Applied Energy 143 (2015) 460–471

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Energy self-supply of large abattoir by sustainable waste utilization based on anaerobic mono-digestion

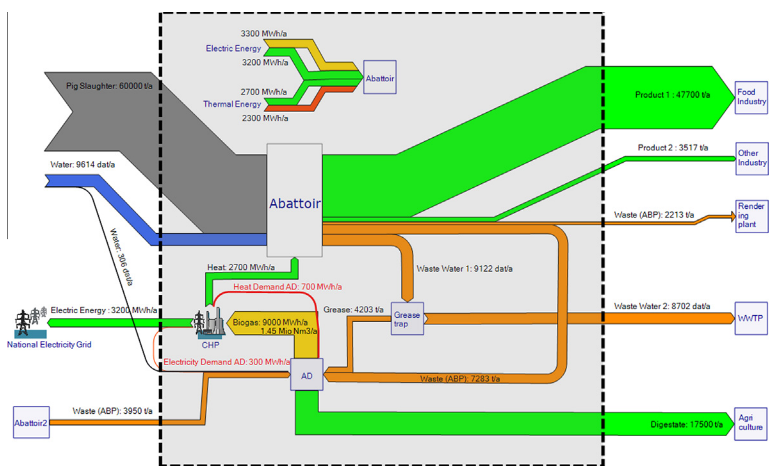
Markus Ortner [a,b,e,*], David Wöss [b,c,1], Alexander Schumergruber [d,2], Tobias Pröll [b,c,1], Werner Fuchs [b,e,3]

[a] Bioenergy 2020+, Konrad Lorenz Str. 20, A-3430, Tulln, Austria
[b] University of Natural Resources and Life Sciences, Vienna, Austria
[c] Institute for Chemical and Energy Engineering, Peter-Jordan-Str. 82, A-1190 Vienna, Austria
[d] Rudolf Großfurtner GmbH, Hofmark 1, A-4972 Utzenaich, Austria
[e] IFA Tulln, Institute for Environmental Biotechnology, Konrad Lorenz-Str. 20, A-3430 Tulln, Austria

HIGHLIGHTS

- Successful implementation of a new waste and energy concept to large size abattoir.
- 85% of slaughterhouse waste accumulated converted to energy by anaerobic digestion.
- Coverage of abattoirs' electrical and thermal energy demand between 50% and 60%.
- Reduction of main energy and disposal cost by 63%.
- Reduction of greenhouse gas emissions by 79%.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 28 June 2014
Received in revised form 17 November 2014
Accepted 9 January 2015

Keywords:
Slaughterhouse waste
Anaerobic mono-digestion
Ammonia inhibition
Trace elements
Heat utilization
Heat storage

ABSTRACT

Abattoirs have a large number of energy intensive processes. Beside energy supply, disposal costs of animal by-products (ABP) are the main relevant cost drivers. In this study, successful implementation of a new waste and energy management system based on anaerobic digestion is described. Several limitations and technical challenges regarding the anaerobic digestion of the protein rich waste material had to be overcome. The most significant problems were process imbalances such as foaming and floatation as well as high accumulation of volatile fatty acids and low biogas yields caused by lack of essential microelements, high ammonia concentrations and fluctuation in operation temperature. Ultimately, 85% of the waste accumulated during the slaughter process is converted into 2700 MW h thermal and 3200 MW h electrical energy in a biogas combined heat and power (CHP) plant. The thermal energy is optimally integrated into the production process by means of a stratified heat buffer. The energy generated by the biogas CHP-plant can cover a significant share of the energy requirement of the abattoir corresponding to 50% of heat and 60% of electric demand, respectively. In terms of annual cost for energy supply and waste

* Corresponding author at: IFA Tulln, Institute for Environmental Biotechnology, Konrad Lorenz-Str. 20, A-3430 Tulln, Austria. Tel.: +43 2272 66280 536.
E-mail addresses: markus.ortner@bioenergy2020.eu (M. Ortner), david.woess@boku.ac.at (D. Wöss), alexander.schumergruber@grossfurtner.at (A. Schumergruber), tobias.proell@boku.ac.at (T. Pröll), werner.fuchs@boku.ac.at (W. Fuchs).
[1] Tel.: +43 1 47654 3531.
[2] Tel.: +43 650 7171535.
[3] Tel.: +43 2272 66280 553.

http://dx.doi.org/10.1016/j.apenergy.2015.01.039

disposal a reduction of 63% from 1.4 Mio € to about 0.5 Mio € could be achieved with the new system. The payback period of the whole investment is approximately 9 years. Beside the economic benefits also the positive environmental impact should be highlighted: a 79% reduction of greenhouse gas emissions from 4.5 Mio kg CO_2 to 0.9 Mio kg CO_2 annually was achieved. The realized concept received the Austrian Energy Globe Award and represents the first anaerobic mono-digestion process of slaughterhouse waste worldwide.

1. Introduction

1.1. General

Food processing factories, particularly abattoirs, have a large number of energy intensive processes that require heat at moderate temperatures between 60 and 95 °C (e.g. scalding tunnel, depilation, daily cleaning of facilities) [1]. Up to now, operating stability and reliable coverage of peak demands have been the dominant design criteria with respect to the selection of energy sources. Natural gas or fuel oil fired boilers provide the low-temperature heat in most cases. The main advantage of boiler-based heat supply is the flexibility with respect to load-changes and the low capital costs of the boiler system. However, the distinct disadvantage of boiler-based heat supply is that high-value fuels are needed, which is a large component of the operating costs of the food processing factory. Prices on the European energy market continued to rise markedly owing to different global developments. The price increase between 2001 and 2012 for medium size industrial consumers with an annual consumption between 10,000 and 100,000 GJ amounted to between 31% (Sweden) and 237% (Hungary) for natural gas and between 34% (Germany) and 164% (Malta) for electricity. The average increase in the European Union (EU27) was 68% for natural gas and 42% for electricity. In the year 2012 in the EU27 the average price including network costs and non-recoverable taxes and levies was 36.4 €/MW h for natural gas and 95.4 €/MW h for electricity [2].

Abattoirs generate high amounts of animal by-products (ABP) which require comprehensive treatment steps owing to national and European hygiene regulations. The current treatment of slaughterhouse waste is a rendering process done in carcass plants. Although rendering is a very energy intensive and expensive process, the sale of meat and bone meal as an animal feed additive was a valuable source of income for abattoirs until new legislation came into force in 2000 in response to the bovine spongiform encephalopathy (BSE) crisis [3]. The European Union immediately banned rendered animal proteins from food- and animal food-chains and enacted a law in 2002 for safe and proper disposal of slaughterhouse wastes [4,5]. As a consequence by-products from abattoirs turned from a valuable product to a problematic waste and the safe disposal of slaughterhouse waste put a severe economic burden on meat production.

To summarize, the main operating costs of an abattoir are – apart from personnel costs – waste disposal costs and energy supply costs spent on electricity and fuels (natural gas or light fuel oil) [1].

To reduce this costs, new strategies in terms of process efficiency, energy supply and sustainable waste management concepts are important.

In this context anaerobic digestion (AD) can play a key role. It is an adequate and well-known technology for the treatment of industrial organic residues almost regardless of their consistency. Anaerobic digestion produces renewable energy in the form of a well combustible biogas containing of 55–70 vol.% methane. Biogas can be used onsite to co-generate process heat and electricity as well as to substitute fossil fuels. Furthermore, it enables a controlled stabilization of the organic material, reduces greenhouse gas emissions and contributes to the closing of nutrient cycles [6].

Also waste materials from abattoirs are a potential source for biogas production. Anaerobic treatment of slaughterhouse wastewater, which derives predominantly from the daily cleaning routines, is already established [7–9].

In addition, several investigators have examined the feasibility of solid or semi-solid slaughterhouse by-products for biogas production. Some studies report on bio methane potential (BMP) of different waste fractions [10–17]. Besides that, continuous AD experiments at different process conditions (temperature, loading rate, influence of thermal pretreatment, NH_4-removal) were conducted [11,16–22].

Comparison of two stage AD versus a single-pass reactor applying slaughterhouse waste as co-substrate was made by Wang and Banks [23]. Other studies addressed modeling of the process [13,24] or innovative applications such as anaerobic membrane reactors or membrane contactor systems [25–27].

Despite these many investigations, little information is available about transfer of lab results into practical application. In particular, the high nitrogen content of slaughterhouse waste and the resulting ammonia inhibition makes process operation difficult. Many researchers suggested co-digestion with other less N-rich substrates, e.g. sewage sludge, food waste or energy crops, as the most promising application [19,25–29].

Accordingly, all full-scale processes where process details are available are co-digestion processes. One plant is established in Linköping, Sweden (1997). It has a treatment capacity of 100,000 t/a and the proportion of slaughterhouse waste in the feedstock mixture varies between 35% and 75% [30]. Another plant is located in Münchwilen, Switzerland (2011) with a treatment capacity of 40,000 t/a. Beside slaughterhouse waste, food waste is applied [31].

However, there is a trend toward very large, centralized slaughterhouses, and it can be difficult to get sufficient amounts of co-substrates. Therefore, there is interest in developing a reliable mono-digestion process using slaughterhouse waste as the sole substrate.

1.2. Animal by-products as substrate for biogas plants

Animal by-products are materials of animal origin that arise mainly during slaughter of animals and are not intended for human consumption. ABPs may represent a source of risk to public health and for that reason their disposal is strictly regulated. There are three categories of risks.

Risk category 1 materials (i.e. spinal cord, brain, eyes of cattle or sheep) represent the highest risk such as TSE (transmissible spongiform encephalopathy) or scrapie and have to be completely disposed of by incineration. Hence this category cannot be used in biogas plants.

Risk category 2 materials include all the materials that do not fit into category 1 or 3 and represent a risk of contamination with other animal diseases. These may not be used in feed, but can be