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Improving the energy efficiency of industrial processes using mathematical modelling

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As energy costs are generally on the increase, industrial processes have to be improved in terms of more efficiency to compensate for the increasing energy costs. Besides, it is generally aimed and politically forced by industrialized countries to reduce their energy demand. The aim of this paper is to present a method to analyze energy flows in industrial processes and to show up the effect of various process optimizations which finally lead to an increase of energy efficiency. The basis for this method is the use and design of dynamic process models that help to reflect complex and dynamic industrial processes in cases where steady-state calculations are not sufficient to exhibit the impact of process variations on the overall energy demand. In order to improve process efficiency, primarily variations of insulation devices and dimensions are investigated. Secondly, improvements in process control are examined with the intention to show up the potential for further heat recovery. The final aim of the presented method is to prove the best optimization procedure in terms of ecological and economical aspects and to visualize the potential of energy reduction and thereby of CO_2 emissions.

1. Introduction

The reduction of greenhouse gas emissions and the question of how we will deal with our future energy demand, or increasing energy costs respectively, are important political and social issues nowadays. Enhancing energy efficiency and reducing energy utilisation is therefore politically strengthened, e.g. by EU directive 2006/ 32/ EG (2006)

One contribution to reduce the overall energy consumption would be to improve the energy efficiency of industrial processes, since many industrial processes are based on high energy inputs. Besides the ecological aspects, this is of economical interest as well. Energy costs become more and more a matter of cost effectiveness for production processes.

As process modifications of complex and dynamic systems are not easy to evaluate in terms of energy efficiency, powerful tools are needed to clarify the potential of reducing their energy demand.

Concerning industrial processes, there are two major aspects controlling the energy demand which are primarily the state of the insulation-system, and secondly the applied

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process control. Normally, insulation parameters are calculated under steady-state conditions, e.g. according to VDI-Guideline 2055 (2008) However, many industrial processes require dynamic modelling, in order to show the influences of changes in velocities and fluxes on temperature profiles and thus, energy losses.

2. Method

The methodological approach is depicted in Figure 1. At the start, a detailed process analysis has to be performed. This includes studying the documentation of the regarded system (P&ID flowcharts) and data collection to get an insight into the relevant dimensions, energy sources, mass flows, temperatures and costs. This has often to be done by own measurements. After performing the process analysis the modelling process can start. Depending on the complexity of the process and the specification of the optimisation aim, modelling can be done either in a stationary or in a dynamic way. Steady state modelling is usually much faster and is often used to calculate different insulation scenarios (KAEFER, 2006). Dynamic modelling can additionally be used to simulate scenarios which account for changing boundary conditions for the process within a user-defined period of time. Both modelling approaches can reveal optimisation potentials in the analysed system which leads to

- Energy conservation
- CO_2 - reduction
- Cost saving

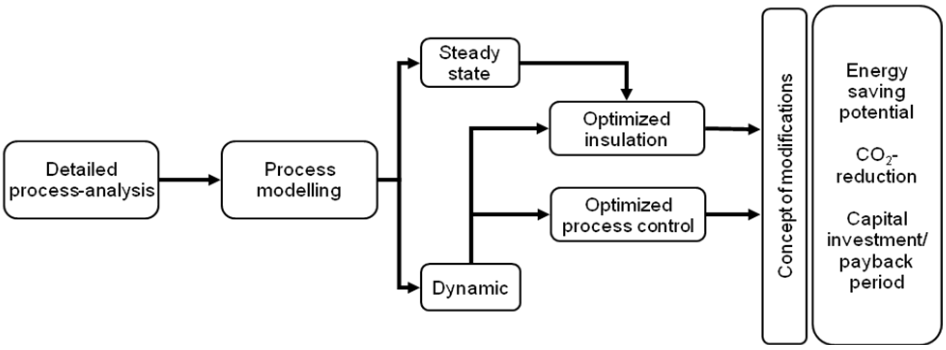


Figure 1: Scheme with the procedural method for modelling of industrial processes.

3. Results

The presented procedure for the evaluation and optimization of energy efficiency was applied in three pilot applications including a drying plant for desiccating paint coats in the automobile industry, a cooled fruit warehouse and a pasteurizer employed in the beverage industry.

3.1. Thermal exhaust air treatment

The investigated drying plant process can be described as a combustion chamber for thermal exhaust air treatment. First of all a Pinch analysis was performed. It showed that a significant heat recovery within the process is not feasible. The next step was to investigate the effects of an adapted insulation system on the energy demand of the process. After a detailed description of the process, a mathematical model was developed. The model basically consists of a number of balance scopes interacting with neighbouring zones and the environment. Physical properties of these zones were calculated as counter current heat exchangers and as insulated pipes. In this way, dynamic models were developed which now could be implemented into the WinErs simulation tool. After several tests and adaptations, a dynamic process model was created. The model allows investigating the influence of material's properties and thickness of up to two layers of insulation material installed on the various process devices. The operation of the simulator as well as the visualization of the results is performed mainly via a realistic graphical user interface (GUI) of the process (Figure 2).

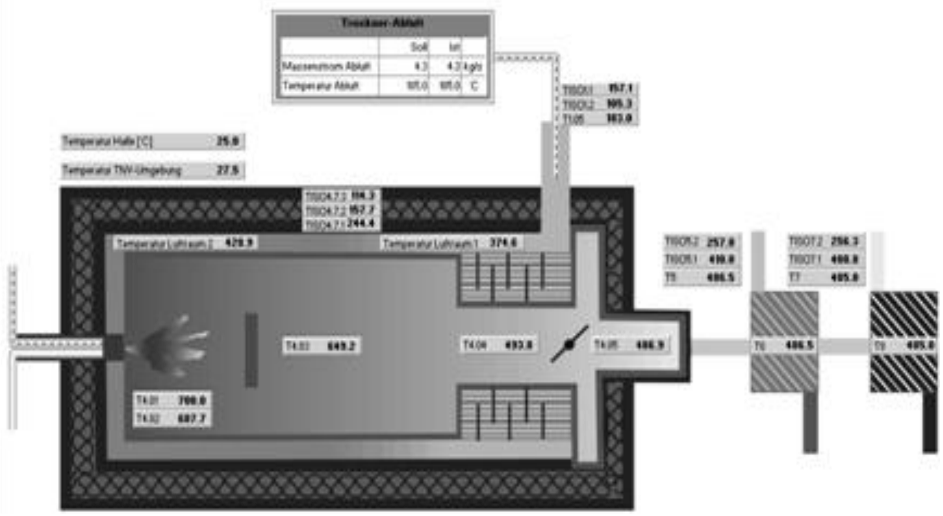


Figure 2: Main graphical user interface of the thermal exhaust air treatment, showing relevant state variables and giving options for influencing parameters and variables of the model.

After calculating six scenarios, the following adaptations to the insulation system were the most efficient:

While increasing the insulation thickness of the combustion chamber would safe 2.7 t of CO_2/y, adaptations on the piping insulation would safe 9.9 t of CO_2/y. Payback periods of 5.3 y and 34.3 y may be achieved, respectively.

3.2. Cold storage warehouse

The second application was a cold storage warehouse for fruits and vegetables. After a detailed process analysis, the warehouse model was developed. The model describes heat fluxes through plain walls. Every compartment of the warehouse has been translated into a balance scope which can interact with its neighbour compartments and the environment. Furthermore, the climatic influences over a year and the various degrees of utilization were considered within the model. The operator can vary four layers of insulation material and thickness of every wall in the warehouse. The model calculates the temperature of the compartment and heat fluxes for every scope. The results were presented in diagrams and in a graphical user interface created with WinErs (Figure 3).

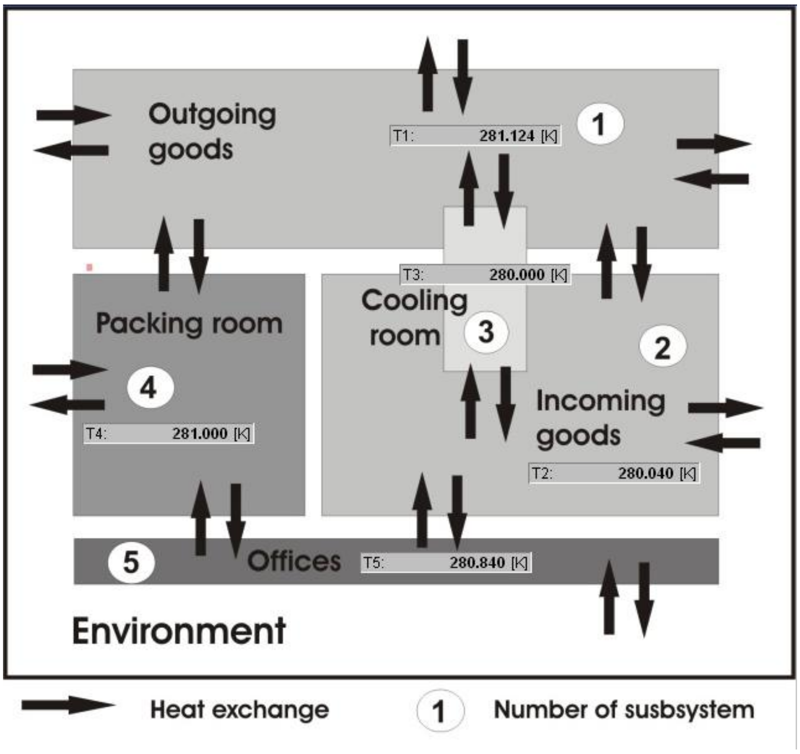


Figure 3: Interactive graphical user interface for the refrigerating storage house.

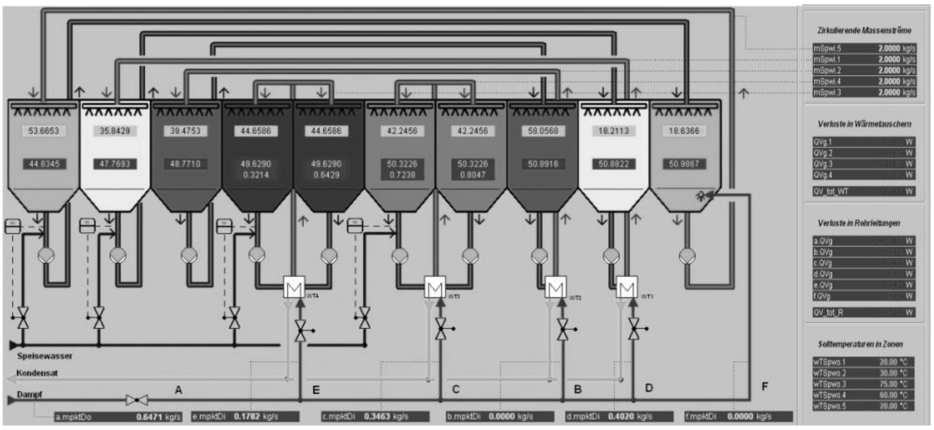
Four scenarios with different setups of insulation systems were calculated. The best scenario showed that about 20 tons of CO_2 per year can be saved. To achieve this, huge areas of the warehouse have to be provided with an improved insulation. This leads to enormous costs and payback periods of more than 200 years. It was clearly demonstrated that the existing insulation of the warehouse is state of the art. Nonetheless, the created model might help to optimize the process logistics in the warehouse.

3.3. Pasteurizer

The third application that has been investigated is a pasteurizer employed in the beverage industry. The pasteurizer is heated with steam and the first part of this application dealt with the piping system that delivers the steam. The steam use and possible savings in this field were of big interest for the plant operators. For this application, the piping model developed for the exhaust air treatment was used. After an adaptation to the new process parameters several insulation scenarios could be calculated.

Based on figures given by the operators, the following results were achieved. A proper insulation of the heat exchanger housings can save 151 t of CO_2/y. The payback period amounts to two weeks. Besides this, the influence of some piping surfaces without any insulation on the energy demand was verified. It turned out that installing proper insulation to less than one percent of the piping surface that is currently without proper insulation would save 12 t of CO_2/y. The investment would pay off within approximately 65 days.

The developed model can now also be expanded to calculate more complex scenarios concerning the actual operation of the pasteurizer. Figure 4 shows the graphical user interface of the pasteurizer model in WinErs.



a.mpktDo 0.6471 kg/s
e.mpktDi 0.1782 kg/s
c.mpktDi 0.3463 kg/s
b.mpktDi 0.0000 kg/s
d.mpktDi 0.4020 kg/s
f.mpktDi 0.0000 kg/s

Zirkulierende Massenströme

mSpwi.5 2.0000 kg/s
mSpwi.1 2.0000 kg/s
mSpwi.2 2.0000 kg/s
mSpwi.4 2.0000 kg/s
mSpwi.3 2.0000 kg/s

Verluste in Wärmetauschern

QVg.1 [illegible] W
QVg.2 [illegible] W
QVg.3 [illegible] W
QVg.4 [illegible] W

QV_tot_WT [illegible] W

Verluste in Rohrleitungen

a.QVg [illegible] W
b.QVg [illegible] W
c.QVg [illegible] W
d.QVg [illegible] W
e.QVg [illegible] W
f.QVg [illegible] W

QV_tot_R [illegible] W

Solltemperaturen in Zonen

wTSpwo.1 20.00 °C
wTSpwo.2 30.00 °C
wTSpwo.3 75.00 °C
wTSpwo.4 60.00 °C
wTSpwo.5 20.00 °C

Figure 4: Main graphical user interface of the pasteurizer, showing relevant state variables and giving options for influencing parameters and variables of the model.

4. Conclusion

Concerns about the energy consumption and increasing energy efficiency have become of growing importance on the sustainability agenda of industrial sites. Therefore, tools are needed to evaluate potential system optimizations in terms of a reduction of energy demand of the investigated processes. In this paper, a method is presented that is considered to be very powerful to assess optimization strategies of complex industrial plants or sites. This is of particular importance as energy demanding processes are very often dynamic as well. The key to handle this is dynamic modelling. It is very likely that dynamic modelling will become of significant importance to ensure an optimized energy use in industrial processes. No other approach allows real time investigation of insulation effects and process control with one tool. While the model can easily be controlled by employing interactive graphical user interfaces, ecological and economical effects of the resulting process modifications can be effectively visualized with the help of comparing Sankey diagrams (Figure 5).

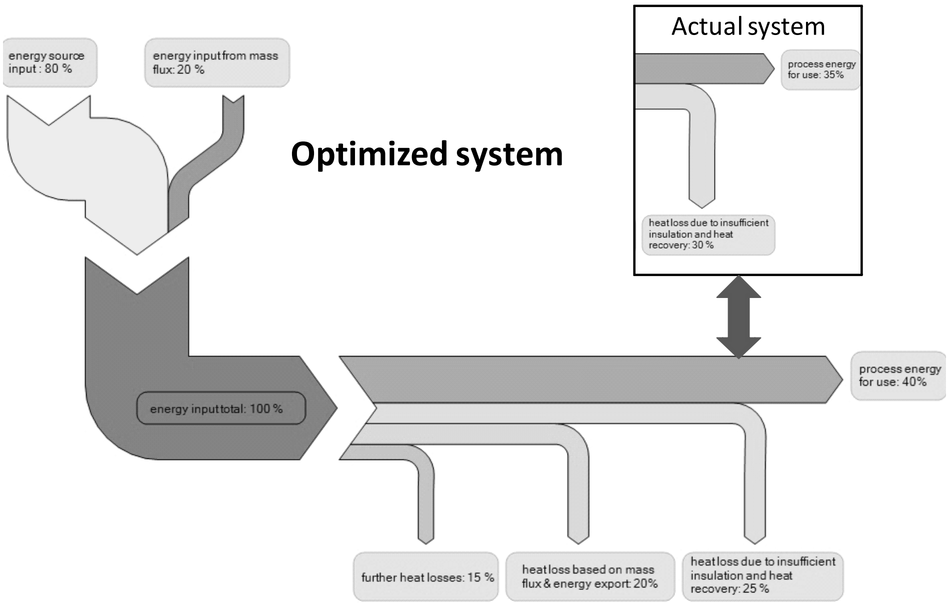


Figure 5: Example for the presentation of the modelling results with energy balance diagrams using comparing Sankey diagrams.

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