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# Low temperature circulating fluidized bed gasification and co-gasification of municipal sewage sludge. Part 1: Process performance and gas product characterization

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ABSTRACT

Results from five experimental campaigns with Low Temperature Circulating Fluidized Bed (LT-CFB) gasification of straw and/or municipal sewage sludge (MSS) from three different Danish municipal waste water treatment plants in pilot and demonstration scale are analyzed and compared. The gasification process is characterized with respect to process stability, process performance and gas product characteristics.

All experimental campaigns were conducted at maximum temperatures below 750 °C, with air equivalence ratios around 0.12 and with pure silica sand as start-up bed material.

A total of 8600 kg of MSS dry matter was gasified during 133 h of operation. The average thermal loads during the five experiments were 62–100% of nominal capacity. The short term stability of all campaigns was excellent, but gasification of dry MSS lead to substantial accumulation of coarse and rigid, but un-sintered, ash particles in the system. Co-gasification of MSS with sufficient amounts of cereal straw was found to be an effective way to mitigate these issues as well as eliminate thermal MSS drying requirements. Characterization of gas products and process performance showed that even though gas composition varied substantially, hot gas efficiencies of around 90% could be achieved for all MSS fuel types.



## 1. Introduction

Modern wastewater treatment techniques lead to a global increase in the production of municipal sewage sludge (MSS). The annual production of MSS in Denmark is approximately 0.14 million ton dry, in Europe, North America and Japan it amounts to around 30 million ton dry matter, while the annual global production has been estimated to be around 50 million ton dry matter (Krüger and Adam, 2015; Sckerl, 2012; Zsirai, 2011). The global MSS production is increasing rapidly, driven by improved wastewater cleaning techniques, a growing global population, increasing wealth in developing parts of the world, and more strict regulations on emissions from wastewater treatment to the environment (Kelessidis and Stasinakis, 2012; Samolada and Zabaniotou, 2014). To avoid problems with pathogens, xenobiotics and toxins, greenhouse gases and foul odor, the produced sewage sludge requires appropriate handling. The benefits of thermal MSS management systems can include; (i) energy recovery, (ii) mass- and volume reduction, (iii) odor reduction, (iv) sterilization and purification by destruction of pathogens and organic xenobiotics (microplastics, pharmaceuticals, phthalates, flame retardants etc.), and, (v) a general reduction of product variations and associated risks, providing increased robustness of the disposal system (Donatello and Cheeseman, 2013; Fytili and Zabaniotou, 2008; Samolada and Zabaniotou, 2014). Thermal gasification is one of the emerging thermal MSS management alternatives. The process has the same general advantages as other thermal processes plus some additional desirable qualities including: (i) A flexible energy product range with a potential for gaseous, liquid and solid energy products, (ii) High electric efficiency, even in very small scale with gas engines or fuel cells (Ahrenfeldt et al., 2013; Thomsen et al., 2015), (iii) Reduced emissions and/or exhaust gas cleaning costs in combustion systems

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when pretreating the gas prior to combustion (Jenkins, 2015; Kang et al., 2011; Samolada and Zabaniotou, 2014), (iv) Potential conservation and recycling of the critical nutrient phosphorous (P) and other valuable macro and micro nutrients in fertilizer ashes with high carbon content to increase security of supply, enhance soil quality and sequester carbon (Cordell and White, 2014; Hansen et al., 2016, 2015).

Several different thermal MSS gasification designs are currently under development including down-draft gasification (Arjharn et al., 2013), two-stage gasification (Mun et al., 2013; Mun and Kim, 2013), three-stage gasification (Choi et al., 2016), fluidized bed gasification (Calvo et al., 2013; Kang et al., 2011), Dual Fluidized Bed gasification (Xiaoxu et al., 2012) as well as fixed bed gasification (Werle, 2015) and fixed bed co-gasification of MSS and woody biomass (Ong et al., 2015; Seggiani et al., 2012a,b). On a commercial or near-commercial level, the designs under development and testing include among others the SÜLZLE Kopf SynGas bubbling fluidized bed gasifier (Judex et al., 2012) and Outotec's dual-circulating fluidized bed gasifier (Buchholz, 2015).

There are several challenges related to efficient MSS management, and in systems with thermal gasification, these issues commonly relate to a very high content of moisture and ash. The implications of these issues may be rapid accumulation of inorganic material in fluid bed systems, widespread ash melting, bed agglomeration or low system efficiency (Calvo et al., 2013; Krüger et al., 2014; Krüger and Adam, 2015; Seggiani et al., 2012a,b).

The aim of this study is to investigate the technical and practical feasibility of co-gasification of MSS with straw in low temperature gasifiers as an alternative platform for MSS gasification. This work involves an investigation of the following: (i) can mixing dewatered MSS and dry straw eliminate MSS drying requirements in low temperature gasification systems? (ii) Can mixing straw and MSS reduce the requirements for bed particle management in low temperature fluid bed gasification systems? and, (iii) How does low temperature gasification and co-gasification of MSS perform with regard to hot gas efficiency and carbon conversion rates compared to other recent MSS gasification technologies?

In addition, the study also includes an assessment of quantity and quality of tar in the product gas from low temperature gasification and co-gasification of MSS. If the gas contains substantial amounts of tar with the proper characteristics, it could possibly be used as a non-fossil oil supplement in existing fossil oil refinery infrastructure. Compared to more conventional LT-CFB systems with downstream combustion of the hot product gas in Combined Heat and Power (CHP) boilers, this might increase the feasibility of smaller decentralized gasification units placed onsite at the wastewater treatment plant where existing gas engines could utilize the residual gas.

A proper mixture of MSS and straw could potentially also increase the fertilizer value of the ashes by improving the phosphorus-potassium nutrient relationship and positively modify P speciation and P plant availability (Li et al., 2013; Zwetsloot et al., 2015). These aspects are outside the scope of the current work, but has been investigated in a related study, which also includes an assessment of elemental balances and heavy metal issues (Thomsen et al., in preparation).

Five experimental campaigns with cereal straw gasification, MSS gasification and MSS/cereal straw co-gasification in two Low-Temperature Circulating Fluidized Bed (LT-CFB) gasifiers of very different scale are analyzed and compared in this work.

## 2. Materials and method

### 2.1. About the LT-CFB gasifier

The LT-CFB process was selected for the investigation as it is a very fuel flexible platform that has been proven to operate on many different fuels including cereal straw, biogas- and manure fibers and organic residues from industry. Schematics of the process are provided in Fig. 1, and a more details on the LT-CFB process design and previous operational results can be found in literature (Ahrenfeldt et al., 2013; Kuligowski et al., 2008; Narayan et al., 2016; Nielsen, 2007; Stoholm et al., 2008).

The LT-CFB technology has been under development for almost 20 years and has been bought and commercialized by DONG Energy under the alias Pyroneer in recent years. The largest LT-CFB built has a thermal capacity (TH) of 6 MW and is located at Asnaes Power Plant in Kalundborg, Denmark. When operating, the 6 MW unit supplies product gas to a suspension-fired coal boiler, thereby substituting coal in a high efficiency CHP system (DONG Energy Power A/S, 2012). In addition to the 6 $MW_{TH}$ unit, a 100 $kW_{TH}$ pilot scale LT-CFB unit exists at the Technical

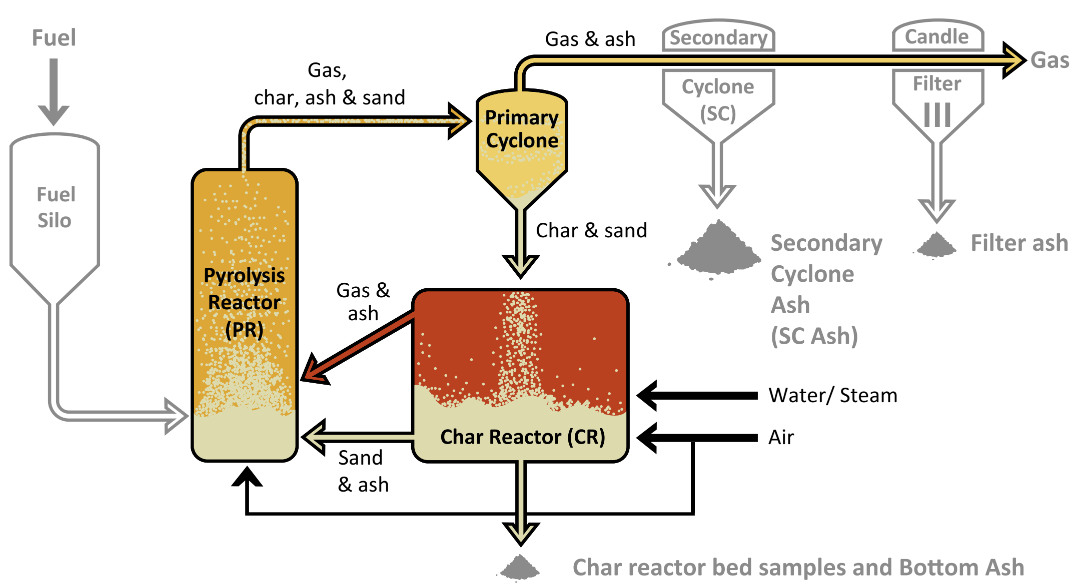


**Fig. 1.** Low Temperature Circulating Fluidized Bed (LT-CFB) gasification system. Modified from (Thomsen et al., 2015).