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Improving downdraft gasifierstability by robust instrumentation and control systems

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Abstract

In updraft, fluidized bed and downdraft gasifiers, tar concentrations are typically produced around the 10-20%, 1-5%, 0.1% levels respectively. If gasifiersare operatedunder specific conditions,a clean syngas with low tar concentrations will be produced [1].The principal objective of this research is to develop a set of robust and inexpensive instrumentation systems to measure gasification parameters and inform control systems to improve gasification performance e.g. temperature, liquid flow and biomass weight for real time mass balance calculations. In the present case nine K-type thermocouples were connected to different positions on an in-house downdraft gasifier that allowed temperature and mass balance profiling. The moisture/ bio-oil flow before steady state conditions was measuredwitha liquid flow sensor that gave real-time flow rates (L/min) and total quantities (mL)[2]. The Arduino platform was used as the core of the instrumentation and control system and integrated with Makerplot software (GUI). These systems offered a high level of control and robustness for low cost with an open source protocol, allowing other developers to benefit and expand the core of this research. The results from preliminary runs are presented which is currently allowing ignition optimization and overall system improvements.

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*Keywords:*Gasification; Arduino; Diagnostic and Control; Sensor.

Nomenclature

CLK	Clock
CS	Chip Select
DO	Data Out.
I/O	Input/Output
ER	Equivalence Ratio
GUI	Graphical User Interface
IDE	Integrated Development Environment

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1. Introduction

Gasification is an established technique to convert feedstock into its gaseous components. Gasification operation, however, can be problematic. The current work seeks to establish robust instrumentation and control

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systems to improve the performance of an in-house, downdraft gasifier and seeks to identify control strategies to allow operation on the minimum tar production point.

The in-house, laboratory based, downdraft gasifier was designed and fabricated as a testbed for developing and analyzing the performance of gasifier instrumentation and control systems. A schematic of the system can be seen in Fig. 1. The downdraft gasifier is 70 mm in diameter (ID)and 720 mm long, with a throat diameter of 31 mm and thermal rating of approximately 3.4 kW. Arduino is an open source C/C++ programmable microcontroller. Founded in 2005 in the IVREA institute Italy, made by Massimo Banzi[3],it has rapidly been adopted into a diverse range of applications requiring microprocessor control, primarily because of its simplicity of use and cheapness. As part of the early adoption and implementation of the instrumentation system for the gasifier, nineK-type thermocouples and a hall liquid flow sensor were interfaced with an Arduino Mega ADK microcontroller. The microcontroller is commanded by Arduino (IDE), which shows live temperature and flow data on the computer screen. The live data was auto-savedby Makerplot software with 5 second intervals between data capture. The temperature sensors operate over a wide temperature range from - 200°C to +1350°C. Figure 1 shows a schematic of the gasification system.

2. Instrumentationstrategy

The Arduino Mega ADK microcontroller ATmega2560 board has 16 analog and 54 digital inputs/outputs (I/O). The microcontroller interfaces with USBperipherals via the MAX3421e IC [4]. The nine K-type thermocouples were connected to different positions on the gasifier system and interfacedwith Max 31855 breakout board amplifiers to produce a temperature signal. The amplifier works with any K-type thermocouple with ±2°C – ± 6 ºC accuracy with an output in 0.25ºC increments.

The hall liquid flow sensor was connected before the moisture/bio oil collection system. The liquid flow sensor works between -25°C to +80°C with an accuracy ± 10% (±2-6 mL) [5]. The pulsed code modulated (PCM) signal is a simple square wave in which the frequency is converted into L/min. The Max 31855 amplifier I/O five pins, CLK, DO, CS, VIN, GND and the liquid flow sensor has three I/O pins, VIN, GND, and Output interfaced with Arduino Mega ADK microcontroller. The liquid flow sensor and amplifier MAX31855, 16×2 LCD screens have their own library which needs to be installed in Arduino software (IDE) [6].

The open-source Arduino software v. 1.8.3 (IDE) was used to write C/C++ coding for the nine Max 31855 amplifiers and the liquid flow sensors. The Arduino Mega ADK board (16MHz clock speed) was set to a baud rate of 9600 bits per second (bps) in this case.

In the present case, the results were monitored and auto-saved in Maker Plot software through the same USB and serial computer port of the Arduino microcontroller. The readings were collected with a 5sec delay for convenience, although much faster rates can be set.

Figure 1 shows the location of the thermocouples (identified as T1 through to T9). Biomass feedstock is fed into the downdraft gasifier, currently under batch conditions. Air is injected at a regulated flow rate via a mass flow controller (Red-Y smart, Vogtlin instruments,Switzerland). The gasifer is mechanically coupled to a hotgas filter system from the exit pipe just below the grate of the gasifier. A custom designed counter-current condenser is connected at the outlet of the hotgas filter, through which the gas is cooled and transported to the tar collection point. Tar collection is achieved via a T-branch connection after the exit of the condensor where condensed liquid products fall into a gas sealed conical flask with an integrated liquid flow sensor. The liquid flow sensor is incorporated within the microcontrol system to provide real-time moisture or bio-oil production data throughout the gasification process particularly after ignition. In the present case, the product gas then continues along the main pipelinefor syngas composition analysis and exhaust extraction.

Electrical heating tape was used to pre-heat the reactor (approx. 1 hr) around the air inlet/throat region of the reactor, typically to a temperature of 350°C for ignition. Subsequently, 100 g of *Miscanthus* (Mx2717)pellets weretransferred to the reactor from the top and ignition was initiated with air injection via an air pump. To facilitate ignition, combustion was initially carried out by supplying an air flow rate of 55 L/min (ER=1.0). Once the temperature started increasing through ignition,600 g of biomass was subsequently added to the vessel whichfilled the reactor near to 3/4 volume (roughly 10 centimeters from the top of the reactor). The top of the system was then sealed after the entire mass was added and the combustion mode was changed to gasification by reducing air flow rate to14.44 L/min (ER=0.30). The exhaust gas was observed in the exhaust system and ignited. At varying time intervals the temperatures were measured using the internally positioned K-type thermocouple sensors to record the temperature at the different locations in the gasification system.

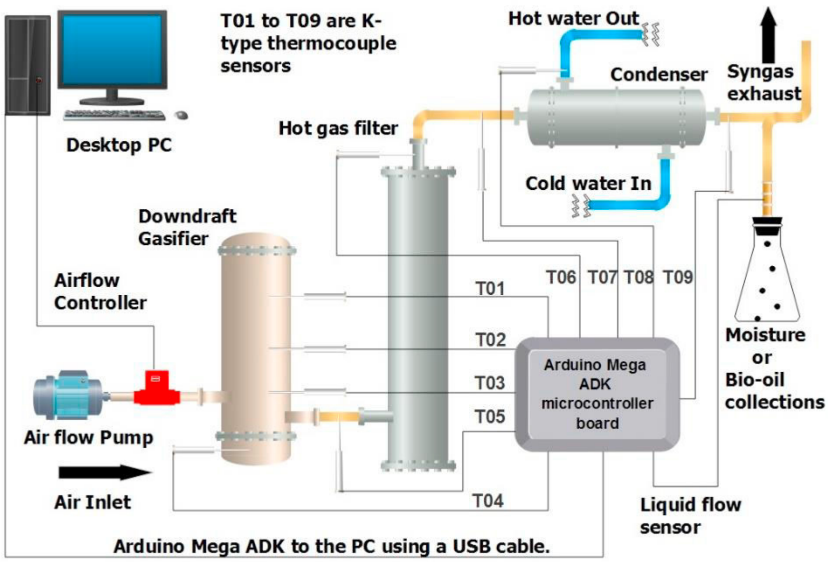

Fig. 1. Schematic of the gasifier system

3. Results and discussions

Figure 2 showsthe temperature dataand Figure 3 shows the liquid flow from preliminary gasification runs with *Miscanthus* (Mx2717). The temperatures measured at the drying (T01), pyrolysis (T02), combustion(T03) and reduction zone(T04) are each below 350°C for the first 12 min of operation. Subsequently, thecombustion zone temperatures rose significantlyfrom 350°Cto 682°Cwhile time varies from 12 min to 14 min, respectively(combustion mode of operation at ignition stage).

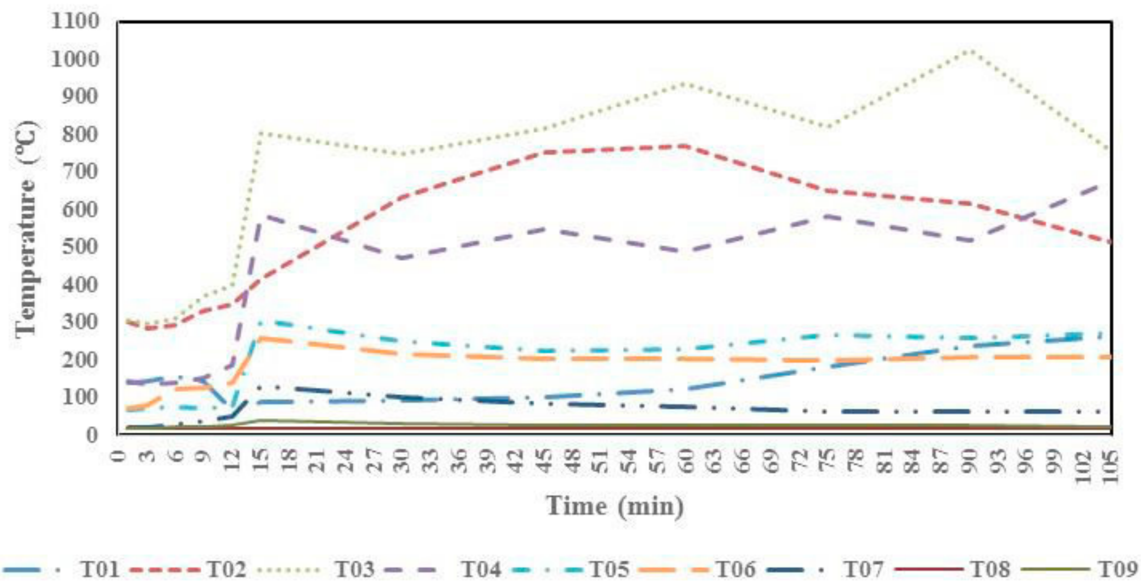

Fig. 2. Temperature sensor data

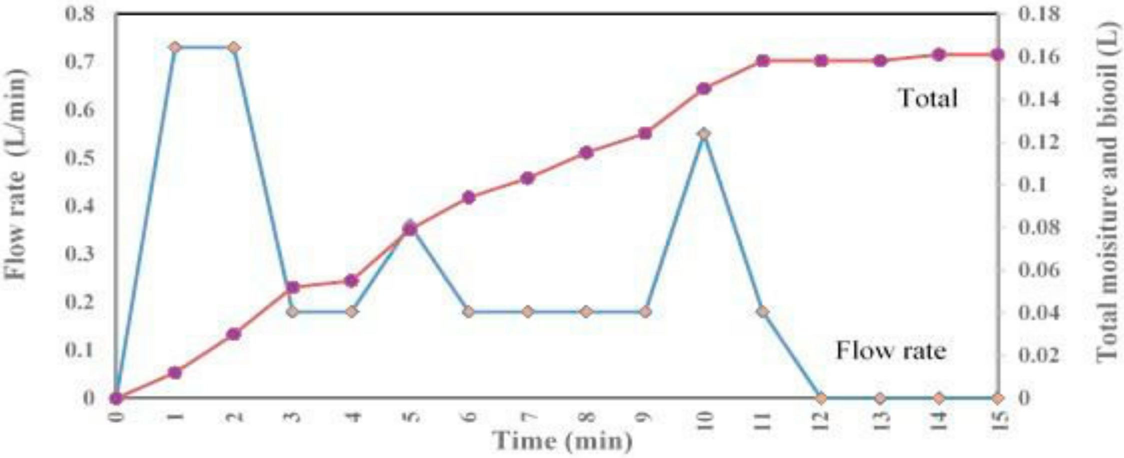

Fig. 3. Liquid flow sensor data

An internal gasifier temperature of 370°C to 1024°C was measured with constant air flowrate (14.44 L/min); thus represents the gasification mode (after 14 minutes as shown in Fig.3). The mixture of moisture and bio-oil (162 mL) was collected within the first few minutes (1-12 minutes) after which no liquids were collected.

The hot gas filter produced a relatively clean gas at the exhaust of the system. After 30 min, the system was clearly producing a combustible syngas, which was able to burn independently. In future tests a tar detection system will be installed into the gasifier test bed, along with implementation of the control strategy.

4. Conclusions

Accurate measurement of the temperature throughout the entire gasifier and system components is central to improveknowledge about the gasification performance. Furthermore, variations in the feedstock and the associated fluctuations in the energy density, size and moisture content of the inputs can significantly affect the temperature of the system and gas quality. The instrumentation system is being expanded to provide more data on the gasification process and allow control systems to be developed. Low cost, robust systems can be rolled out into large and small scale gasifiers to increase their operating profile and increase their tolerance to feedstock variation.

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