Case Studies in Thermal Engineering 10 (2017) 283–291

Contents lists available at ScienceDirect

Case Studies in Thermal Engineering

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

Performance evaluation and optimization of fluidized bed boiler in ethanol plant using irreversibility analysis

Nugroho Agung Pambudi[a,b,*], Maedanu Fasola[a], Lukad Valiant Perdana[a], Ria Laurensia[a], Danar Susilo Wijayanto[a], Muhammad Imran[c], Lip Huat Saw[d,e]

[a] Department of Mechanical Engineering Education, Universitas Negeri Sebelas Maret, Jl. Ahmad Yani 200A, Pabelan, Indonesia
[b] International Institute for Carbon-Neutral Reserch (WPI-I2CNER), Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan
[c] Department of Energy Engineering, School of Engineering, University of Management and Technology, CII Johar Town Lahore, Pakistan
[d] Department of Mechanical Engineering, Faculty of Engineering, National University of Singapore, Singapore 117576, Singapore
[e] Lee Kong Chian Faculty of Engineering and Science, UTAR, Kajang 43000, Malaysia

ARTICLE INFO

Keywords:
Exergy analysis
Fluidized bed boiler
Ethanol
Performance assessment
Irreversibility

ABSTRACT

This research aims to evaluate the performance of a fluidized bed boiler in an ethanol production plant through exergy and irreversibility analysis. The study also includes the optimization of the pre-heater and the deaerator in order to improve the system efficiency. Operational data from the ethanol production plant was collected between 2015 and early 2016. The total exergy derived from the fuel was determined to be 7783 kJ/s, while the exergy efficiency of the system was found to be 26.19%, with 2214 kJ/s used in steam production, while 71.55% was lost to component irreversibility and waste heat from the pre-heater. The exergy efficiencies of individual components of the system such as the boiler, deaerator, and pre-heater were found to be 25.82%, 40.13%, and 2.617%, respectively, with the pre-heater having the lowest efficiency. Thus, the pre-heater has the highest potential to significantly improve the efficiency of the boiler system. The optimization of the pre-heater shows that a rise in temperature in the outlet of the pre-heater positively affects the exergy efficiency of the deaerator.

1. Introduction

The rapid depletion of fossil fuel resources coupled with unstable prices and environmental concerns have accelerated concerns in the area of energy efficiency. A study conducted by McGlade to estimate the total volume of tight oil recoverable worldwide suggests that between 150 million to 508 million barrels exist [1]. Similar estimates for coal and gas resources, such as coal bed methane, tight gas, and shale gas are put at 39, 54, and 193 TCM, respectively [2]. It is evident from these values that all non-renewable energy sources will be depleted in the near future. Despite oil prices plummeting to below $30/barrel in 2015, crude oil resources will still be depleted in the future. In order to ensure energy security, countries are currently engaged in activities geared at improving fossil fuel management. In a study by Ediger et al., 2007, a sustainability index comprising several factors such reserve-production, production-consumption, and carbon emission ratio was designed using data from 62 countries [3]. This indexing allows for better planning regarding fossil fuel consumption relative to its reserves.

In the power generation and commercial sectors, there are various methods employed in order to reduce the consumption of fossil fuels. The methods include the reduction of fossil fuel consumption as well as the replacement of fossil fuels by renewable energy

* Corresponding author at: International Institute for Carbon-Neutral Reserch (WPI-I2CNER), Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan.
E-mail address: agung.pambudi@staff.uns.ac.id (N.A. Pambudi).

http://dx.doi.org/10.1016/j.csite.2017.07.008
Received 1 June 2017; Received in revised form 22 July 2017; Accepted 26 July 2017
Available online 02 August 2017

Nomenclature

Symbols

$\dot{m}$	Mass flow (kg/s)
$\dot{Q}$	heat flow (kJ/s)
$\dot{W}$	Work flow (kJ/s)
$\dot{EX}$	Exergy (kJ/s)
h	Enthalpy (kJ/kg)
g	gravity (m/s^2)
Z	elevation (m)
ex	specific exergy (kJ/kg)
I	irreversitility (kJ/s)
T	Temperature (K)
s	entropy (kJ/kg K)
TCM	Trillion Cubic Metres
RP	Reserves-production
PC	Production-consumption
Mtoe	Tonne of oil equivalent
FDF	Force Draft Fan
IDF	Induced Draft Fan

Subscript

CV	Control Volume
i	Inlet
o	Outlet
k	Specific stream
ke	Kinetik
po	Potential
ph	Physical
ch	Chemical
p	Product

sources. This is to ensure that fossil fuels remain available for a longer period of time. It is, however, at an economic disincentive to the commercial sector, as it usually translates into lower profit; hence, it is rarely implemented. In the power generation sector, the implementation of this method also usually translates into slowed economic growth and, as such, is not commonly implemented. For instance, China's energy consumption increased drastically from 1793 Mtoe in 2005 to 3014 Mtoe in 2015. This puts China as the highest consumer, having overtaken the United States, which has a total energy consumption of 2280 MToe [4]. Most of the fossil resources used are coal and petroleum [5].

Therefore, the optimization of the plant seems to provide the highest opportunity for energy management. It does not require a huge investment or translate into the reduction of energy consumption in the plant. Rather, it can minimize energy waste and reduce associated emissions. Energy optimization in a plant can also improve labor productivity since the same amount of energy is used to produce better products in terms of both quantity and quality. Exergy analysis is an optimization method widely used in several studies and instances such as the improvement of geothermal power plant efficiency [1–4], coal power generation plant [5], gas power generation plant [6], Solar tower power generation plant [7], nuclear power generation plant, etc. [8]. In ethanol production, it is also widely used in improving chemical reactions within the reactor [9–14]. Dadak et al. conducted the exergy performance assessment of ethanol and acetate formation in a batch bioreactor using clostridium ljungdahlii under various syngas pressures of between 0.8 and 1.8 atm. The result showed that the lowest overall normalized exergy destruction was found to be 49.96 kJ/kJ [9]. Also, Aghbashlo et al. conducted the exergy analysis of an ethanol production process using a continuous stirred tank bioreactor [10,12]. Furthermore, Ojeda et al. carried out studies on the enzymatic hydrolysis reaction of lignocellulosic biomass for the

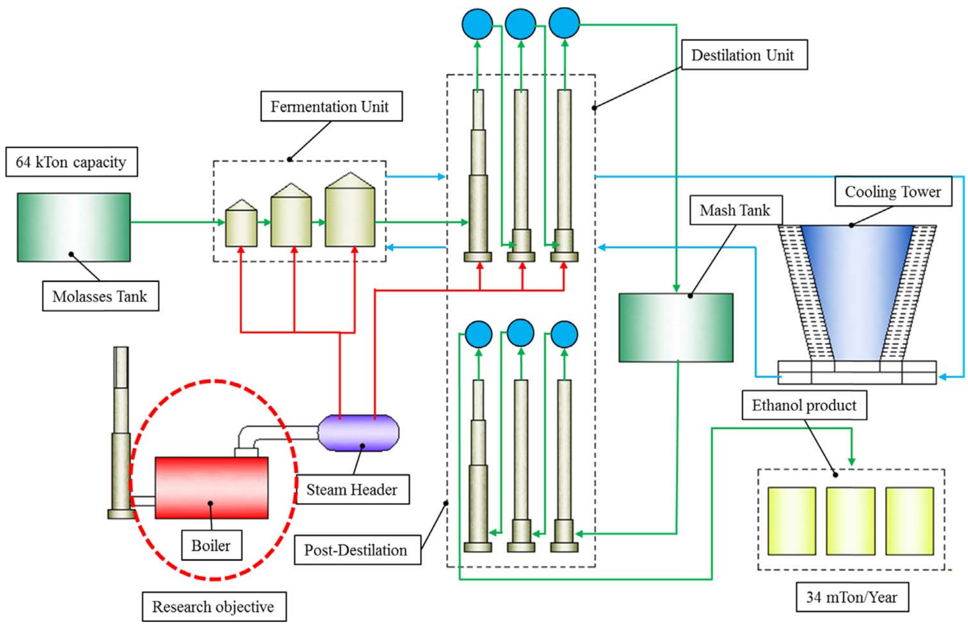

Fig. 1. Process layout of the ethanol production plant.