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Waste heat recovery from cement production for faecal sludge drying

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Photos title page:

Sococim cement plant, Rufisque, Senegal
Sludge emptying truck, Senegal
Faecal sludge drying bed, Senegal
Sococim cement plant, Rufisque, Senegal
All photos by Sandec/Eawag

Summary

In Africa and Asia, 65–100 % of urban residents are served by on-site sanitation facilities, such as septic tanks or latrines. These systems are typically emptied with suction trucks or manual labour. The contents are most commonly dumped directly into the environment, or disposed of in a treatment plant if one is available and affordable. This practice has its origin in the common perception that FS is a waste product without any value. However, this is a misperception, as faecal sludge not only contains nutrients for use as agricultural fertilisers but also could replace fossil fuel sources in industrial processes, such as boilers and kilns. Use of alternative fuel sources (e.g. tires, animal meal, sewage sludge, waste oil) in industrial kilns and boilers is a recent trend driven by increasing fossil fuel costs. However, before using FS which was passively dried on sand and gravel filter beds, it would need to undergo an additional drying process before being blown into a burner. A possible option for an energy efficient approach to eliminate excess moisture is the use of waste heat from the clinker production process in cement factories. The objective of this study was to assess the technical and economic feasibility of using waste heat from a cement factory in Rufisque, Senegal, to enhance the dryness of faecal sludge. Two sources of waste heat are generally available in a clinker production line: i) recovery of hot gases and ii) radiant heat loss from the kiln's surface. In this case, the flue gas from the kiln was already used directly in the preheater and for drying the raw material, leaving the flue gas from the chimney as the only hot gas stream available for recovery. Its heat transfer rate is 2.8 MW, which would be sufficient to evaporate 2.5–3.1 tons of water per hour. If the total FS production of Dakar was dewatered on filter beds to 80% solids content, the recovered waste heat would be sufficient to achieve a 90% dry solids content. The resulting 26.7 tons of dried faecal sludge would cover ~2% of the daily energy requirements of the factory.

Background

Strauss et al. (2000) estimate that 65–100% of urban dwellers in Africa and Asia and some 20–50% of urban dwellers in Latin America are served by on-site sanitation systems such as septic tanks or latrines. In low and middle-income countries, these onsite sanitation systems produce enormous amounts of faecal sludge every day. In Kampala, Uganda, for example, cesspool emptiers fetch 300 m3 of faecal sludge every day (NETWAS Uganda, 2011), in Dar-es-Salaam, Tanzania, the faecal sludge removed from pits and septic tank adds up to 700 m^3 per day (Chaggu et al., 2002) and it is estimated that in Dakar, Senegal, 6,000 m^3 of fresh faecal sludge is produced daily (Bill & Melinda Gates Foundation, 2011). High costs for households are a major impediment for emptying, transport and proper treatment of the faecal sludge and often leads to improper operation of on-site sanitation systems. Problems include septic tanks with reduced hydraulic retention times due to sludge accumulation and pit latrines that are flood-washed with rainwater into the street during the rainy season. On-site systems are typically emptied with suction trucks or manual labour. The faecal sludge is commonly dumped directly into the environment, or disposed of in a treatment plant if it is available and affordable. This practice has its origin in the common perception of faecal sludge being a waste product without further value. But this perception is wrong. For example, faecal sludge contains nutrients (N, P, K) for agricultural purposes, can be used as feedstock for biogas plants or may replace fossil fuel sources in industrial heat consuming processes such as boilers or kilns.

Figure 1: Stock of old tires to be used as alternative fuel in a cement factory in Würenlingen, Switzerland

Alternative fuel in cement industry

The use of alternative fuel sources in industrial kilns and boilers is a recent trend driven by increasing costs for fossil fuel and/or raised awareness for environmental aspects in company policies (Figure 1). The cement industry especially shows an increasing interest in the use of alternative fuels, as a large part of production costs are directly linked to the energy intensive production of clinker. Today, even state-of-the-art cement kilns (rotary kilns with preheater and precalciner) have an energy demand of ~3,000 MJ/t clinker produced (Madlool et al., 2011; Schneider et al., 2011) which corresponds to ~70 kg of crude oil per ton of clinker (net calorific value of crude oil = 42 MJ/kg, (European Commission, 2010)). However, alternative fuels such as tires, animal meal, sewage sludge, waste oil or waste paint have to fulfil certain minimum criteria not only concerning their energetic composition but also their physical characteristics. Solid fuels most often are fed into the kiln by air flows and have therefore to have a minimum degree of dryness (≥90% DM). It has never been evaluated whether faecal sludge could be used as fuel, but this seems promising based on the common use of sewage sludge as an alternative fuel (Groupe Lafarge, 2007; Murray and Price, 2008; Schneider et al., 2011). The dryness of faecal sludge, passively dried on uncovered sand drying beds depends on climatic conditions but varies between 60% and 80% (Badji et al., 2009). It would therefore need to undergo an additional drying process before fed into the burner. One possibility for an energy efficient approach to eliminate the excess moisture would be the use of waste heat from the clinker production process.

This study was conducted at the Sococim Cement factory in Rufisque, Senegal. The objective was to evaluate the possibility of recovering waste heat from cement, and to evaluate the technical and economic feasibility of using the waste heat to enhance the drying of faecal sludge, thereby using two waste streams to provide an efficient fuel.

Figure 2: Truck unloading FS at FS treatment plant in Niayes, Dakar.

Faecal sludge in Dakar

Dakar, the capital of the west African country Senegal is located on a peninsula at the very western point of the country. Of the 2.5 million inhabitants of Dakar, 30% are served by a centralised sewer system and a wastewater treatment plant. The remaining 1.8 million residents are served by a faecal sludge management system, including cistern/pour flush toilets connected to septic tanks on household level (Strande et al., 2012). The sludge from the septic tanks is transported to the wastewater treatment plant in Cambérène, where the faecal sludge is co-treated with wastewater, or it is unloaded at the faecal sludge treatment plants in Niayes or Rufisque (Figure 2). The treatment plants have settling/thickening tanks followed by unplanted drying beds, with the leachate at Cambérène going to the wastewater treatment plant. According to an estimation by the Bill & Melinda Gates Foundation (2011), greater Dakar generates 2.2 million m^3 of faecal sludge per year. However, the solids content of faecal sludge in Dakar is very low, in the range of 3.5–4.5 g/l (Dème et al., 2009; Tounkara, 2007).

Sococim Industries, Rufisque

The Sococim Industries (VICAT group, since 1999) factory is located in Rufisque, about 30 km east of Dakar. It is the largest cement producer in West Africa and the factory has the capacity to produce up to 7,500 tons of clinker per day in three production lines. The most recent kiln plant (3,500 t/day) has been in operation since 2010 and consists of a 5-stage, 2-string DOPOL®’90 preheater with a PREPOL®-AS-CC calcining system, a rotary kiln and a POLYTRACK® clinker cooler. The lime for the clinker production is mined directly on Sococim’s premises and since 2007, the factory runs its own power plant enabling the cement plant to be self-sufficient in terms of electric power.

Clinker production process

In a typical dry rotary kiln system (Figure 3), raw material (crushed limestone, iron, bauxite, quartzite and/or silica) is preheated in a cyclone type pre-heater. The last stage of the pre-heater would act as a precalciner, where a big part of the raw material is calcined (decomposition of $CaCO_3$ to CaO and CO_2). The rotary kiln itself is a lined tube with a diameter up to 6 m. It is generally inclined at an angle of 3–3.5° and rotates 1–2 times per minute. At the lower end of the kiln, the product falls into the clinker cooler. Fast cooling enables waste heat recovery and improves the product quality (Engin and Ari, 2005).

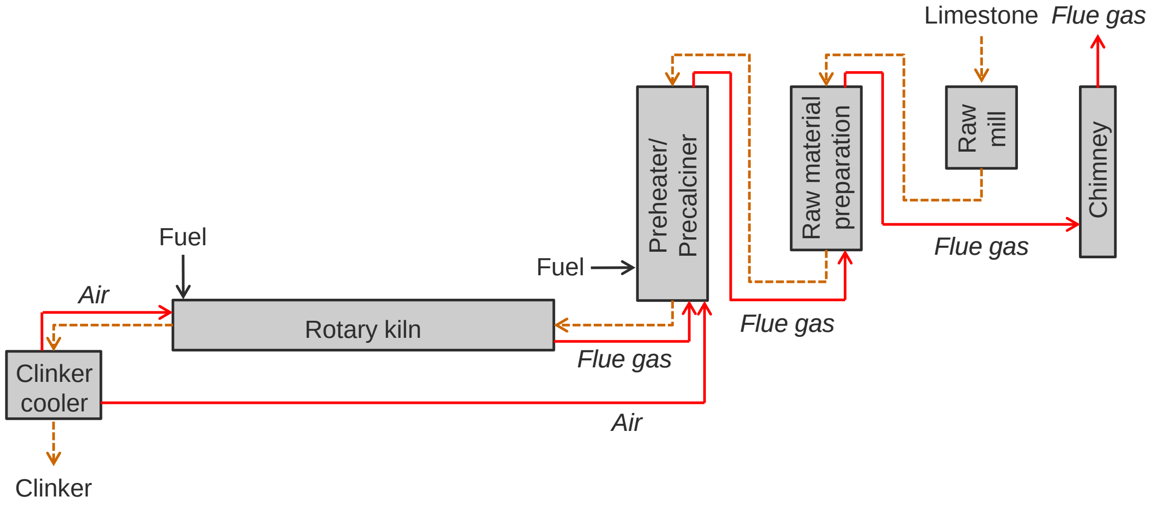

Figure 3: Overview of the clinker production process.

Waste heat recovery technologies

Generally, there are two sources of waste heat available in a clinker production line: i) waste heat recovery from hot gases and ii) radiant heat loss from the kiln surface. One of the most effective and simple waste heat recovery methods is the preheating of the raw material prior to it being fed into the kiln. To achieve this, the hot flue gas from the preheater is directed unaltered to silos where the raw material is stored, to eliminate excess moisture. Sometimes such straightforward use of the excess heat is not possible, either because the physical (e.g. humidity, particles) or chemical (e.g. toxic elements) characteristics of the air stream do not comply with the secondary utilization. In this case, heat exchangers are indispensable to transfer the heat to another medium such as water or oil. The temperature of exhaust air from the clinker cooler is about 215–250°C (Madlool et al., 2011; Trenkwalder, 2010), allowing for the use of a variety of heat exchange technologies. For example, the heat can be directed through a waste heat recovery steam generator (WHRSG). The generated steam is then used to power a steam turbine driven electrical generator, and the produced energy can then replace a large part of the production facility's electrical energy demand (Madlool et al., 2011). Another possibility is an air to thermal oil heat exchanger. The oil is used to transport the thermal energy to applications in other locations. In most cases, the thermal oil is used to convey heat within a premise, but it can also be tapped using an oil/water heat exchanger if long transport distances are required. For example, contributing to a municipal heating network or to external companies. An example of such an application is illustrated in Figure 4, where a private company in Würenlingen, Switzerland, uses the waste heat from a cement factory for the drying of dewatered sewage sludge, which then is sold back to the cement factory as alternative fuel in their clinker production. A similar system is described by Trenkwalder (2010) for a cement plant in Karlstadt, Germany, where the entire fuel stream for the clinker production is provided for with the use of alternative fuels. In this case, dried sewage sludge makes up ~10% of the total firing heat capacity.

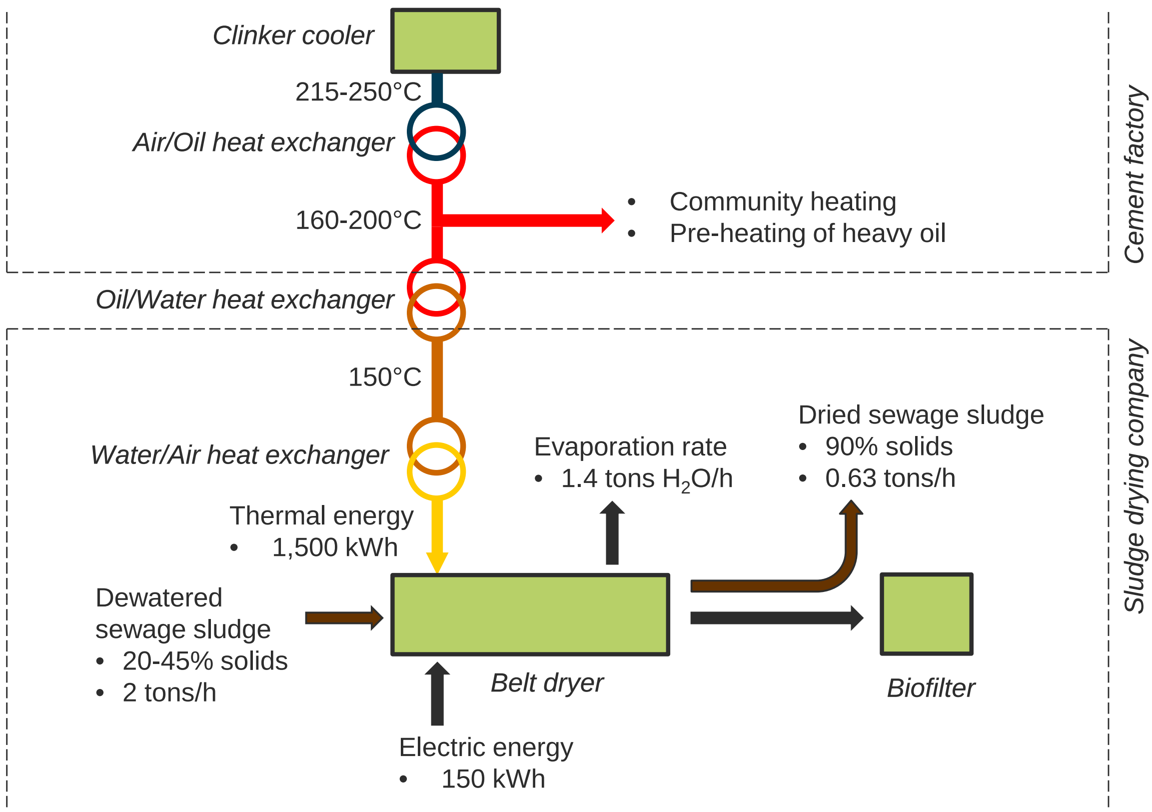

Figure 4: Use of waste heat from clinker production for the drying of sewage sludge in Würenlingen, Switzerland

As an alternative to traditional energy recovery methods, using the radiant heat loss from the rotary kiln has been proposed in literature (Ari, 2011; Caputo et al., 2011; Engin and Ari, 2005). Up to 15% of the total energy input is lost through radiation and convection from the kiln surface (Engin and Ari, 2005). Major obstacles for the implementation of this new technology are the high investment costs and the limited access to the rotary shell for monitoring and maintenance due to complex mounting of new equipment.

More common technologies for waste heat recovery are air-to-air heat exchangers. Heat can be recovered from low temperature air streams (100–200°C) using flat plate air-to-air heat exchangers (recuperator) or rotary heat exchangers (Oğulata, 2004). These air-to-air heat exchangers utilize relatively simple technology. For the production of electricity it has to be considered that using water as a working fluid in a cycle that converts heat into work (Rankine Cycle) cannot be operated in an economically feasible manner with waste heat below 370°C (Hung et al., 1997). In this case an Organic Rankine Cycle (ORC) containing working fluids with a much lower boiling point such as NH_3, Benzene, R134 or R11, has to be considered.

Possibilities for heat recovery at Sococim

The situation of low temperature air streams also applies to the most recent production line of Sococim. The flue gas has a temperature of 115–140°C with an air flow stream $\dot{V}$ of 450,000–500,000 Nm^3/h. The heat transfer rate $\dot{Q}$ for this air stream can be calculated applying equation (1). To provide the most conservative estimate, the inlet temperature of 115°C and a decrease in temperature of 25K (ΔT), typical for air-to-air plate heat exchangers, have been assumed. A temperature of 115°C and ambient pressure of 1 bar was assumed to set the values of relative density (ρ = 0.9 kg/m^3) and the heat capacity (cp = 1.0138 kJ/kgK) of the air.

$$\dot{Q} = \dot{V}\, \rho\, c_p\, \Delta T \qquad (1)$$

The 450,000 Nm^3/h eventually bear a heat transfer rate of 2.8 MW which can be used for the conditioning of the faecal sludge before it is used as fuel in the cement factory.

For the efficient use of the faecal sludge, Sococim requires a minimum dryness of 90%. Given the high water content of raw faecal sludge, and the costs associated when transporting water weight long distances from where it is collected to the cement factory (~30 km), it was assumed for these analyses that faecal sludge undergoes first a dewatering and drying process in a semi-centralized treatment plant near the city.

60–80% dryness can be achieved on a sand bed (Badji et al., 2009). The energy required for the evaporation of the remaining water before the faecal sludge can be fed to the burner therefore varies. Theoretically, the energy needed to evaporate one kilogram of water is 2.26 MJ (= 627 Wh). However, in reality, depending on the efficiency of drying systems, the energy demand varies from 3.3–4.0 MJ/kg of water (= 916–1,100 Wh/kg) (Water Environment Federation, 2004). This means that using the flue gas, 2.5–3.1 tons of water can be evaporated per hour. Based on this the amount of faecal sludge that can be dried using this waste heat source can be calculated (Table 1).

Table 1: Maximum hourly amount of faecal sludge that can be dried using flue gas from Sococim cement plant depending on water content. Assumptions: heat transfer rate = 2.8 MW; Energy demand to evaporate water = 920 Wh/kg

Solids content of incoming FS	Amount of FS processed per hour	Final product (90% DM)
percent	tons/hour	tons/hour
80	27	24
60	9	6
0.4	3	0.012

The flue gas energy would be sufficient to treat the total 6,000 m^3 of faecal sludge produced in greater Dakar area per day (DM 0.4%) if the sludge was dewatered to 80% solids content prior to drying at Sococim. The resulting 26.7 tons of dried faecal sludge (DM 90%) would cover ~2% of Sococim's daily energy requirements.

The technology of reusing hot flue gas has been successfully implemented to dry sewage sludge in Jiangyin, China (Ma et al., 2012). The systems uses two serial rotary driers, the flow rate of the flue gas is about 150,000 m^3/h and its temperature is 170°C. This way, about 100 tons of sewage sludge with a water content of 78% are dried to below 30% daily. A wide range of drying technologies for sewage sludge is described in literature with rotary dryers and belt dryers being the most prominent (Chen et al., 2002; Gruter et al., 1990; Kasakura et al., 1993; Kragting, 2002; Lowe, 1995; Stasta et al., 2006; Trenkwalder, 2010; Water Environment Federation, 2004).

Conclusions and Recommendations

Even though the clinker production line studied already reuses state-of-the-art waste heat recovery technologies, the energy deriving from hot flue is not utilised and could also be recovered for the final drying of dewatered faecal sludge before it is being used as fuel. In older production lines, waste heat might also be recovered from the clinker cooler or the kiln exit. However, many cement production lines already dispose of a heat-recovery and -distributing system using thermal oil.

Even when waste heat and space for drying infrastructure are available on spot, the economic and ecologic feasibility of FS drying has to be evaluated carefully. Transportation costs are an important consideration in FS management, as the associated water weight is very costly to transport. The economic feasibility of waste heat recovery for FS drying will therefore also be determined by the location and logistics of transporting FS from household level on-site sanitation systems to pre-drying and drying facilities, in addition to the energy potential of the waste heat.

It might be a promising solution that the drying of the FS is done by a company which is formally detached from the heat producing plant, with the FS drying company tapping the existing thermal oil system. The coupling between the different actors is limited to a heat exchanger and the handling of the faecal sludge can be done outside the cement factory’s ground. However, since the successful operation of the drying facility is closely linked to the cement plant and possibly involves big infrastructure investments, only long-term contracts will guarantee an effective and sustainable operation of the heat recovery system (Stehlik, 2007).

The combination of the two waste sources, FS and waste heat, can create a financially attractive alternative to fossil fuel in industries. This valorisation process will enhance the motivation for FS collection and proper disposal and will help to alleviate financial pressure of households.

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