CHEMICAL ENGINEERING RESEARCH AND DESIGN 89 (2011) 2470–2476

Contents lists available at ScienceDirect

Chemical Engineering Research and Design

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

On-line monitoring of fuel moisture-content in biomass-fired furnaces by measuring relative humidity of the flue gases

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ABSTRACT

Combustion of biomass for heat and power production is continuously growing in importance, because of incentives for replacing fossil energy resources with renewable ones. In biomass combustion, the moisture content of the fuel is an essential operation parameter, which often fluctuates for biomass fuels. Variation in moisture content complicates the operation of the furnaces and results in an uncertainty in the energy content of the fuel delivered to a plant. The fuel moisture-content in a furnace may be determined either by direct measurement on the entering fuel or by measuring the moisture and oxygen contents of the flue gases deriving the moisture content of the fuel. However, reliable methods of a motivated cost for the small to medium-scale furnaces are today not available. An exception is if the furnace is equipped with flue-gas condenser, which can be used to estimate the moisture content of the flue gases. A limitation of this method is, though, that not all furnaces have flue-gas condensers and that the measured signal has an inherent time delay.

In this work, measurement of the relative humidity (RH) of the flue gases from a furnace is investigated as the central component in the on-line monitoring of the moisture content of the fuel in a furnace. The method was analysed with humid air in a laboratory environment and tested for accuracy and dynamical behaviour in two biomass-fired heat-production units, one circulating fluidised-bed boiler (CFB) and one grate furnace. The results show that the method, which is easy to calibrate on site, can be used to predict the moisture content of the biomass fuel in the grate furnace with very good precision (<4% error). Furthermore, the method detects variations in moisture content of the furnace flue gases due to changes in the moisture content of the combusted fuel within the order of seconds. Since the transport time of the flue gases from the furnace to the measurement position is of the same order of magnitude, the total time for detection of a change in the moisture content of the fuel is small enough for the signal to be used to control both the fuel feed and the combustion air in a grate furnace.

Keywords: Combustion; Biomass; Moisture content; Relative humidity; Grate furnaces; Sensors

1. Introduction

Combustion of biomass for heat and power production is expanding due to the search for renewable alternatives to fossil fuels. An important parameter when using biomass is the moisture content of the fuel, which normally is a blend of different batches typically varying between 30 and 55%, related to the total mass of biomass as delivered. Variation in moisture content complicates the operation of the combustors and results in an uncertainty in the energy content of the fuel delivered to a plant. This is especially problematic for smaller units where the economical and technical resources are more limited than in larger ones. Within this segment of boilers, the most common conversion method is grate firing. Grate furnaces are typically installed in heat production plants with capacities below 40 MW_{th}. For example, in Sweden there are about 350 furnaces operated with reciprocating grate for production above 1 MW_{th} (Svensk Fjärrvärme AB, 2007) and in the rest of Europe and North America the technique is increasingly applied in the segment below 20 MW_{th}.

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Received 10 November 2010; Received in revised form 28 March 2011; Accepted 29 March 2011

doi:10.1016/j.cherd.2011.03.018

Nomenclature

c_p	specific heat (J/kg K)
LHV	lower heating value (J/kg)
m	mass flow (kg/s)
P	pressure (Pa)
Q	heat (W)
R	calibration factor
t	time (s)
T	temperature (K)
X	volume fraction (m^3/m^3)
Y	mass fraction (kg/kg)
ΔH_{evap}	heat of evaporation of water (J/kg)
η	efficiency
φ	relative humidity, RH

Indices

b	furnace boiler
err	error
d	delay
dry	dry matter
fg	flue gases
cond	flue-gas condenser
fuel	fuel
m	moisture
sat	saturation
uncomb	products of incomplete combustion

A major advantage with the grate furnace is its ability to manage a variety of wet fuels (Yin et al., 2008). However, even if a grate furnace is reasonably stable to changes in fuel quality, fluctuations still are challenges to the operation. One important parameter to maintain a stable operation is the moisture content, which commonly varies both between and within delivered fuel batches. Today, the standard procedure to determine the moisture content of the fuel in small to medium-scale grate furnaces is to analyse a number of manually collected samples from each fuel batch delivered to the plant. Such a crude method only serves as a rough estimation to calculate the price of an entire truck load. Furthermore, it is not accurate enough to predict the moisture content of the fuel-mix that continuously enters the furnace; a change in moisture content of the fuel-mix needs to be detected at high-frequent resolution (seconds) to enable a correct response from the combustion-air system or within minutes to produce a response from the fuel-feed system. More accurate methods for monitoring of the moisture content of the fuel are, therefore, requested. However, to make the methods available to small to medium scale plants the investment cost of such installations must be within reasonable limits.

On-line measurements of the moisture content of a fuel mix are carried out with direct or indirect methods. Direct methods focus on the fuel itself, while the indirect methods derive the fuel moisture-content from quantities measured in the flue gases and in the combustion air. Methods for direct measurements of the fuel moisture-content are near-infrared spectroscopy (NIR), dual X-ray, radio frequent, microwave and nuclear magnetic resonance (NMR) measurements (Nyström and Dahlquist, 2004). Especially NIR has been investigated and implemented as a promising method to analyse the fuel for moisture content either by automatic sampling at delivery or, for control purposes, in the fuel mix before it is injected into the furnace (Berg et al., 2005). However, these methods are hard to motivate for small-scale combustors on economical basis and, furthermore, they demand measurement set-up, calibration and handling skills (Aulin and Karlsson, 2008). Therefore, the direct measurement-methods often become unfeasible in the capacity area of grate furnaces.

The alternatives to the direct methods are the indirect methods for determining the moisture content, which are both easier to handle and less costly. The key to the indirect method for finding the moisture content of a solid fuel is to determine the moisture content of the flue-gases. From the measurement of gas moisture-content, the moisture content of the fuel can then be derived by a mass balance, including the moisture content of the combustion air, the elementary composition of the fuel and the composition of the combustion-air (Nyström and Dahlquist, 2004; Marklund and Schuster, 1991). In this process, the only inherent delay of measurement signal is the transport time of the gas from the combustion chamber to the measurement position. This time delay is approximately less than 2 s, opening up possibilities of controlling both the combustion air and fuel feed. However, the large dimensions of the flue-gas ducts and the temperature levels in the flue gas system, which normally is above 150 °C, are complicating factors; Fourier-transform infrared technology (FT-IR) qualifies as the sole method among the available methods summarised in Table 1 to determine the moisture content with enough accuracy while approaching a reasonable cost level in relation to the combustion unit. Still, the accuracy of the FT-IR is sensitive to the absolute temperature level, pressure, temperature gradients and particles carried with the gas, complicating measurements directly in the flue-gas duct. As an alternative to FT-IR – also listed in Table 1 – in combustion units equipped with a flue-gas condensation-unit, the moisture content may be estimated from a heat balance over the condenser (Eriksson et al., 2008). On the other hand, this measurement signal is delayed because of the heat transfer resistance in the heat exchangers. This method is, therefore, limited to detection of low-frequent fluctuations, in the order of minutes, which in most cases is sufficient for control of the fuel feed (Bood et al., 2010), while too crude to be used for control of the combustion air.

Recently, sensors have been developed for measuring relative humidity (RH) in gases up to 200 °C, qualifying the method for determining the moisture content in the temperature range of flue gases. These RH-sensors use chemically modified polymers as detector materials, responding by capacitance to the RH of the surrounding gas (Sakai, 1993), which have been shown to be resistant to environments contaminated with different organic compounds (Ikonen et al., 2006). In addition, and as listed in Table 1, the cost of the sensors is reasonable and the handling skills required are less than for FT-IR. However, the accuracy of the RH-sensors in high temperature flue gases is too low to be used for indirect determination of the moisture content of the fuel in furnaces (Eriksson et al., 2008) because of the low RH-level (<0.01) typical for biomass flue-gases. In this work, the method using a RH-sensor is developed with the aim of improving the accuracy to levels acceptable for indirect determination of the moisture content of the fuel in a biomass furnace. This is achieved by cooling of an extracted flue-gas stream, elevating the RH of the flue gases, before performing the measurement. The method is tested for accuracy and dynamic behaviour in laboratory environment and in two heat production units, one multi-fuel circulating fluidised-bed