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Research paper

Traceability of bulk biomass: Application of radio frequency identification technology on a bulk pellet flow

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ABSTRACT

Radio frequency identification (RFID) technology has been used since the 1950s in a wide range of applications. In the energy sector, there is a potential to use the technology to follow biomass fuels throughout a supply chain. In addition to logistic information, the RFID tags can be used to convey vital information of the fuel properties directly to the energy plant to be used at the moment of combustion. A detailed knowledge of the fuel composition at the moment it reaches the furnace can be used to improve energy efficiency, reduce emissions and limit problems with fouling and slagging. In this work, RFID technology was used in three separate trials to trace wood pellets, from the production site to the furnace. In the trials, RFID tags were added to batches of pellets containing 5% or 100% peat. In this way it was possible to follow the shift in pellet quality from standard pellets (100% wood) to the pellets containing the RFID tags by monitoring the change in flue gas composition. From the results it can be concluded that RFID tags indeed can be used to convey logistic information and thus information of fuel quality parameters throughout a supply chain for wood pellets. However, work on optimization is needed to design the RFID carrier properly to mix well with the pellets as illustrated in a separate trial. Finally, an economic estimate indicates that the marginal cost to implement a RFID system would be less than 1% of the total production cost of wood pellets.

1. Introduction

The combustion quality can be profoundly affected by changes in fuel quality [1–3]. This is especially relevant for biomass fuels since it typically is characterized by different properties, such as shape, size and composition. With real time knowledge of the characteristics of the fuel, the operating parameters could continuously be adjusted to optimize the combustion process. An improved control could then result in higher efficiency [4], less fouling and slagging [5] and a reduction of emissions [6,7].

Logistically, a biomass fuel can be transported from a supplier, sometimes via transshipment sites, to the energy plant where it is often stacked before combustion. The storage is complex [8]. It is not uncommon that the fuel is located on the fuel stock for months and that fuels with different compositions are placed next to or even on top of each other. This can make the boundaries between the different fuels difficult to distinguish. When the fuel finally is fed to the furnace it can therefore be a mixture of different fuel batches instead of only one fuel batch. In addition, depending on storing conditions there can also be significant fuel degradation over time. Altogether, this results in a varying fuel quality delivered to the combustion plant, challenging a stable and efficient operation.

A potent solution to improve the quality control of a certain fuel supply chain is RFID (Radio Frequency Identification). RFID technology is today used to trace information in a variety of applications, from people control to monitoring goods [9,10]. An RFID system basically consists of two parts: an RFID tag in which information is stored and an RFID reader that reads the stored information. When the RFID tag passes the RFID reader, a capacitor is energized, sending out a signal that enables the RFID reader to register the information stored within the RFID tag. This gives the possibility to convey information of the fuel composition embedded with the fuel supply chain. The information could be assigned to the flow at the production site, followed up in the fuel supply chain and eventually and automatically be used in the combustion control as the fuel enters the furnace.

A predominant feature of the state-of-the-art RFID systems is that they are used for the tracing of well-defined entities, i.e. the RFID tag is linked to an object such as a container, a person etc. While RFID

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technology has been used to trace closed-up batches of biofuels [11] and for laboratory scale tracing of solid biomass fuels in well-defined environments [12], it is not known to have been used for tracing bulk biofuel in larger scale [13,14]. The aim of this study is therefore to demonstrate that RFID technology can be used to enable traceability of a bulk biomass fuel throughout a fuel supply chain. This was achieved by, i) performing three separate trials investigating the technological aspects where RFID tags were traced along a biomass fuel supply chain and, ii) making an economic assessment of a medium scale RFID system for tracing a bulk biomass fuel.

2. Material and methods

Three trials were performed in which biomass pellets were doped with RFID tags to trace information along the fuel supply chain. Two of the trials were performed as large-scale trials with the objective to investigate if RFID tags could identify a fuel switch in a furnace. The third trial was performed to see how well the RFID tags follow the flow and are distributed over time in a fuel supply chain. In the experiments, three different types of pellets were used: pellets composed of 100% peat (Trial 1), pellets composed of a mixture of 5 w-% peat and 95 w-% stem wood (Trial 2) and 100% wood pellets (Trial 3). The 100% wood pellets were produced at a large scale plant (> 100 000 tons of pellets per year) while the mixtures were produced at a small scale plant (< 30 000 tons of pellets per year). The tree species used for the pellets was a mixture of 60% spruce and 40% pine. The peat was typical Scandinavian fuel peat, with relatively high Si content and high Ca/Si ratios. The diameters of the pellets were in all tests 8 mm, with an average length of 10 mm, while the spread in length was found to be in the range 5–20 mm for 95% for the pellets. The average specific density of the pellets was 1210 kg/m^3.

The RFID tags used in the trials can be seen in Fig. 1. The tags were selected to resemble the shape of the fuel pellets, i.e. cylindrical with a physical size resembling the pellets. The chosen tags were of make and model HITAG 256, 125 kHz (manufactured by NXP China), a cylindrical glass tag that is 4 × 34 mm in size. The density of the tags was 2240 kg/m^3, i.e. significantly higher than the pellets. Initial lab scale trials showed that the effective range of the RFID tags, applicable for these trials, were 0.5 m. Some of the glass tags were encased in cylindrical hard shells, HITAG Hard Shell Tag, model number 18449-04 A (manufactured by NXP China), 10 × 40 mm in size. When put into the hard shells, the density for the entire tag was reduced to 1560 kg/m^3, still somewhat higher than for the pellets used.

The RFID-system for tracing of information along the fuel supply chain consisted of the following steps: 1) initializing the tags with relevant data, 2) releasing the RFID-tags into the fuel supply chain at the supplier's site, 3) transportation with bulk truck and discharging of the fuel upon arrival at the plant, and 4) registering the RFID-tags at the end of the fuel supply chain, i.e. the feeding gate of the combustion furnace. Prior to the trials, all RFID tags were given a unique identity

Fig. 1. RFID tag and hard shell.

Table 1
The trials' general design.

Trial no.	Type of trial	Biomass fuel	Number and type of RFID-tag used
1	Fuel switch	100% peat pellets	6 cased
2	Fuel switch	5% peat/95% stem wood-pellets	5 cased
3	Distribution	100% wood pellets	30 cased and 30 uncased

before being dropped into the bulk of pellets at the manufacturing sites.

In Trial 1, the cased RFID tags were released into the fuel supply chain via a tractor bucket loading a bulk truck with pellets. During loading, RFID tags where dropped into every second tractor bucket, resulting in approximately one RFID tag per three tons of pellets or six tags for the 20 tons of pellets that was used in total. In Trial 2, the cased RFID tags were dropped into every fifth 600 kg bag of pellets, which was emptied into a truck. Here, 15 tons of pellets were used, which equals five tags or one RFID tag per three tons of pellets. In both these cases the first RFID tags were dropped into the bulk of pellets after approximately three tons of pellets had been loaded. For Trial 3, 10 cased and 10 uncased RFID-tags were placed manually at the exact same place in the bulk truck – on top of the bulk of pellets. This was repeated in two more bulk spaces on the truck, which means 60 RFID tags in total were used in three subsets. A summary of the trials' general design can be found in Table 1.

Upon arrival at the combustion plant (1 MW$_{th}$) the bulk truck used a pneumatic conveyor, 0.8 bar, to unload the pellets into the high end of a fuel silo in such a way that the RFID tags left the truck in the same order as they were dropped into it. From the bottom of the silo, a feeder unloaded the pellets to a couple of screw conveyors, connected via a chute, transporting the pellets to the furnace. A RFID reader consisting of an electrical loop was installed in the chute, from which the serial number and clock time of each passing tags were recorded. The loop was shaped as a square, 500 × 500 mm. Inside the loop, an electrical conductor with a cross sectional area of 6 mm^2 was wound four turns. The RFID reader operated in the low frequency band, 125 kHz. The loop was configured such that the distance to the RFID tags would be at a maximum of 0.5 m.

To enable the correlation of the RFID tags with the switch of fuels in Trials 1 and 2, the furnace was initially operated only with wood pellets. Operation parameters of the furnace were throughout the entire trial periods continuously logged, enabling a correlation between an RFID tag and the furnace operation. In Trial 3, however, no follow-up was made of how the furnace had performed, since the primary objective was to investigate how the RFID tags was distributed over time.

3. Results & discussion

The results from Trial 1, as depicted in Fig. 2, clearly show that RFID can be used to convey embedded important information along the fuel supply chain. This principal result can be seen as a parallel to the results obtained from a previous study where it was traced what could be called a bulk flow on a furnace grate [12]. The registration of RFID-tags at the furnace coincide very well with the fuel switch. This is indicated by the oxygen concentration of the flue gases: it decreased once the test pellets reached the furnace, and recovered once the test pellets had been consumed. Furthermore, the results show that the registration of RFID tags is rather evenly distributed over time and that the RFID tags arrived in the same order as loaded onto the bulk truck. However, a significant delay can be observed before the first RFID tag arrives at the furnace. This is due to the fact that the release of RFID tags into the fuel was effectuated only after three tons of pellets had been loaded. To ensure a more direct correlation between the switch in fuels and detection of the RFID tags, the RFID tags should in a real situation be added to the fuel as early as possible in the fuel supply chain.