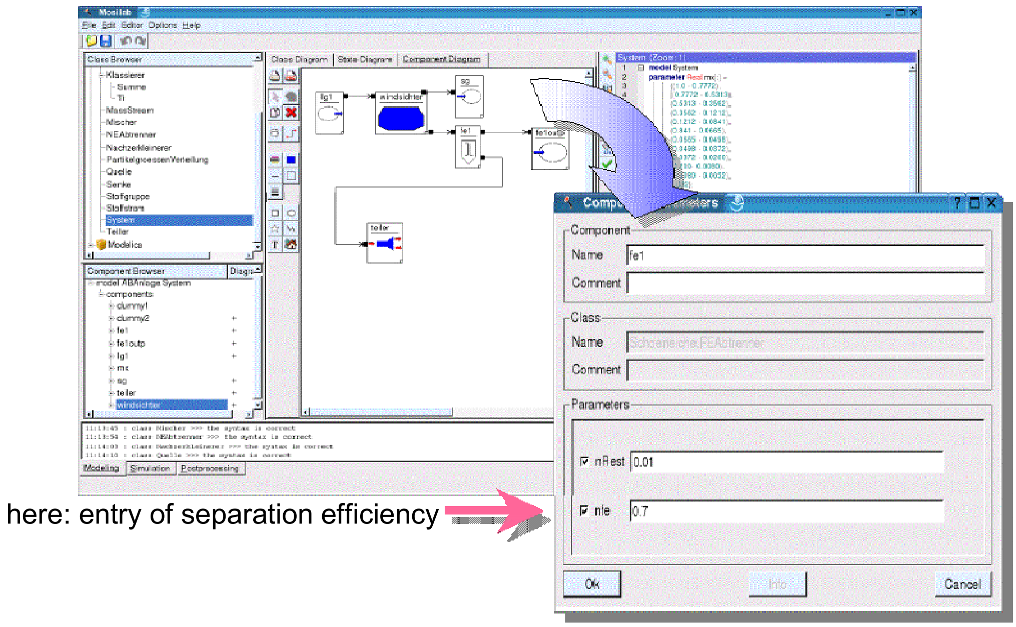


Figure 6 Parameterization of the machines/processes: example magnetic separator

Figure 6 makes clear that a plant model in MOSILAB can easily be parameterized. For each plant component there is a context menu with which all parameters describing the component can be modified.

4 Example simulation of a plant section

For the demonstration example described in Figure 1 a stationary plant model was generated and simulated with the simulation system. The production targets of the plant lie in the processing of a material fraction with high calorific value in order to produce refuse derived fuel. The contained recovered materials, ferrous and non-ferrous metals, are to be separated as completely as possible. The plant is supposed to meet defined foreign material contents, calorific values as well as pellet properties.

Solid pre-treated wastes, consisting of the substance groups light solids (plastics, textiles, paper/cardboard), high-gravity solids (wood, course pieces of plastic, wet paper clots), minerals and ferrous and non-ferrous metals, were used as feed materials.

The multi-stage comminution (particle size reduction, pulping), the flow sorting (air separation), the magnetic separation, the eddy current separation and the briquetting ("pelletization") were used as processes and had to be modelled accordingly. For the modelling of the solid matter flow the material composition and the particle size distribution were taken into account and for the process the following model approaches were used:

Air separator:	Multi-parametric separation function
Magnetic and non-ferrous metal separator:	Particle size-independent discharge probabilities different for the substance groups
Impact crusher:	Fraction or also population balances using multi-parametric selection functions or fraction distribution functions
Pelleting press:	Presetting of a defined particle size distribution

The stationary simulation permits estimations about the size of the achievable yield for the finished products at pre-set characteristics of the components and depending on the material flow at the entrance of the plant. An example for the model result can be found in **Figure 7**.

Strom-ID	LG1	SG	LG2	FE-1	LG3	LG3s	FE-2-3	LG4	NE-12	LG5	SBS
Name	Aufgabe Windsichter	Schwergut	Leichtgut	Eisenmetalle	Aufgabe Nachzerklei-nerung	Zerkleinerung sprodukt	Eisenmetalle	Leichtgut	NE-Metalle	Leichtgut	Produkt
gesamt	10,000	3,031	6,969	0,153	6,816	6,816	0,081	6,734	0,050	6,684	6,684
FE	0,291	0,099	0,193	0,121	0,071	0,071	0,068	0,004	0,000	0,004	0,004
NE	0,105	0,053	0,053	0,004	0,049	0,049	0,001	0,048	0,024	0,024	0,024
Mineralik	0,225	0,160	0,065	0,006	0,059	0,059	0,001	0,058	0,005	0,053	0,053
Schwergut	3,129	2,057	1,072	0,011	1,061	1,061	0,005	1,056	0,011	1,045	1,045
Leichtgut	6,250	0,663	5,587	0,011	5,576	5,576	0,007	5,569	0,011	5,558	5,558

●*Column 1:*
- *Strom-ID – flow-ID*
- *Name – name*
- *gesamt – total*
- *FE – ferrous*
- *NE – non-ferrous*
- *Mineralik – minerals*
- *Schwergut – heavy material*
- *Leichtgut – light material*

●*Line 2:*
- *Aufgabe Windsichter – feed air separator*
- *Schwergut – heavy material*
- *Leichtgut – light material*
- *Eisenmetalle – ferrous metals*
- *Aufgabe Nachzerkleinerung – feed secondary comminution*
- *Zerkleinerungsprodukt – comminution product*
- *Eisenmetalle – ferrous metals*
- *Leichtgut – light material*
- *NE-Metalle – non-ferrous metals*
- *Leichtgut – light material*
- *Produkt - product*

Figure 7: Mass data calculated for the demonstration plant in t/h

Figure 8 displays the goodness of fit of the simulation to the measured values. In the evaluation of the goodness of fit it has to be taken into consideration that the process parameterization was carried out with the empirical data of the plant. Further simulation scenarios have to show how well the model assumptions react to changed plant configurations, changed charge or changed operating states.

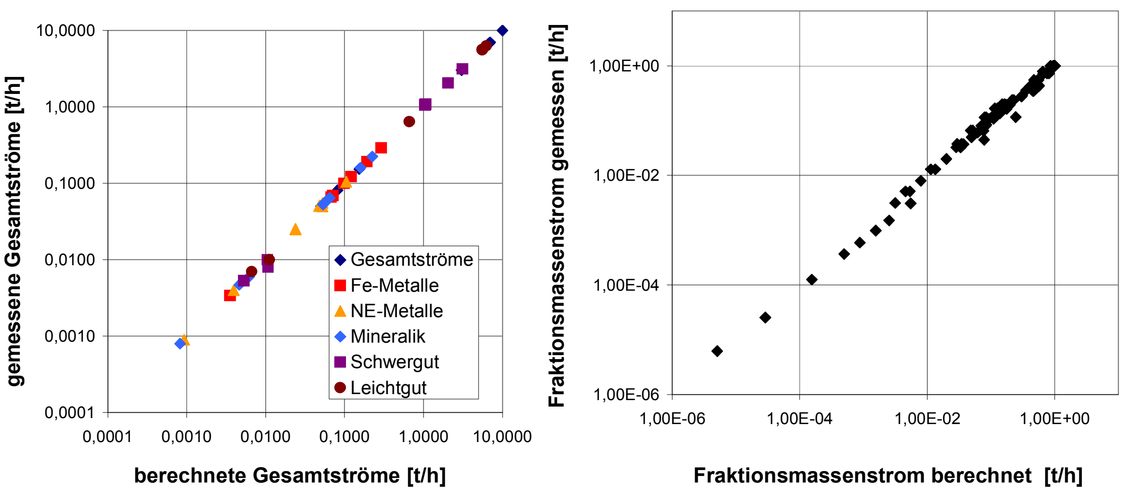


Figure 8: Adaption quality of the model for material composition and particle size distribution

- *gemessene Gesamtströme – measured total flows*
- *berechnete Gesamströme – calculated total flows*
- *Gesamtströme – total flows*
- *Fe-Metalle – ferrous metals*
- *NE-Metalle – non-ferrous metals*
- *Mineralik – minerals*
- *Schwergut – heavy material*
- *Leichtgut – light material*
- *Fraktionsmassenstrom gemessen – measured fraction mass flow*
- *Fraktionsmassenstrom berechnet – calculated fraction mass flow*

As the model was developed for the analysis of the stationary behaviour, the state variables are time-independent. If the throughput of a plant is to be examined, the model has to be developed further to that effect that capacities and residence time of and in components are supported. To obtain more realistic models also moisture-dependencies are to be introduced to the definitions of the behaviour functions. For this purpose some of the previous constant parameters have to be replaced by functions of time, load, moisture and temperature. The language characteristics of Modelica are excellently suitable for such kinds of model refining.

5 Application reference and benefit of the simulation model

A demonstration model for a simple plant configuration with air separator, magnetic separator, non-ferrous metal separator and comminution aggregate is available. It was possible to achieve first promising results for a defined waste mixture with known particle size distribution. The underlying material data base and the process description are being currently worked on. Furthermore, it will be important, together with partners from the industry, to fill the model with process data, to refine the process description and to adjust the simulation functions to the requirements of the plant operators in practical use.

After this stage of further development, for which a research plan is currently being applied for, a tool which offers support in the following domains is available for interested planners, manufacturers and operators of plants:

- Planning and expansion of waste treatment plants
- Weak-point analysis and optimisation of existing plants
- Quality management
- System analysis and development of plant-specific simulation models
- Model adjustment to operational data

6 Literature

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