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Integration of the bio-ethanol process in a network of facilities for heat and power production from renewable sources using process simulation

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Abstract

The economic competitiveness of ethanol as a liquid fuel strongly depends on the amount of energy used during the production. To a sustainable production of fuel ethanol contributes also the use of energy from renewable sources. Process simulation is used to integrate a bio-ethanol plant in a network of facilities for heat and power production from residues of ethanol and feedstock production. Results show that depending on plant capacity and form of biogas utilization it is possible to cover heat demand using biogas produced from stillage of bio-ethanol fermentation. Partial combustion of straw from feedstock production even enables to cover the heat demand of small ethanol facilities.

Keywords process simulation, bio-ethanol, renewable energy, sustainable fuels, heat integration, process integration

1. Introduction

Ethanol production from agricultural feedstock by fermentation is a well known process. In the last few years a growing importance of ethanol in the area of liquid fuels can be observed. Besides safety in supply – import of 90% of fossil fuels will be necessary to the countries of the EU within the next 20-30 years –

also environmental, social and economic reasons as well as legislative reasons are responsible for the interest in bio-ethanol production.

2. Problem Statement

Additional to the substrate costs, the economic competitiveness of ethanol as a liquid fuel strongly depends on the amount of energy used during the production. To a sustainable production of fuel ethanol contributes also the use of energy from renewable sources. Process simulation is used to integrate an bio-ethanol plant in a network of facilities for heat and power production from residues of ethanol and feedstock production.

Plants with bio-ethanol capacities of 15000 / 60000 / 100000 / 200000 t/a were examinated using wheat as feedstock. The design capacity of 200000 t/a fuel ethanol will be able to substitute 5.75 % of the total gasoline consumed in Austria today [1].

3. Simulation work

3.1. Simulation tool

The ethanol production plant, as well as single units for heat and power generation, are modelled using the equation-oriented industrial software package IPSEpro, initially designed for power plant engineering purpose.

The simulation package consists of two parts [2]; the process simulation environment (PSE), to model single process steps as well as the whole process configuration and the model development kit (MDK), to create user defined units. The very efficient equation solver of IPSEpro enables the tool to solve large projects consisting of many process units within a short time.

3.2. Bio-ethanol process and simulation models

The model of the bio-ethanol production process is based on data from literature concerning the state of art [3, 4] and includes milling the raw material, mashing, liquefication, saccharification and the fermentation step (Fig. 1).

The calculation considers the stoichiometry of the ethanol formation (Eq. 1), the degradable fraction of the biomass and the toxic maximum of about 8 % (mass based) of ethanol in the alcoholic mash as well as the exothermic behaviour (-58.75 kJ/mol Ethanol) [5] of the reaction. The developed fermentation model is based on starch content and elemental analysis of the fermentation feedstock. Consideration of elemental analysis is important to calculate the composition of the resulting by-products.

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2 \qquad (1)$$

The equimolar produced carbon dioxide is partly dissolved in the alcoholic mash following to Henry's law whereas the remaining gas is removed from the production process via a gas exit at the fermentation unit.

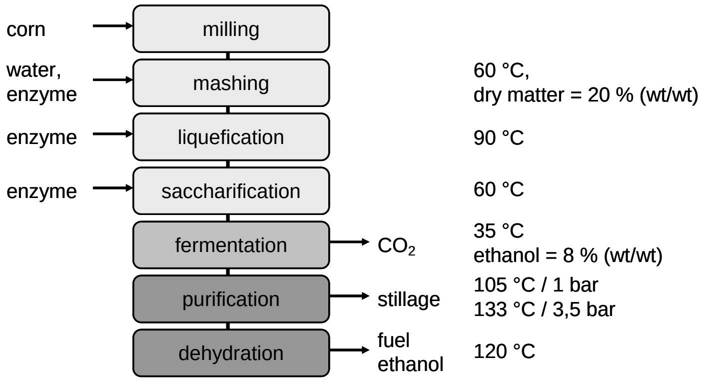

Figure 1: Scheme of bio-ethanol process

The model for the purification of ethanol consists of two rectification steps and starts with the separation of bio-ethanol from the fermentation broth in the beer-column. At the top of this column carbon dioxide is stripped from the ethanol solution and leads to an ethanol concentration of approx. 40-45% (mass based) in a side stream. This ethanol is further concentrated in the rectification-column up to 94% (mass based). Afterwards, ethanol is dewatered using adsorption on a molecular sieve to an ethanol content of 99.7% (mass based). Concentration and dewatering of ethanol are based on the concept described by NREL [6]. The model of the distillation section considers soluble and insoluble inert substances as well as by-products like fusel oils and organic acids.

Ethanol-free stillage from the beer column usually dried to give animal food in our concept is used to produce biogas which can be converted to electric power and heat in a CHP-plant (gas engine) or be used to produce only heat in a simple combustion chamber. The obtained thermal energy is used in the bio-ethanol process to satisfy the energy requirement of the distillation process.

The model of biogas production consists of a two stage fermentation. After anaerobic digestion the produced biogas is discharged from H_2S in a scrubber equipped with immobilized bacteria and afterwards converted to heat and/or power. The units for calculating the biogas digestion and the subsequently utilisation of the received biogas in the CHP-plant are taken from previous works [7, 8], while the alternative path of biogas usage consists of a standard combustion chamber followed by a standard gas fired boiler.

An alternative to biogas utilisation is to obtain process steam by combustion of the remaining straw from the feedstock production. Calculations are based on the elemental analysis or the calorific value of the used straw. Units of the IPSEpro standard-library are used for realising the model of the biomass combustion. Only the combustion chamber model was slightly modified to handle the remaining ash.

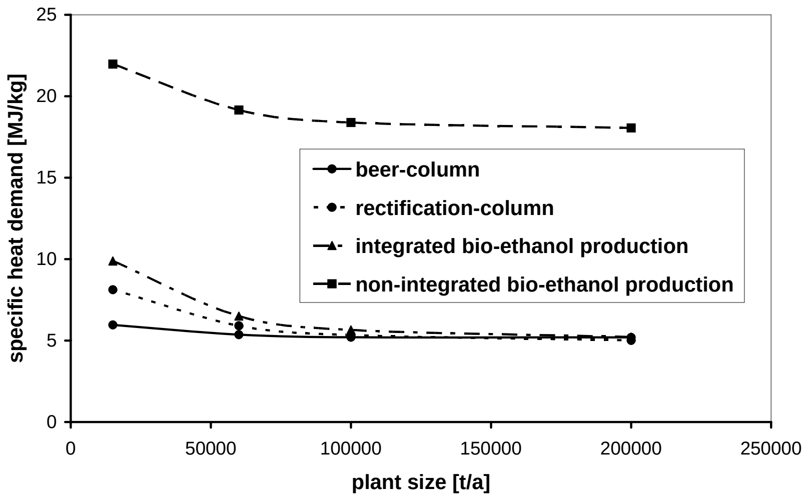

Figure 2: Specific heat demand of single units as well non-integrated and integrated bio-ethanol production facility for feedstock wheat

3.3. Heat integration

For the analysis of the simulation results regarding heat integration and optimisation of the heat demand, heat vs. temperature diagrams (q-t-diagrams) were used [9, 10]. Fig. 2 shows the importance of heat integration comparing the specific heat demand of single beer- and rectification column and non-integrated bio-ethanol plant with the heat demand of a fully integrated production facility. Heat demand of the non-integrated bio-ethanol production plant is more than two times higher than the integrated one. By heat integration the heat demand of the whole bio-ethanol plant can be reduced being finally only slightly higher than the demand of the rectification column.

3.4. Results & discussion

Despite heat integration, production of bio-ethanol shows a considerable heat demand. Fig. 3 compares the heat demand of a bio-ethanol plant (without DDGS production) with the heat produced by biogas conversion in a CHP-plant (gas engine) and a gas fired boiler for different plant capacities.
Burning biogas in a gas-fired boiler covers the total heat demand of a plant with a capacity higher than 100000 t/a ethanol without DDGS production when using wheat as feedstock.

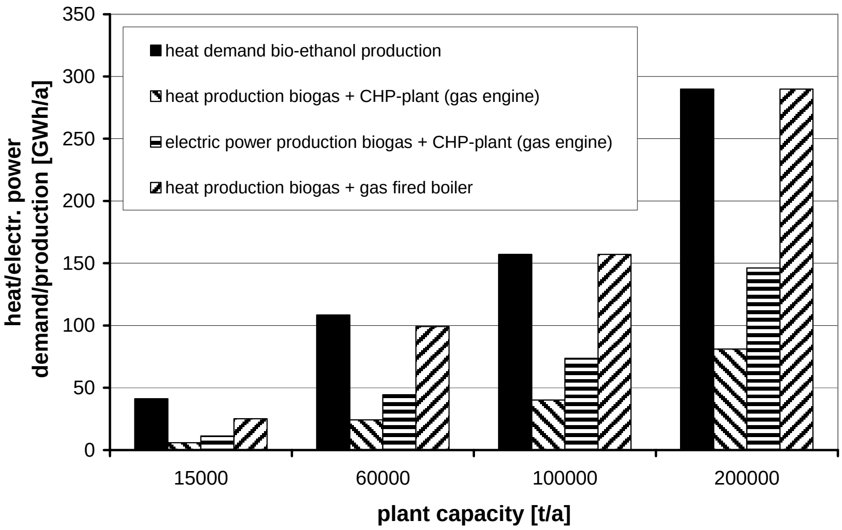

Figure 3: Heat demand during bio-ethanol production from wheat and generation of heat and electric power from biogas in CHP-plant (gas engine) and gas fired boiler

Using the produced biogas in a CHP-plant (gas engine) gives a lower amount of heat, contributing only a little to the coverage of the heat demand of ethanol production, but provides a considerable amount of electric power.

However heat demand of all facilities can be covered by burning straw arising during production of wheat for the bio-ethanol production. The obtainable amount of heat exceeds the 5-10 fold of the demand for ethanol-production. In this way also the coverage of the demand of small bio-ethanol facilities with a capacity of 15000 t/a ethanol and even smaller is possible using only heat from by-products from feedstock production (Table 1).

plant capacity	heat demand	total heat production from straw	amount of straw to cover demand
[t/a]	[GWh/a]	[GWh/a]	[%]
15000	41.2	220.1	18.7
60000	108.4	880.4	12.3
100000	157.1	1467.4	10.7
200000	289.8	2934.8	9.9

Table 1: Covering heat demand of bio-ethanol production by straw combustion

Surplus heat might be used for generating electric power in a steam turbine. To reduce transport and storage of straw only the amount of heat necessary in the bio-ethanol facility should be produced. The necessary amount of wheat straw for burning to cover the heat demand of different plant capacities lies between 10 % and 20 % of the straw arising from feedstock production (Tabel 1).

4. Conclusions

Heat integration saves considerable amount of energy during production of bio-ethanol. But further increase of sustainability of bio-ethanol production is possible by the use of renewable energy from by-products of feedstock and bio-ethanol production. Depending on plant capacity and form of biogas utilization it is possible to cover the heat demand using biogas produced from stillage of bio-ethanol fermentation. Partial combustion of straw from feedstock production even covers the heat demand of small ethanol facilities. New combustion technology based on balled biomass seems suitable for heat supply of these small bio-ethanol production plants.

Acknowledgements

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References

1. Directive 2003/30/EG of the European Parliament and the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport.
2. E. Perz, ASME Paper IGTI GT-351, (1990) 8P.
3. M. Roehr (ed.), The Biotechnology of Ethanol – Classical and Future Applications, Wiley-VCH, Weinheim, 2001.
4. W. Gerhardtz, Y.S. Yamamoto, L. Kaudy, J.F. Rounsaville and G. Schulz (eds.), Ullmann’s Encyclopedia of Industrial Chmistry, Volume A9, 5th Ed., VCH, Weinheim, 1987.
5. M. Kaltschmitt, Nachwachsende Energieträger, Vieweg, Braunschweig, 1997.
6. A. Aden, M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, B. Wallace, L. Montague, A. Slayton, and J. Lukas, Technical Report NREL/TP-510-32438, NREL, Colorado, 2002.
7. S. Kaiser, PhD Thesis, Vienna University of Technology, Vienna, 2001.
8. A. Friedl, L. Schlegl, M. Pfeffer and M. Harasek, CHISA 2004 - 16th International Congress of Chemical and Process Engineering. Prague, Czech Republic, 2004.
9. B. Linnhoff and J.R. Flower, AIChE Journal, 24 (1978) 633-654.
10. M. Pfeffer, W. Wukovits and A. Friedl, Pres05 - 8th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, Giardini di Naxos, Italy, 2005.