Energy Conversion and Management 52 (2011) 2448–2454

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Biomass fuelled trigeneration system in selected buildings

Y. Huang [a,*], Y.D. Wang [b], S. Rezvani [a], D.R. McIlveen-Wright [a], M. Anderson [a], N.J. Hewitt [a]

[a] Centre for Sustainable Technologies, School of Built Environment, University of Ulster, Newtownabbey, BT37 0QB, UK
[b] The Sir Joseph Swan Institute for Energy Research, Newcastle University, Newcastle Upon Tyne, NE1 7RU, UK

ARTICLE INFO

Article history:
Available online 21 February 2011

Keywords:
Trigeneration
Computational simulation
Biomass
Gasifier
Techno-economic analyses

ABSTRACT

Many buildings require simultaneous electricity, heating and cooling. Biomass is one of the renewable energy sources which is not intermittent, location-dependent or very difficult to store. If grown sustainably, biomass can be considered to be CO_2 neutral. A trigeneration system consisting of an internal combustion (IC) engine integrated with biomass gasification may offer a combination for delivering heat, electricity and cooling cleanly and economically. The producer gas generated by the gasifier is used to provide electricity for building use via the IC engine. The waste heat is recovered from the engine cooling system and exhaust gases to supply hot water to space heating, excess heat is also used to drive an absorption cooling system. The proposed system is designed to meet the energy requirements for selected commercial buildings and district heating/cooling applications. This work focuses on the modeling and simulation of a commercial building scale trigeneration plant fuelled by a biomass downdraft gasifier. In order to use both energy and financial resources most efficiently, technical and economic analyses were carried out, using the ECLIPSE process simulation package. The study also looks at the impact of different biomass feedstock (willow, rice husk and miscanthus) on the performance of a trigeneration plant.

1. Introduction

The emission of carbon dioxide from fossil fuel-fired power generation plants and the consequent effect on the global environment is a major concern. Given the global challenges related to climate, methods for managing and reducing these emissions must be found and implemented. The replacement of all or part of these fossil fuels by renewable energy sources, such as biomass and waste, is the obvious alternative. Biomass is available in abundance and practically everywhere. If grown in a sustainable manor the use of biomass, which is considered to produce no net CO_2 emissions in its life cycle, and as a replacement for fossil fuels in power generation systems is one of the most attractive applications of reducing CO_2 emissions. There are a range of technologies for providing heat and electricity from biomass [1], but most of these technologies have reduced system efficiency at small scale [2].

Trigeneration, as an efficient solution, offers simultaneous generation of electrical power, heating and refrigeration/cooling utilizing desirable feedstock combinations from a single primary energy source [3,4]. Typical applications can be found in many commercial buildings, such as hotels, hospitals or multi-residential communities. Instead of aiming towards a high electricity output, as an innovative type of renewable energy application, the goal of trigeneration powered by biomass is to improve the overall energy utilization efficiency. In this study a trigeneration system, based on an engine genset, which produces electricity from the producer gas generated in a biomass gasifier and which simultaneously supplies heating and cooling by making use of waste heat has been examined. In order to substitute conventional energy and to use financial resources [5] most efficiently, the proposed trigeneration system, which is based on the previous experimental work [6], a biomass gasifier is modelled and simulated using the ECLIPSE [7] process simulation package, and a technical and economic analysis is carried out. The ECLIPSE simulation is validated against this experimental work, which has been standard procedure to ensure the reliability of the modeling process.

2. The trigeneration system and the simulation software

2.1. The proposed trigeneration system

The proposed trigeneration system contains three main units: an internal combustion engine genset, which is the basic primary mover of the system; a heat recovery and storage system; and an absorption refrigeration/cooling system, as seen in Fig. 1. The system is operated in the following way:

- A biomass gasifier with an integrated gas cleaning system generates producer gas as a fuel.

* Corresponding author.
E-mail address: y.huang@ulster.ac.uk (Y. Huang).

0196-8904/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enconman.2010.12.053

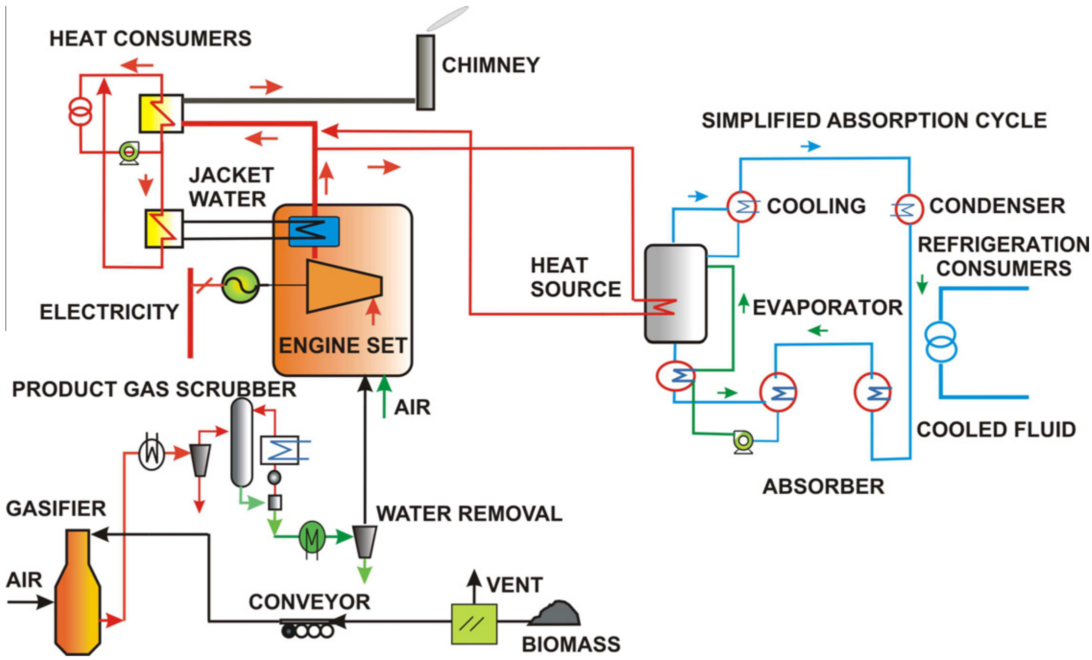

Fig. 1. Schematic diagram of the proposed trigeneration system integrated a biomass gasifier.

- The fuel is utilized in an engine genset to generate electricity for the use in the building.
- The engine cooling system and the exhaust gases are used to recover the waste heat for the thermal storage and supply of hot water/central heating in the building.

An ammonia absorption system, which is run by a part of the waste heat from the engine exhaust, is used to supply the cooling for the building when necessary.

2.2. Type of gasifier

Gasification is a process developed to convert carbon based solid fuels to a gaseous form containing carbon monoxide and hydrogen as main constituents. Being a renewable, low cost and environmentally friendly energy alternative, various biomass gasification systems have been developed worldwide [8], as demonstration systems and as commercial plants to utilize different feedstock types. Since the type of gasifier technology used and the oxidant employed determine the quality of the gas produced, some important considerations should be given to matching the trigeneration system with the selected gasification process [9]. In the above context, the producer gas should be suitable for efficient operation of the IC engine. A range of gasification technologies is available for different scale applications. Downdraft gasifiers are suitable for small and medium-sized applications. This technology offers a relatively efficient biomass to gaseous fuel conversion and produces a gas with sufficiently low tar content to operate an internal combustion engine. In this case, a fixed bed, downdraft gasifier is considered to be most suitable, as shown in Fig. 2.

2.3. The properties of the fuels

In order to evaluate the technical, environmental and economic performance of the proposed trigeneration system, especially the impact of different fuels three common biomass or biomass waste species are chosen for the simulation. The ultimate, proximate analyses and calorific values of the fuels used in the simulation are shown in Table 1. The biomass and biomass waste types selected during the case studies are willow chips, miscanthus and rice husk [10–12], which have calorific values ranging from 17.93 MJ kg^{-1} to 19.26 MJ kg^{-1} (HHV, dry and ash free). The carbon contents range from 45.81% to 51% (daf) and the moisture contents

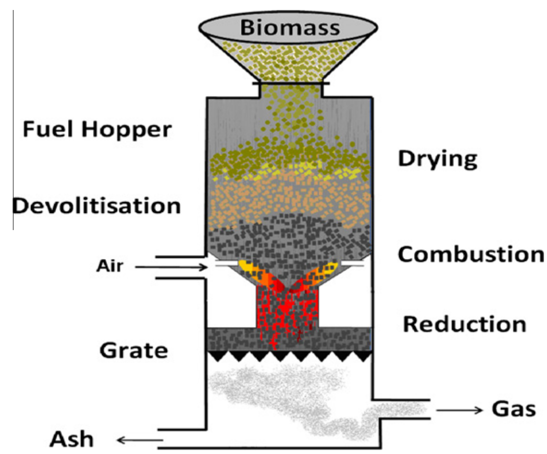

Fig. 2. Schematic of the proposed downdraft biomass gasifier.

Table 1
Analysis of biomass species.

Biomass	Willow chip	Miscanthus	Rice husk
Water (%ar)	33.51	11.29	11.25
Ash (%ar)	0.57	2.59	14.26
VM and FC (%ar)	65.92	86.12	74.49
Biomass ultimate analysis (wt.%, daf)			
HHV (MJ/kg)	18.73	19.26	17.93
LHV (MJ/kg)	17.37	17.73	16.56
Carbon	51.00	47.96	45.81
Hydrogen	6.00	6.75	6.11
Nitrogen	0.05	0.52	0.42
Sulphur	0.05	0.11	0.14
Chlorine	0.00	0.25	0.00
Oxygen	42.90	44.41	47.52