Applied Thermal Engineering 43 (2012) 20–28

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

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

Pinch and exergy analysis of lignocellulosic ethanol, biomethane, heat and power production from straw

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A R T I C L E I N F O

Article history:
Received 15 August 2011
Accepted 10 January 2012
Available online 18 January 2012

Keywords:
Bioethanol production
Pinch analysis
Exergy analysis
Exergy efficiency

A B S T R A C T

In this work a complex process for production of bioethanol, biomethane, heat and power from the wheat straw is introduced and analyzed with regard to pinch and exergy analysis. The pinch analysis is focused on the bioethanol production where a well-designed heat exchanger network increases heat integration up to 45 MW. To obtain optimal total site external hot and cold utilities demands at different temperature levels as well as maximum power generated by steam turbine, an integrated steam cycle composite curve has been added to the grand composite curve of the "background process". The exergy analysis takes into account three production sections separately and exergy efficiencies are calculated to find the quantity of irreversibilities the bioethanol processes. The results from exergy analysis show that the bioethanol process has the highest exergy efficiency because of usage of stillage for other processes in which a considerable part of exergy entering is converted into irreversibility because of heat losses and non reacting unknown material produced as material losses.

1. Introduction

In the past few years, the use of biomass for biofuel production is increased because of increasing energy demand and avoiding the global warming and greenhouse gas emissions (GHG) caused by fossil fuel consumption [1]. Bioethanol as the major biofuel used in transportation and as a clean and sustainable resource compared to the fossil fuels, is produced by simultaneous enzymatic saccharification and fermentation (SSF) process where fermentable sugars extracted from different feedstock are enzymatically saccharified, fermented and converted to ethanol. Some studies have shown that greenhouse gas emissions released through bioethanol production from starchy crops are high compared to production from lignocellulosic materials such as straw [2]. In this study, a complex process producing bioethanol, biomethane as well as combined heat and power (CHP) from straw is analyzed from energy and exergy point of view. Main by-products generated during the bioethanol process are fed into other sub-processes as feedstock. Pfeffer et al. [19] performed an energy analysis of a polygeneration process in which bioethanol, biogas, heat (steam) and power are produced from wheat and residues of bioethanol production process to decrease external energy demand. Macedo et al. [3] studied that during bioethanol production from sugarcane, need of fossil fuel consumed to supply required process energy is much lower compared to corn as feedstock. One of the challenges during bioethanol processing is the reduction of utility demands by means of process heat integration [4]. Morandin et al. [21] suggested some heat integration improvements to a combined sugar and biofuel production process coupled with a CHP system fueled with bagasse as well as multi effect evaporation unit by means of integrated composite curve of steam cycle in which different CHP system configurations are investigated. Besides mass and energy balance exergy analysis can be applied to identify, exergy dissipations (irreversibilities) from exergy saving point of view. A few investigations on bioethanol production process combined with CHP system have previously been published from energy and exergy point of view. Most of the recent studies have been focused on the pinch or exergy analysis and have not considered the both of them. Ojeda et al. [5] have applied energy and exergy analysis with heat integration approach which suggest some process improvements resulting in minimization of residual waste streams and a new heat exchanger network. Tovazhnyansky et al. [26] applied pinch technique to conserve energy in the sodium hypophosphite production plant and investigated influence of energy and equipment (heat exchanger) cost on minimum temperature difference to obtain well-designed cost-effective heat exchanger network according to the optimum minimum temperature difference.

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1359-4311/$ – see front matter
doi:10.1016/j.applthermaleng.2012.01.026