FUZZY CONTROL OF THE SINTERING OF SEWAGE SLUDGE IN A HIGH TEMPERATURE FLUIDIZED BED SYSTEM

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ABSTRACT: Target of the presented research work, which was done in cooperation between the „VTI Thüringer Verfahrenstechnisches Institut für Umwelt und Energie e.V.“ and the Technical University of Ilmenau (department of system analysis) was the implementation of a fuzzy based control for the process of ceramization of sewage sludge mixed granulate in a high temperature fluidized bed system. The employment of the burned granulates as lightweight aggregate material in the building industry and the quality criteria which have to be fulfilled thereby, presupposed the exact adherence to defined process conditions. These refer in the special to the compliance to a very close temperature band in a area of very high temperatures. The process of fluidization is characterized thereby by a large number of system inputs and outputs and their interconnections among themselves. The general strategy of the solution of this problem definition shall be described in the present report. Further the obtained results are to be presented. The practical investigations were executed at the test range of VTI Thüringer Verfahrenstechnisches Institut für Umwelt und Energie e.V.

TARGET

Sewage sludge resp. types of dust incurred within many areas of the industry as well as in the communal sector. The bringing out on agricultural areas and the deposition as a disposal facility will be cutted by the law [Klärschlammverordnung 1992, TA Siedlungsabfall 1993]. The *TA Siedlungsabfall* prohibites by law the deposition of sewage sludge after the 1st june 2005, if the organic mass exeedes a percentage of 5%.
The disposal of these kinds of waste could take place in different manner. In the VTI Saalfeld e.V. the sludge from munincipal sewage plants is burned in a high temperature fluidized bed system (Figure 1) at temperatures between 1050-1100 degrees celcius. The final product includes no organic components and the anorganic materials are strongly build in the granulate by the the ceramization. In case of an optimal temperature control in a very small tolerance band, a final product can be won, which could be used as a high-quality lightweight aggregate material in the building industry. This tolerance band is limited by an insufficient ceramization on the one hand and by the begin of melting on the other hand.
The process is characterized by a multiplicity of input and ouput values, their interconnections as well as strong disturbances. There are two major reasons of these disturbances. The first is the uneven composition of the sludge mixed granulates regarding dampness and heat value. The second major reason is the nature of a fluidized bed process in these temperature ranges.

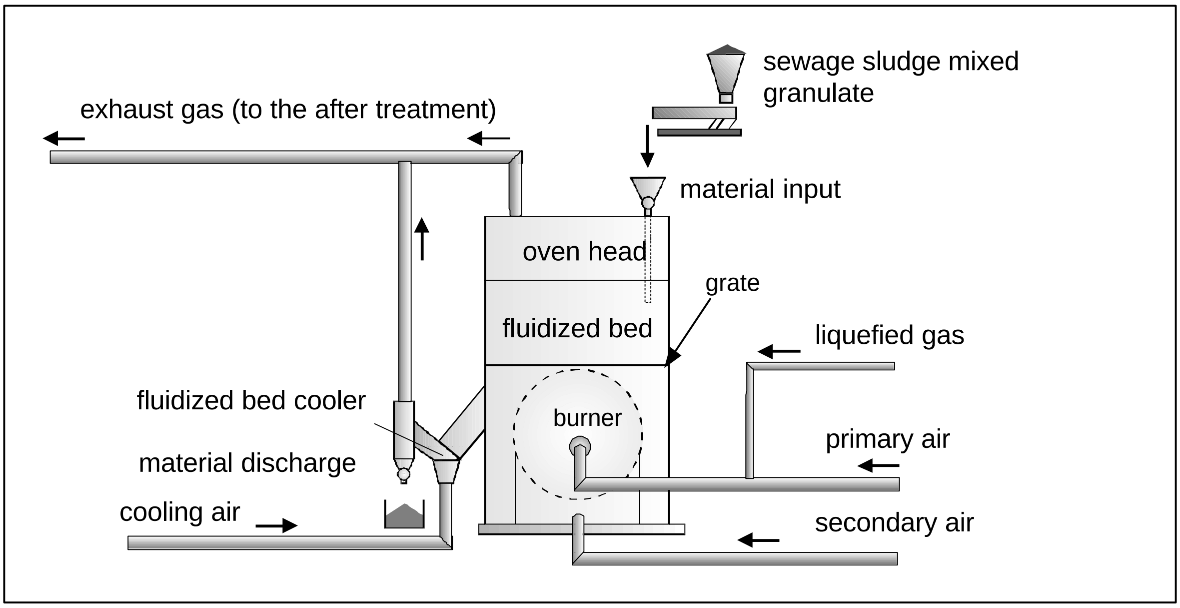

Figure 1: scheme of the high temperature fluidized bed system

The application of a fuzzy based control is justified thereby due to the following characteristics of the process:

- high complexity of the process regarding the amount of the inputs, states and ouputs
- necessary compliance to very close tolerance bands of the process variables,
- nonlinear process behavior,
- strong disturbances,
- insufficient possibility of building a exact process model,
- managment of extreme situations only with expert knowledge.

MODELLING

As design projection of the fuzzy based control the concept of SOFCON (**S**trategy of **O**ptimal **F**uzzy **CON**trol Design) is used [Kuhn 1994], [Eichhorn 1995], [Koch 1996]. This engineering founded strategy includes the following basic design steps:

1. Definition of the optimization criteria of the control
2. Design of the control structure
3. Creation of rough models for the static and dynamic behavior
4. Optimal model-supported design of the fuzzy control
5. Implementation and finetuning of the Fuzzy control.

The exactly modelling of such a complex process only with methods of theoretical process analysis is very difficult [Görner 1991]. A simplification regarding the structuring in subprocesses and the neglect of fewer meaning interactions enables it nevertheless to create a rough model for the process. With the assistance of this simplified model the circuit layout can be implemented. To devide the process in the single output processes the following demands can be used:

- quality of the final product,
- energy optimal managment of the process,
- compliance of specified limits of the exhaust gas,
- compliance of necessary conditions for the secure operation of the system.

As a result of these considerations three essential single output subprocesses (Figure 2) can be defined.

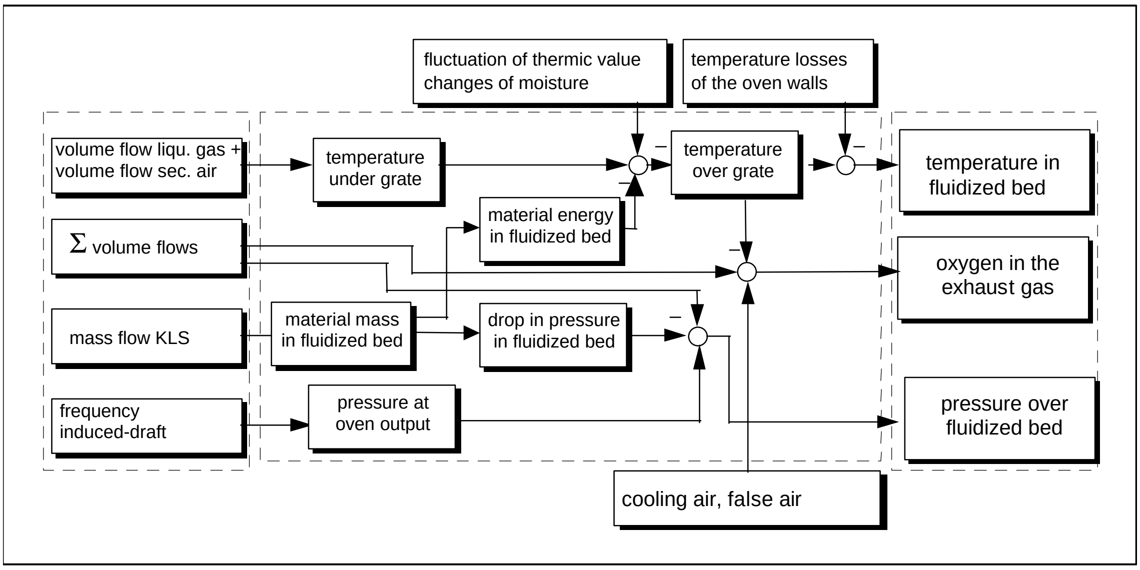

Figure 2 structure of the system

SUBPROCESS 1: “FLUIDIZED BED TEMPERATURE”

For the quality of the final product its physical and chemical characteristics, like the firmness and the solubility are decisive. Since these characteristic values cannot be determined directly during the process, the temperature in the reactor is consulted as an indicator for the quality of the burned granulate. At the same time the temperature under rust supplied by the burner is included, in order to achieve a minimization of the liquid gas quantity with a maximization of the mass flow of the mixing granulate.

SUBPROCESS 2: “OXYGEN IN EXHAUST GAS”

The optimal energy managment of the process and the complete burning out in the fluidized bed with a maximization of the input of the mixing granulates at the same time, can be attained by means of the process variable " oxygen content in the exhaust gas ". The value of the oxygen in the exhaust gas in combination with the value of the temperature in the fluidized bed shall be used as an indicator of the pollutant emission after the reactor.

SUBPROCESS 3: “PRESSURE OVER FLUIDIZED BED”

The mode of operation of the liquid gas burner of the HTA presupposes flow conditions over the fluidized bed, which ensure a continuous evacuation of the exhaust gas from the reactor.

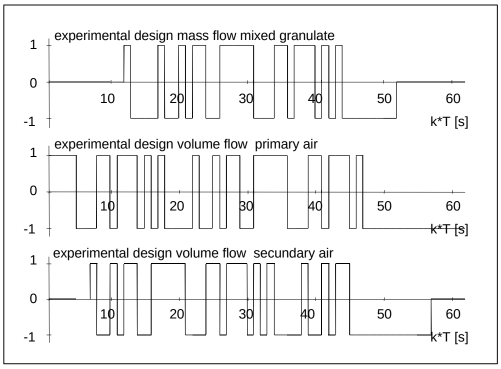

Figure 3: experimental design for temparture model

The partial models needed for the controller design were won by the implementation of optimal experimental design. Based on the transition times of the subsystems determined in first tests, three experimental designs for the several models were developed. The used approach of the system identification an modelling should be represented by the example of the temperature model:
The experimental design for the model ***fluidized bed temperature*** possesses the inputs:

- mass flow sewage sludge — transition time: approx. 10 min
- volume flow liquid gas — transition time: approx. 20 min
- volume flow secondary air — transition time: approx. 15 min

with an sampling time of Ta = 2 min. The test signals of the experimental design are represented in Figure 3. Based on the executed experimental design the modelling of the dynamic linear behavior in several working points was realized. As model structure the difference equation model (ARX model) was used.

DESIGN OF THE FUZZY CONTROL

The control design based on the estimated input-output models of the process was performed with the "Fuzzy Control Design Toolbox für Matlab®" [Eichhorn 1995] wich was developed at the Technical University of Ilmenau, field of system analysis.
The whole structure of the drafted control is shown in Figure 4. A superiored setpoint generator has the task, to give the initial values as well as the lower and upper linits to the outputs of the several fuzzy based controllers in dependence of the granulate size. The fuzzy controllers give the setpoints to the field controllers of the several process inputs wich are implemented in the lowest level. The field controllers are implemented as conventional controllers for instance PID- or 3-point-step-controller.

Three controlling subsystems result from this, according Figure 4:

- temperature in the fluidized bed
- oxygen in the exhaust gas
- pressure over the fluidized bed.

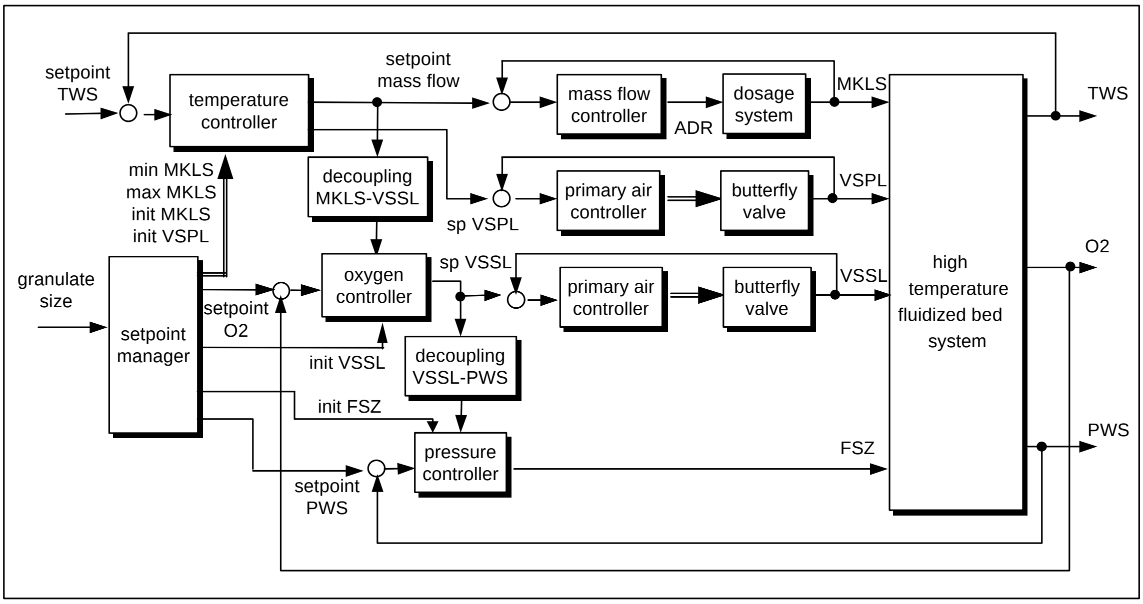

Figure 4 Structure of the control

Because of the interaction between the several process variables, decoupling elements have to be inserted into the control structure for the avoidance of feedbacks between the control circuits. A closer explanations concerning these decoupling elements is not neccesary at this point.

The described controlling structure shows the unimpaired operational case. For the security of the several operation modes the following structures for:

- starting regime
- operational case
- operational disturbance
- shut down regime

are necesary.

A hybrid structure of the control for the fulfillment of all operating modes have to be created with a special attention to the switching between the several tasks.

The conversion of the fuzzy concept in the controller design should be described in the following by the example of the temperature control.

The temperature in the fluidized bed is the result of two major input variables, the temperature produced by the liquid gas burner and the quantity of head released from burning the organic constituents of the sewage sludge. Thats why the temperature controller is build from two, the relevant process variables influencing, partial controllers (Figure 5).

The level 1 of the temperature controller regulates the mass flow of the sewage sludge in dependance of the temperature in the fluidized bed. Due to the dynamic characteristics of this subprocess the task of this part is the compensation of short term modifications of the temperature in the fluidized bed.

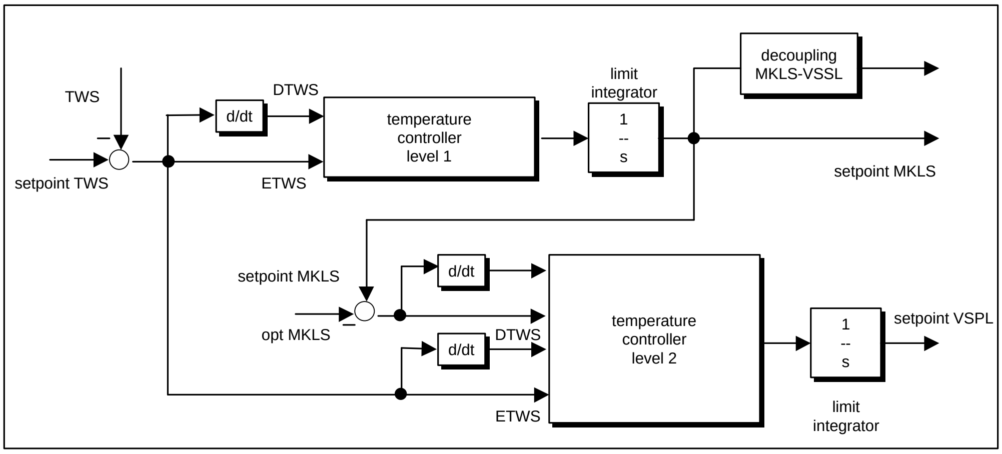

Figure 5: structure of temperature control

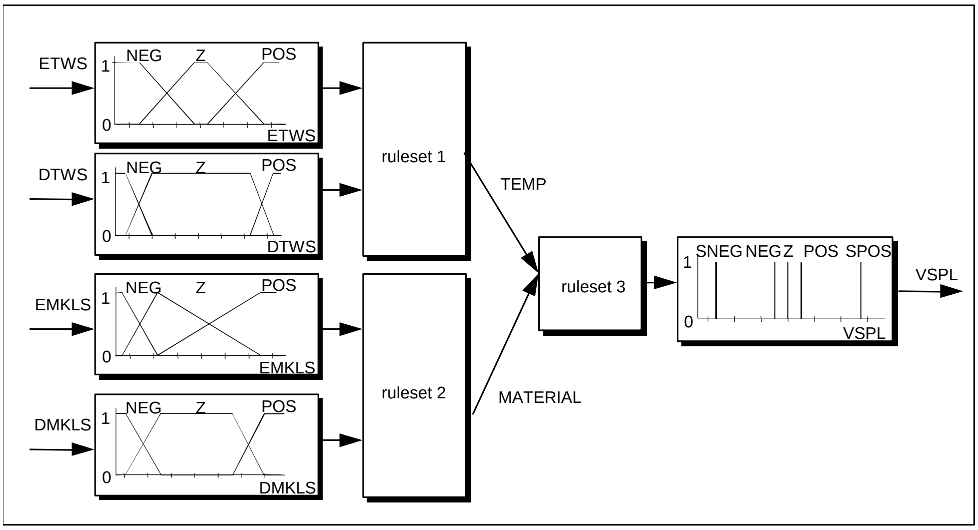

Figure 6 fuzzy based temperature controller (level 2)

The inputs of the level 1 are the following variables:

- deviation of temperature in fluidized bed (ETWS)

(5 terms: SNEG, NEG, Z, POS, SPOS)

- the gradient of the deviation temperature in fluidized bed (DTWS)
  (5 terms: SNEG, NEG, Z, POS, SPOS)

and as output value:

- the gradient of the mass flow of sewage sludge (DMKLS)
  (5 terms: SNEG, NEG, Z, POS, SPOS)

A complete set of 25 rules was created.

The level 2 of the temperature controller influences the volume flow of the liquid gas as a function of the temperature in the fluidized bed, considerating the current mass flow of the mixed granulate. This controller has two fundamental functions. The first task is to adapt the volume flow of the liquid gas to the respective thermal status of the high temperature fluidized bed system with the target of its minimization. The second task is to adjust larger deviations of the temperature in the fluidized bed, which can not be compensate by the mass flow of the mixed granulate over a longer time.

The fuzzy rule set of the level 2 (Figure 6) consists thereby of two layers. The inputs *deviation of temperature in fluidized bed* ETWS and their gradient DTWS (3 terms in each case), are linked over the ruleset 1 to the fuzzy variable TEMP. The same takes place with the inputs EMKLS and DMKLS (3 terms) by means of the ruleset 2 to the fuzzy variable MATERIAL. EMKLS represents thereby the difference of the actual value of mass flow of mixed granulate and its aspired value. DMKLS is the gradient of EMKLS. The two variables received in such a way are finally linked over the ruleset 3 to the output value DVSPL (*change of volume flow of the primary air*) with 5 terms.

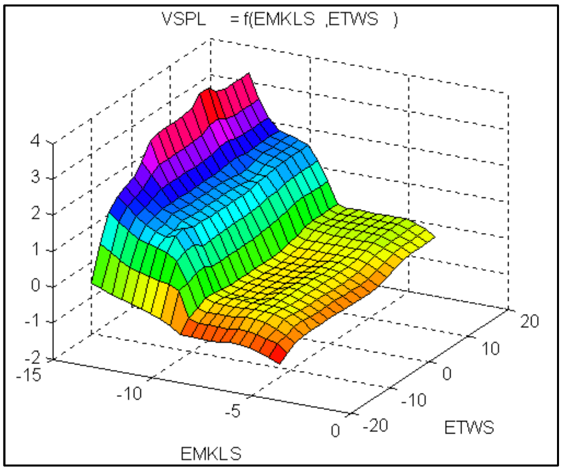

Figure 7: characteristic of fuzzy based temperature controller (level 2)

Figure 7 represents the nonlinear controller characteristic diagram of the level 2 of the temperature control as area in a special working point for only two of four inputs.

The optimization of the developed fuzzy controllers was performed with the Fuzzy Design control Toolbox for MATLAB©. As the optimization criteria the trajectory (Figure 8) was used. As optimization methods evolution strategies and gradient methods were used.

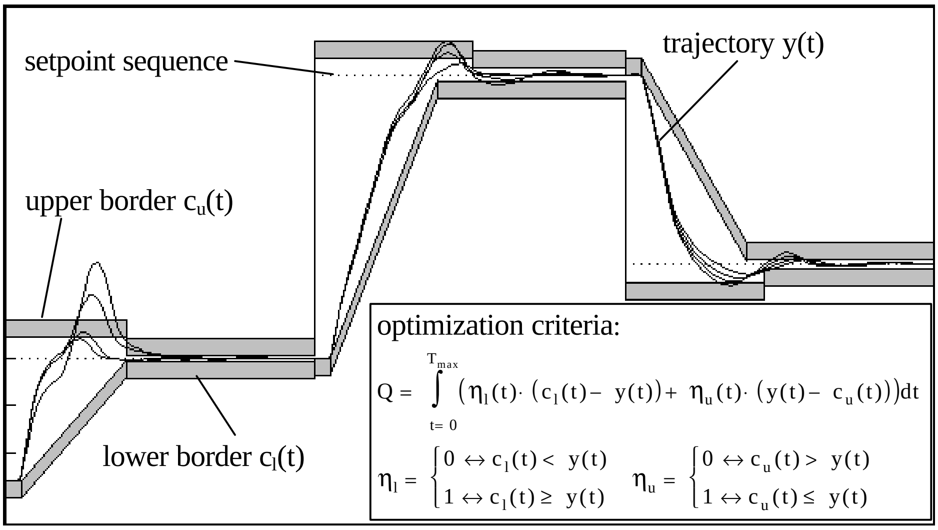

Figure 8: trajectory criteria for optimization

RESULTS

The achieved results could correspond to placed expectations. With the executed test series, apart from fluctuations in the starting phase of the system, the setpoint value of the fluidized bed temperature was kept with in the given tolerance band. The method of operation of the temperature control and the interaction of the two levels of the controller shows Figure 9, by the example of a transient after the starting phase of the system.

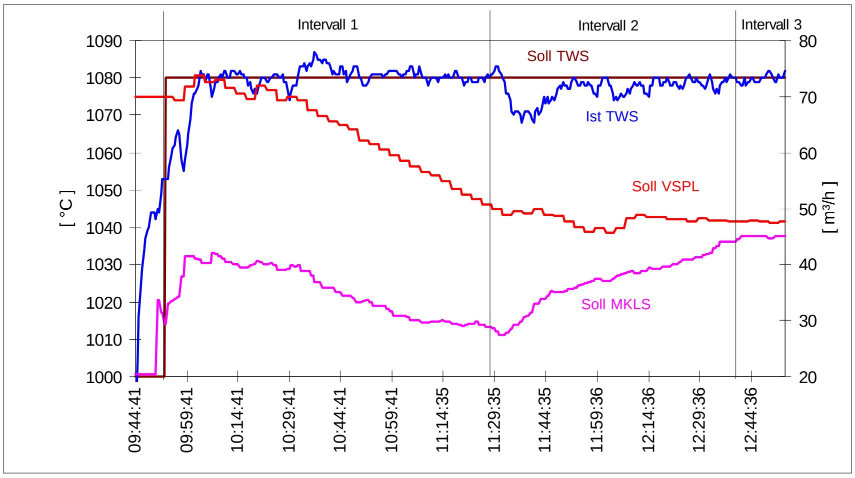

Figure 9: Transient after starting phase of the process

The initial value of the volume flow liquid gas was selected too high to show the transient between the process variables mass flow of the sewage sludge and the volume flow of liquid gas. After terminating the heating phase the setpoint for the temperature in the fluidized bed is given (setpoint TWS). The level 1 of the temperature contoller adjusts the developed deviation of the temperature in short time by increasing the mass flow of the sewage sludge (setpoint MKLS). A setpoint for the MKLS is adjusting, which is situated substantially under the aspired value of the mass flow. Thereupon the level 2 of the temperature controller reduces slowly the volume flow of the liquid gas (setpoint VSPL).

The decrease of the liquid gas quantity entails a gradual decrease of temperature in the fluidized bed. Due to the different dynamic characteristics of the two subprocesses, the level 1 of the temperature controller adjusts this deviation constantly. The mass flow of sewage sludge rises therefore continuously up (interval 2). This transient is terminated with the achieving of the desired area of the mass flow of the sewage sludge. The achieved status of the process is characterized by a maximized mass flow of sewage sludge with a minimized volume flow of liquid gas at the same time.

OUTLOOK

The application of the presented solution is far attached to special characteristics of the input material. These are the composition of the material and the resulting heat value of the input granulates. This value is assumed relatively high for the present control strategy. A substantially smaller heat value would prevent the effect of the energy release at the ceramization of the mixed granulates.

Since the described high temperature fluidized bed system represents a relative small test range, considerations are necessary to transfer the solutions to larger industrial plants. The conversion of fuzzy control for similarly constituted thermical and burning processes [Koch 1995] shows the necessity for a general design projection for multivariable control systems. Possibilities for the knowledge-based design of the control structures for such processes, including the extremely important decoupling elements, should be regarded and transferred on basis of the fuzzy concept.

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