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SCIENCE DIRECT

Energy Conversion and Management 47 (2006) 3105–3118

ENERGY CONVERSION & MANAGEMENT

www.elsevier.com/locate/enconman

Increased power to heat ratio of small scale CHP plants using biomass fuels and natural gas

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Received 1 February 2005; received in revised form 24 August 2005; accepted 6 March 2006
Available online 18 April 2006

Abstract

In this paper, we present a systematic study of process changes for increased power production in 1–20 MW_e combined heat and power (CHP) plants. The changes are simulated, and their economic feasibility evaluated by using existing small scale CHP case plants. Increasing power production in decentralised CHP plants that operate according to a certain heat demand could reduce the fuel consumption and CO_2 emissions per power unit produced and improve the feasibility of CHP plant investments. The CHP plant process changes were simulated under design and off design conditions and an analysis of power and heat production, investment costs and CO_2 emissions was performed over the whole annual heat demand. The results show that using biomass fuels, there are profitable possibilities to increase the current power to heat ratios, 0.23–0.48, of the small scale CHP plants up to 0.26–0.56, depending on the size of the plant. The profitable changes were a two stage district heat exchanger and the addition of a steam reheater and a feed water preheater. If natural gas is used as an additional fuel, the power to heat ratio may be increased up to 0.35–0.65 by integrating a gas engine into the process. If the CO_2 savings from the changes are also taken into account, the economic feasibility of the changes increases. The results of this work offer useful performance simulation and investment cost knowledge for the development of more efficient and economically feasible small scale CHP processes.

Keywords: Combined heat and power; Power to heat ratio; Simulations

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1. Introduction

In this paper, we present the results of simulation research into different process change possibilities that can increase the power to heat ratios (α) of small scale (1–20 MW_e) combined heat and power (CHP) plants. The deregulation of the electricity market and the economic requirement to utilise CO_2 neutral biofuels as the fuel source offer both new opportunities and challenges for small scale decentralised power plants [1–4]. The heat demands in more remote areas are often limited, so two possible ways of improving the economic

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doi:10.1016/j.enconman.2006.03.005

feasibility of biomass fuelled plants are to increase their power generation and to convert heat only plants to CHP production.

Small scale CHP plants are usually operated according to the heat demand. The parameter indicating the electricity production versus the heat production in a CHP plant is the power to heat ratio, α. Currently, the α in 5–20 MW_e CHP plants using biomass fuels is between 0.35 and 0.45 [5–7]. In smaller CHP plants producing from 1 to 5 MW_e, α varies from 0.10 to 0.30. A higher α would increase power production and could improve the economic feasibility of new small scale CHP plant investments.

Important factors defining power generation in steam Rankine cycle processes are the temperature and pressure of the superheated steam. They are mostly kept at their current levels by material limitations in the turbine. A review by Fridh [8] of the admission temperatures and pressures of 600 steam turbines producing from 1 to 25 MW_e noted that the admission temperatures to small scale steam turbines are generally below 520–540 °C. This is 40–60 °C lower than the usual temperatures in large scale plants. Currently, the larger plants can have admission temperatures up to 630 °C. The economic feasibility of small scale plants with higher steam temperatures depends on the potential for reducing the use of the more expensive materials needed in high temperature applications and on the successful scaling of these results from large scale plants to smaller ones.

Another possibility to increase the power production is to extract the superheated steam from the steam turbine and to reheat it with flue gases to a higher temperature. In the case of a condensing plant, turbine materials limit the steam moisture content and, thus, the steam exit pressure from the turbine. Reheating makes it possible to have a lower exit pressure than without reheating. In CHP plants with back pressure turbines, the steam exit pressure from the turbine is defined by the forward temperature of the district heating (DH) water. In the back pressure turbine processes, reheating improves power production if the extraction pressure of the reheated steam is selected so that the reheating increases the average temperature of the incoming heat to the process. Usually, the extraction pressure of the reheated steam is selected so that the steam can be reheated to the same or to a higher temperature than it had before entering the turbine. It is economical to choose a temperature so that it is possible to use the same material both in a superheater and in a reheater. Reheating is common in larger power plants, but in smaller plants, it has not been used as its economical feasibility has been considered to be low.

In CHP plants, one possible way to increase the power generation of back pressure steam turbines is to reduce the steam exit pressure by dividing the DH exchanger into two or more stages and by extracting the steam from the turbine to the DH exchangers in several phases. The exit pressure of the saturated steam from the turbine is then defined by the DH water temperature after the additional stage of the DH exchanger, which may be significantly lower than the forward temperature. DH exchangers with two stages have already been used in CHP plants producing from 15 to 20 MW_e, but their economic feasibility in the case of smaller plants has not yet been demonstrated.

The moisture content of biofuels can be up to 55 wt.%, so fuel drying with flue gases or steam has significant potential to increase the power production in a biomass fired CHP plant. An overview of the current fuel drying technologies is presented by Wimmerstedt [9] and Brammer and Bridgewater [10]. In the case of a power plant situated near large biofuel resources, it may also be profitable to dry the fuel for transportation to the more remote plants. Wahlund et al. [11] describe a system configuration for a CHP plant where a fuel dryer producing wood pellets utilises steam heat during the part load operation, thus increasing the annual power production of the plant.

A gas turbine and a gas engine integration to the CHP plant is an efficient way to increase the electricity generation and the power to heat ratio of the plant. In larger CHP plants, a gas turbine is often connected directly to a heat recovery boiler, but the turbine can also be integrated to a solid fuel fired boiler by using the exhaust gas from the gas turbine in a feed water preheater, or using the gas turbine exhaust gas as combustion air in the boiler. Manninen and Zhu [12] have presented a method for finding the optimal integration of a gas turbine to the utility. Harvey et al. [13] have studied gas turbine CHP plant performance including part loads and its effects on district heating costs and CO_2 emissions. Carcassi and Colitto Cormacchione [14] presented a comparison of gas turbine part load performances in a heat recovery boiler CHP application. In smaller plants especially, the investment costs of a gas turbine or a gas engine integration may become critical, as the investment per generated power increases when the size of the turbine or engine decreases.