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Sewage sludge gasification in a bench scale rotary kiln

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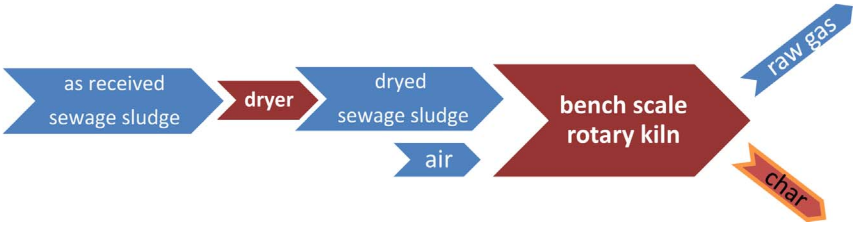
GRAPHICAL ABSTRACT



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ABSTRACT

The goal of this work is to investigate the potentiality of energetic recovery by sewage sludge gasification. Experimental gasification tests were carried out in a bench scale rotary kiln under simulated autothermal condition. The mass rate of sludge was in the range 170–260 g/h. The gasification temperature was varied from 750 to 850 °C, equivalence ratio was increased up to 0.24. The tests run for about 3 h. Input and output streams of the process were quantified and analyzed as to assess the cold gas efficiency. Tar content in the raw gas was determined as well. The main drawbacks occurred during the tests were highlighted to have a realistic frame of the experimented technology.

1. Introduction

Sewage sludge is the solid fraction of urban and industrial wastewater. It is produced in treatment plants by mechanical, biological and chemical methods. These latter are necessary in order to return the clarified water in nature without altering the ecosystem of the receiver (sea, rivers, lakes or some cases the superficial ground). The main problem of the sludge production concerns its final fate. The strategies for its treatment and disposal have been strongly influenced by the attention of the laws to the environment, by the scientific research and the subsequent technological developments.

The total sewage sludge production in EU countries was about 13×10^6 ton/year in 2012, moreover it is in increasing trend [1]. Fig. 1 shows the relative management of sludge in Europe from 1992 to 2005. The landfill disposal has a decreasing trend, on the contrary the incineration has an increasing one. The reuse, which includes agricultural utilization and composting has a slight increase. This is accordance with the guidelines in waste management. “Others” fates were adopted such as: pyrolysis, temporary storage, landfill cover, exportation to other countries. The disposal to surface waters has been forbidden since 31/12/1998 [2].

Sewage sludge contains inorganic and organic substances. Usually, the organics are higher and mostly bio-degradable. The bio-degradability encourages to use biological treatments. Anyway, pathogen microorganisms, such as Salmonella and Streptococcus of human dejection could be in the sludge. It is well known that they are dangerous for the human health. From this point of view, thermal treatments, such as combustion gasification and pyrolysis, are methods to sterilize the sludge and to reduce the volume of the waste. Moreover the recovery of chemical energy of the sludge seems to be possible. From a literature survey information was recovered about sewage sludge gasification.

Miccio et al. gasified dried sewage sludge in a bubbling fluidized

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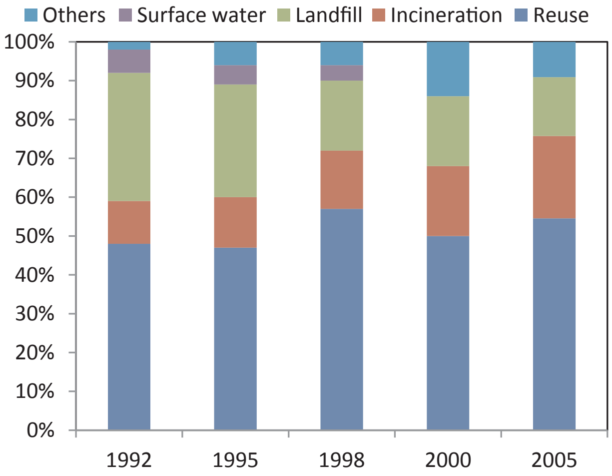

Fig. 1. Sewage sludge management in Europe.

bed [3]. They observed poor performances and difficulties to approach steady state, because of the high elutriation rate of fines, the continuous increasing of the bed height and the interaction between ash and bed materials. Calvo et al. gasified sewage sludge in an atmospheric fluidized bed gasifier at bench scale [4]. The accumulation of material inside the reactor was the main problem. This was avoided by removing and adding bed media during gasification. Successively Manyà et al. gasified dried sewage sludge in a laboratory scale bubbling fluidized bed reactor [5]. They observed that a bed height increase improves the efficiency of gasification. They justified this with the high ash content of dried sewage sludge (about 40 wt%) that is an obstacle to the gas diffusion [6]. Kopf SynGas GmbH & Co. KG is developing a CHP gasification technology to dispose sewage sludge. The reactor is a fluidized bed with no additional bed material. The ash of the sludge itself is used as bed material. The gasifier works at excess air ratios between 0.28 and 0.35. The optimum temperature range is between 800 and 870 °C. Two prototypal plants were built up in Balinger. A pilot plant in Mannheim is under investigation. It is slated to go into continuous operation in the near future. Anyway, ordinary challenges of the gasification have been faced in the experimentation: rotary feeders with bad gas tight, weighting cells did not accurately feed sludge, new problematic sludge dryer technology, leakages at butterfly valves, tar condensation in pipelines [7,8]. Dogru et al. gasified sewage sludge in a 5 kWe-throated downdraft gasifier [9]. The main problem during the tests was a clinker formation problem on the grate of the gasifier at the higher feed rates. This arisen from the not uniform temperature distribution in the oxidation zone. They suggested that minor agitation of the grate or better grate design will overcome this problem. As concern downdraft gasifier, Phuphuakrat et al. studied the effect of equivalence ratio on the tar yield in the syngas produced by a pilot-scale downdraft gasifier [10]. Seggiani et al. co-gasified sewage sludge with wood pellets in a fixed-bed updraft plant [11]. They investigated the effect of sewage sludge content in the feedstock and the equivalence ratio. At high sewage sludge content (70 wt%) slagging and an excessive clinker formation may occur in the oxidation zone because of the high ash content and low ash fusion temperatures of the sludge making the gasification process unstable. For each feedstock tested, the rise of ER from 0.15 to 0.25 resulted in the production of more gas with almost constant LHV allowing to higher cold gas efficiencies. Chun et al. developed a pyrolysis gasifier, combined with carbonization and activation processes, for the production of a pyrolysis gas fuel and activated char from sewage sludge [12]. The pyrolysis gasifier was made of a screw carbonizer and rotary activator for pyrolysis carbonization and steam activation. Under the optimal conditions, a specific area of 40.1 m^2/g, average pore diameter of 63.49 A, and pore volume of 0.2354 cm^3/g were achieved with the activated char. Pyrolysis gases had a higher heating value of 10.11 MJ/Nm^3. Choi et al. gasified dried sewage sludge in a bench scale three-stage gasifier consisting of an auger as well as fluidized and fixed bed reactors [13]. A high temperature of auger reactor within the temperature range of ~420–710 °C and a high temperature of fixed bed reactor within the temperature range of 660–830 °C decreased the tar, while an elevated temperature of the fluidized bed gasifier mainly influenced the producer gas composition. The three-stage gasifier enhanced the H_2 production up to 29 vol%. The tar content in dry syngas was 200–700 mg/Nm^3. Obviously, a three stage gasifier is more complex to run compared to a single stage. Thence sewage sludge was gasified with different technologies such as downdraft and updraft fixed beds, bubbling fluidized beds, double stages and triple stages. Each one has its advantages and disadvantages, as function of operating condition (temperature, pressure, equivalence ratio, feeding mass rate, ash and moisture of the sludge). Anyway, from the above written literature survey, the high ash content in sewage sludge has emerged as an obstacle both in fluidized bed both in the fixed bed. In rotary kiln, the continuous rotational motion helps some degree of bed mixing, and the associated thermal phenomena radially level the bed temperature avoiding ash slagging and clinkering. Rotary kilns have always showed good reliability in ore reduction, drying, cement industry, waste and biomass pyrolysis and gasification [14–17]. Unfortunately, technical scientific reports or articles about sewage sludge gasification in rotary kiln are not available, non-exhaustive information was collected only. Therefore, in this paper, experimental gasification tests of sewage sludge in a bench scale rotary kiln will be presented and discussed to give novelties about the efficiency of the process, raw gas pollution with tar, raw gas composition and heating value. The main problems linked to sewage sludge gasification in rotary kiln will be faced i.e. biomass feeding and kiln sealing.

2. Experimental and method

2.1. Sewage sludge characterization

About 20 kg of sewage sludge were provided by an urban wastewater treatment plant. The as received sewage sludge was wet (moisture content of 47 wt%), sticky, brown and bad smelling. The feeding system did not work well with the as received sludge. In fact it stuck to the hopper wall, moreover critical plugs along the screw of the feeding system were observed during trial tests. Therefore the as received sewage sludge was partially dried in an oven at 120 °C for 2 h. The partially dried sewage sludge consists of hard and brittle granules having linear dimension approximately of 1 cm. The bad smelling of the sludge was reduced. The drying process decreased the starting volume and mass of the sludge. Obviously, the heating value of the sludge increased. Surely, the pathogen microorganisms were destroyed at the drying temperature. Thence a biological and chemical alteration occurred during the drying. The sludge after drying was thoroughly analyzed as concern, proximate and ultimate analysis, heating value, metal content and bulk density. The samples were prepared according UNI EN 14778. Proximate analysis was carried out by a Perkin Elmer Thermogravimetric Analyzer TGA 7. Moisture, volatile matter, fixed carbon and ash content were determined, by weight loss measured with the following thermal scan: under nitrogen flux heating at 10 °C/min up to 105 °C isothermal at 105 °C for 20 min, heating up to 900 °C at 100 °C/min, isothermal at 900 °C for 7 min, cooling to 550 °C at 50 °C/min; under air flux isothermal at 550 °C for 40 min. This method was adopted as it is faster compared to time consuming UNI EN 1474-1, UNI EN 14775, UNI EN 15148. Moreover it was verified that for several biomass the deviations of proximate analyses are below 3%. The ultimate analysis of sludge after drying was carried out by CHN Perkin Elmer Series II 2400, in order to quantify carbon, hydrogen, nitrogen according to ISO 16948. Oxygen was calculated by difference. The heating value was measured by an IKA Werke Bomb Calorimeter according to the UNI EN 14918. Metal concentrations were determined by