NEW TECHNOLOGIES FOR THERMAL DISPOSAL OF SEWAGE SLUDGE

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Abstract

The traditional methods for the disposal of sewage sludge are landfilling, recycling as fertilisers in agricultural lands, dumping into sea and incineration. In the recent past, sludge incineration has been rapidly gaining ground due to environmental constraints facing the other methods. However, the cost of pollution control during sewage sludge incineration is currently very high due to the expensive flue gas treatment facility required. Futhermore, large quantity of ash is produced which is highly contaminated with heavy metals and must be disposed off in special landfilling sites in order to avoid ground water pollution. To reduce the cost of pollution control, new technologies for thermal treatment of sewage sludge are currently being introduced into the market. These include co-combustion of sewage sludge in brick works, cement works, municipal solid waste incinerators and coal power plants. Other new processes are wet oxidation, oil from sludge and fuel from sludge processes as well as gasification. The peculiarities of these technologies include low emissions of air pollutants, low quantity of flue gas and the production of molten ash in which the heavy metals are firmly bonded. This paper discusses some of these technologies.

Introduction

Sewage sludge is formed during wastewater treatment process and its disposal is perhaps one of the most complex environmental problems facing the engineer in this field. This is particularly because, sludge is composed largely of the substances which are responsible for the offensive, pathogenic and toxic characteristics of the untreated wastewater[1]. Whereas the offensive and pathogenic nature of sludge may be eliminated through stabilization, the toxic elements as well as organic and inorganic compounds are retained and may lead to pollution if proper care is not taken during disposal. Currently the sludge disposal outlets employed are recycling as fertiliser, land filling, dumping in the sea and incineration.

Several countries are currently using sewage sludge as a fertiliser or a soil conditioner due to its high contents of nitrogen and phosphorus. For example, 60 and 54 % of the sludge produced in France and Denmark respectively are used as fertiliser[2]. In the recent past, however, this disposal method has met a lot of setbacks due to the presence of heavy metals in the sludge. Analysis by Poletschny[3] of 6800 sludge samples from different parts of Germany showed that the average content of heavy metals in municipal sludge is higher than the average for most farming soils. Thus uncontrolled application of sludge may increase the concentration of the heavy metals in the farmland. Apart from affecting plant's production, this could also lead to the transfer of the heavy metals to human beings through food chains[3].

Landfilling of sewage sludge still takes the bulk of sludge in developing countries. About 40 and 48% of the sludge produced in the European community and USA respectively are landfilled[2,4]. However, the future of landfilling is doubtful in many countries because of the problems of stability, emissions of odour and gas as well as pollution of ground water through leaching. In the developed countries, the available capacities for landfilling sites are limited and getting approval to construct new ones is tedious. These problems have increased tipping charges so that land filling is no longer a cheap disposal method[5].

The problems facing sludge landfilling and use in agriculture as well as the expected ban in Europe of sludge dumping into the sea as from 31st December 1998, when the North Sea Conference Agreement comes into force[6], have stimulated interest in thermal processing of sludge in general and incineration in particular. Incineration enjoys a combination of several advantages, including 90% volume reduction to a stabilised ash and thermal destruction of toxic organic constituents. Furthermore, the energy content of the sludge, which corresponds to that of brown coal (in dry mass) can be recovered during incinneration[7]. Due to considerable improvements in the technology of inceneration, techniques are now available to control gaseous emmissions and incineration costs are becoming much more competitive with other dsposal options, to the extent that inceneration is now seen as the only solution to the increasing problems of other sludge disposal options[5]. For example, in the European Union, projection shows that by 2005, incineration will increase to 38% whereas only 17% of the sludge will be landfilled, Fig. 1[4]. In Japan, over 55% of the sludge produced is incinerated which is attributed to the increasing shortage of suitable land for disposal sites[8].

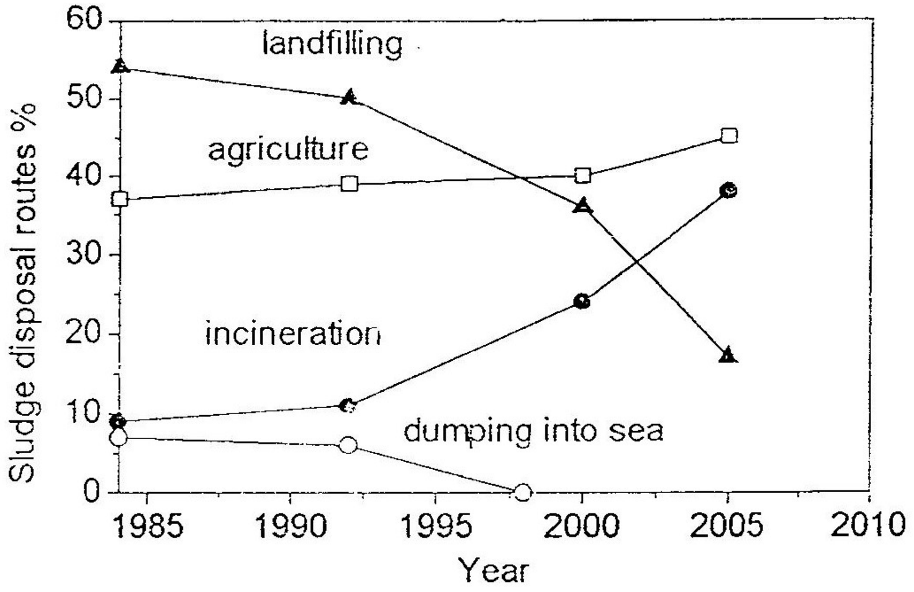

Fig.1 Sludge disposal routes in the European Community up to 2005

One major shortcoming of sludge incineration is the high cost of pollution control which is associated with the large quantitu of flue gas ans ash formed. The ash, which is contaminated with the heavy metals in the sludge, must be deposited in special sites to avoid groung water pollution. These problems have stimulated the development of new combestion technologies for sewage sludge which can be grouped in three classes nemely; mono-combustion, combustion and alternative technologies. These are discussed below.

Mono-Combustion

Mono-combustion technologies which have been used for sewage sludge incineration include fluidised bed (FBC), multiple hearth (MHF), rotary kiln, cyclone and smelting furnaces. Currently, the FBC and MHF are dominating. For example, in Japan, out of the 151 sludge incineration plants in operation in 1988, 72 and 53 units were MHF and FBC respectively[8], whereas 70% of the 39 sludge combustion palnts operating in Germany are FBC type[9]. By 1992, more tahn 100 FBC incinerators were installed in the USA and over 300 world-wide[10].

As already mentioned, the main shortcoming of MHF and FBC furnaces is the production of large quantity of ash due to their low operation temperatures. The problem is solved in smelting furnaces where pre-dried sludge is incinerated at higher temperatures, leading to the formation of molten ash and consequently to a reduction of the ash volume by 2-3 times. The heavy metals, which are firmly bonded in the crystallised slaf, are no longer leachable. The molten ash can thus be used in costruction works[11]. Due to very severe land shortage, rapid increaseof s,elting plants is being wotnessed om Japan where in 1988 there were onlly three large-scale sewage sludge smelting plants but by 1993 already more than 15 plants were reported operating or under construction.[8]. Nanbu sewage sludge smelting plant in Tokyo, Japan, is the alrgest and has been in operation since 1991. It handles 40 tons per day of sewage sludge, pre-dried to 80 wt.% solid content. The sludge is crushed and the fed into a cyclone smelting furnace which is co-fired with gas and maintained at 1400-1500 ^{0}C[8]. Several small Germany companies are also trying to popularise sewage sludge smelting technology in the European market. For example Klein Energietechnik is currently marketing small sewage sludge smelting cyclone furnaces operating at 1500 ^{0}C. The furnaces are of capacity 0.5 t/d dry sludge are suitable for small and medium size wastewater treatment plants[12].

Co-Combustion of sewage sludge with coals and wates

Another new technology for thermal disposal of sludge is the co-combustion with coals and wastes. Available information indicates that sewage sludge can be co-fired in coal power plants, municipal solid waste incinerators, waste-fired boilers, as well as durng cement and brick production. The quantity of sludge used is small compared with the main fuel and therefore co-firing does not adversely affect the product or process.

Co-combustion in power plants

Co-firing of sewage sludge in power plants is very attractive because this gives the opportunity to use the available capacity of the plant with well trained and experienced personnel to handle it. Modern power plants are currently eqipped with flue gas cleaning facility which should be able to handle the expected increase in emissions during co-firing with sewage sludge[13]. An example of a large scale co-firing plant is the BASF's facility at Ludwigshaten site in Germany in which sewage sludge has been co-fired in pulverised coal power plant since 1984, Fig. 2. The sludge is conditioned, dewatered in filetr presses, dried and then co-fired with coal at a rate of 4t/h sludge[9]. Another example of co-firing in coal power plant is the EcoEnergy Bubbling Fluidised Bed Combustion Boiler at the Golbey Paper Mill-France, in which bark and sawdust are co-fired with paper mill sludge. The boiler was commissioned in 1993 and produces about 35 t/h saturated steam at 26 bar[14]. Other examples include the 110 Mwth CFB plant in Lnzing- Austria to co-combust refuse derived fuel with rejects, sewage sludge, wood waste and coal to be build by the consortium Austrian Energy and Lurgi Lentjes Babcock[15] and the bark boile belonging to Champion International Corporation in Sheldon, Texas, USA which was upgraded by Tampella Power to co-fire sludges mixed with waste wood[16].

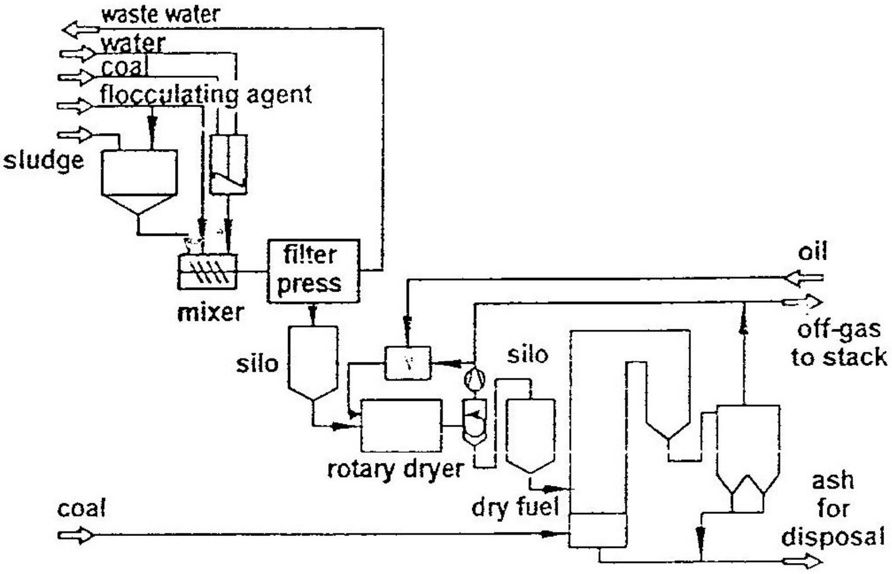

Fig. 2 Co-combustion of sewage sludge in BASF's pulverised coal power station[9]

Co-incineration with municipal solid wastes

Co-incineration of sewage sludge with municipal solid wastes has the objective of redusing the combined costs of incinerating sludge and solid wastes. The process can generate sufficient heat energy necessary for drying the sludge, supporting the co-combustion process and generating process steam. Like in the case of power plants, co-firing of sewage sludge with MSW provide use of capacity of some existing MSW incinerators equipped with modern flue gas cleaning technology. Whereas most MSW incinerators currently operate at full capacity and may not provide opportunity for co-incineration with sewage sludge[17], new ones could be planned with co-firing in mind. As shown by Liem and van Zorge[18] the percentage of waste incinerated is still low in most countries, Table 1.

The grate furnace is the most dominant firing system for co-firing sewage sludge with municipal solid wastes (MWS). For example, eight large scale grate firing plants in which pre-dried sewage sludge is co-fired with different types of wastes have been reported to operate in Japan[19]. One of them is the combustion facility in Sapporo, in which sewage sludge, 60 wt. % dry mass, is co-fired with timber wastes at 800-900 ^{0}C. The plant prodeces superheated steam at 300 ^{0}C and 19 bar. Other furnaces such as MHF and FBC have also been employed for co-firing of sludge with municipal wastes. A new technology is the combined grate and MHF plant operated at Marktoberorf, Germany in which 2.5 t/h and 1.0 t/h waste and sludge, respectively, are co-fired. The wastes are burnt in the grate furnace (GF) and the sludge in MHF. The flue gas from the GF is used to provide the energy foe drying and combusting the wet sludge[17].

Table 1 Quantity of waste incinerated in various countries[18]

Country	Amount of waste incinerated(1000t/a)	% of waste incinerated	No. of MSW incinerators
Denmark	1500	70	48
France	6395	40	260
Germany	9300	23	49
Italy	2000	10	54
Japan	37582	73	1841
Netherlands	2805	46	11
Norway	440	23	50
Sweden	1550	55	22
Switzerland	2300	80	48
UK	2780	10	33
USA	28900	16	152

Combustion of sewage sludge in clay brick and cement production

In an endeavour to reduce the energy demand for the firing of raw brick, sewage sludge has been added to clay during production to partally provide the energy required. For example, in Port Elizabeth municipality, South Africa, the 45 t/d thermally conditioned and centrifuge dewatered sludge from the wastewater treatment plant is all consumed in a local brickwork[20]. Up to 30% by volume of sludge is blended with the clay for the production of common bricks and between 5% and 8% for face bricks. The mixture is crushed, milled, homogenised and thereafter sliced into bricks of conventional lengths. The obtained bricks are dried and then tracked into tunnel kiln, where upon attaining a temperature of 150 ^{0}C the sludge devolatilises and burn causing a rapid increase in the bricks' temperature. A fuel saving of about 55 liters per every 1000 bricks is achieved through the use of sewage sludge. The appearance of the bricks is reported to be excellent, being uniform in colour and texture and free from extensive cracks and are indistinguishable from conventional bricks. They are reported to meet the requirements of South African Beareau of Standard. Similar processes are being developed in Humburg, Germany and in Russia.

Pre-dried sludge can also be used as supplementary fuel during cement production. During a one week large scale tests, Lang and Obrist[21] successfully co-firing 280 t of sewage sludge in a large cement industry in Austria. These tests showed that pre-dried sludge can be successfully co-fired with coal in the main firing stage. Co-firing in the secondary firing stage although was possible, resulted into incompleye combustion of the sludge and higher CO emissions. As a rule of the thumb, the recommended maximal sewage sludge feed rate was 5% of the clinker production capacity of the cement plant. The quality of the clinker did not worsen due to the co-firing. Furthermore, the suspended fine limestone particles were effective in the removal of SO2 formed during sludge combustion whereas the heavy metals from sludge were absorbed on the particles and returned into the kiln after separation in the E-filter.

New technologies for thermal disposal of sewage sludge

Several alternatve technologies to mono-combustion of sewage sludge are currently being tested. These include gasification, wet oxidation, oil from sludge, fuel from sludge and a combination of pyrolysis, combustion and gasification processes. All these technologies are aimed at reducing the cost of pollution control.

Wet oxidation of sewage sludge

Wet oxidation is a unique process in that no formal flue gas treatment is required. The combustion of sewage sludge takes place in an aqueous phase at 150-330 ^{0}C and 10-220 bars using pure O_2 or air. The high pressure is needed to prevent boiling at the operation temperature. During the process the organic matter in sewage sludge is thermally degraded, hydrolised, oxidised and converted to carbondioxide, water and nitrogen. The first large scale plant was recently commissioned at Apeldoorm, in the Netherlands[22]. The 22800 t/a dry matter capacity plant has a cement-encased well, 1200 m deep, with a diameter of 950 mm into which concentric tubes are suspended together with heat exchangers to control the temperature, Fig. 3.

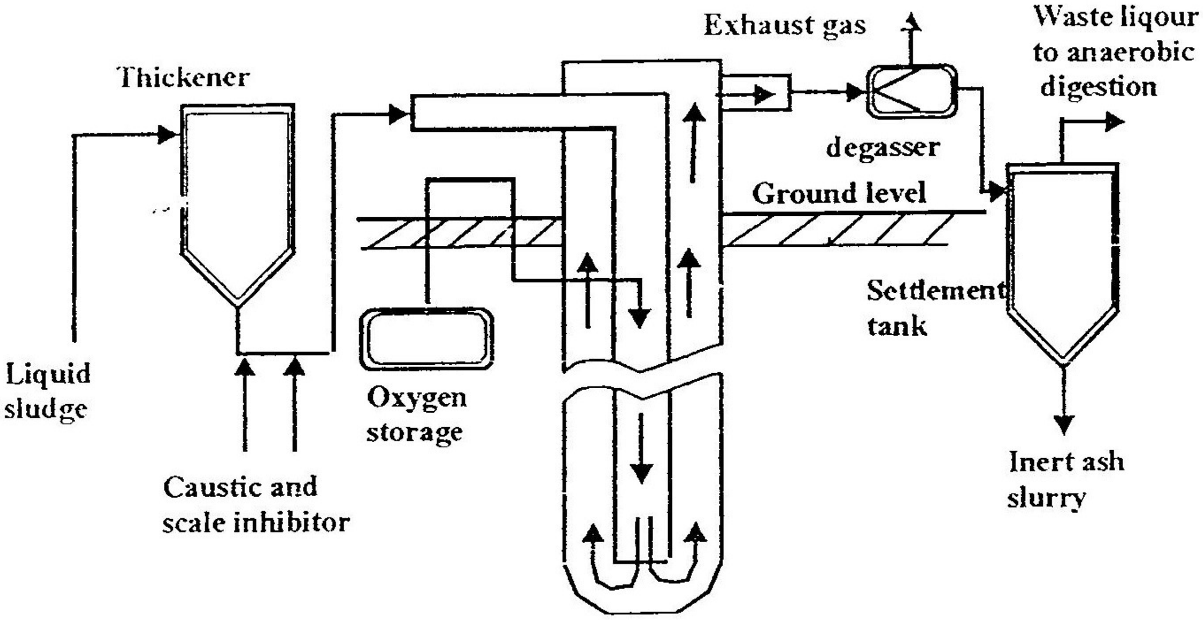

Fig. 3 The VerTech system (Boom and Thomas[22]

The vertical design is meant to produce a high hydrostatc head at the bottom of the system. Sewage sludge with solid content of about 5 wt.-% is initially milled to particles with diameter 3-5 mm, homogenised and then fed into the reactore in which pure O_2 is also fed. The plants operate at a temperature of 280 ^{0}C and a pressure of 100 bar. 70% reduction in COD is achievable. The S. Cl and P present in the sludge form compounds which dissolve and leave the process in a liquid form whereas larger part of the N leaves as dissolved NH_3 and is removed in the nitrification and denitrification stages. The ash formed is dewatered and decanted water is biologically treated.

Oil from sludge (OFS) processes

Sludge pyrolysis is a thermal decomposition process of the organic matter in the absence of air. The products of pyrolysis are gas, oil and char. The low operation temperature eliminates the formation of SO_2, NO_x and dioxin[23]. The char, with heavy metals firmly bonded in its matrix, can be landfilled or used as an absorber for gas cleaning or burnt to supply the energy for pyrolysis, the gas is useful fuel whereas the oil is both a fuel (calorific value 29-38 kJ/kg) and raw material for chemical industries[24]. The process can be directed such that the oil becomes the main product of the process- Oil From Sludge (OFS) process. The OFS process takes place in two stages, first the organic matter of the sludge is converted to a vapour state and then through catalytic reaction in the presence of char, these vapours are converted to hydrocabons[25]. The high content of silicate and copper in the sludge provided additional catalyst for the reaction. The oil recovery is reported by Kyraokos[26] to range from 18-52% oil per kg of dry sludge, Table 2.

Table 2 Comparison of oil yields, kg/kg sludge (daf), from various groups

	Universty Tübingen	Environmenal Canada	Universty Hamburg	Universty Waterloo	Universty Brüssel
300	25-40	-	25	-	16-18
350	-	18	-	41	24-39
400	-	-	38	52	-
450	-	32-36	-	52	30-41
500	-	-	42	47	-
600	-	-	24-42	39	-
700	-	-	24-42	20	-

Sludge derived fuels - The C-G process

The Carver-Greenfield (C-G) technology uses multiple evaporation effect to ptocess sewage sludge into fuel. The main advantage of the process is the reduction in the energy (steam) required for the drying to a third of the requirement for conventional dryers[27]. Mechanically dewatered sludge is mixed with an industrial oil whose boiling point is above that of water and thereafter pre-dried, Fig. 4. The oil maintains the sludge in a liquid form even after its water content has been reduced to below 5%. After drying the oil is separated using press filter and recycled back. The fuel sludge has 87% solid sludge, 9% oil and 4% water. The heating value is about 16700-18000 kJ/kg. The C-G process is part of the $ 200 million Hyperion Energy System of the City of Los Angles, USA, which recovers energy from the 405 t/d dry sewage sludge produced from the municipal's wastewater treatment plant[28].

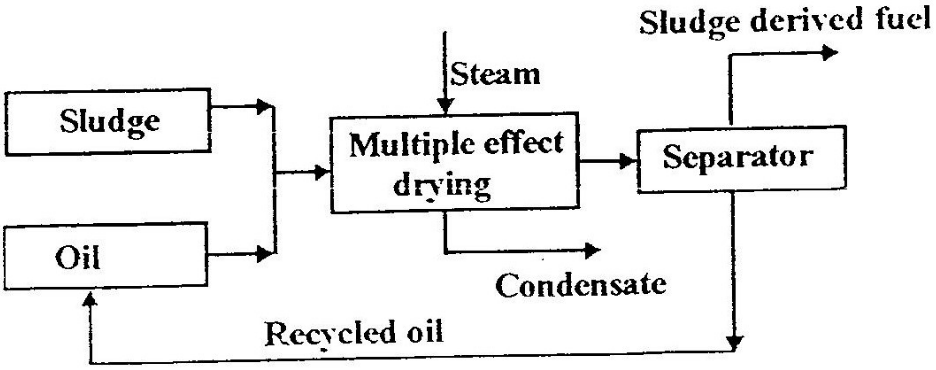

Fig. 4 Flow diagram of C-G process[28]

Gasification and combined processes

The main advantages of disposing sewage sludge thriugh gasification are three folds. First a large reduction in flue gas volume can be achieved. This is because the CO_2 and H_2O, internally formed, participate in the reaction and the burdensome N_2 may be avoided by using pure oxygen. Steier[29] has shown that the volume of flue gas released per kg dry sludge can be reduced from 24-30 m^3 (during combustion) to only 1.7 m^3 during gasification with supply of pure oxygen. Secondly, a synthesis gas is produced which can be used as fuel or raw materials for chemical industries. Finally, where possible, useful material in the ash can be recovered.

Examples of gasification processes are the SVZ plant in Berlin and the waste gasification technology of Krupp Uhde Consortium. In the SVZ process, after removing the metallic components, the solid waste materials are crushed, milled, briquetted and thereafter gasified with oxygen and steam at 1300 ^0C, Fig. 5. The gas formed consists of CO, H_2, CH_4 and CO_2 and is used for methanol production and power generation. Several wastes, including refuse derived fuels, sludge, contaminated wood, plastics and hazardous wastes can be co-handed[30]. In the Krupp Uhde PreCon Process, apart from the formation of synthesis gas, the molten ash formed is processed in a Catalytic Extraction Process Chamber in which the ceramic products and metals are recovered[12].

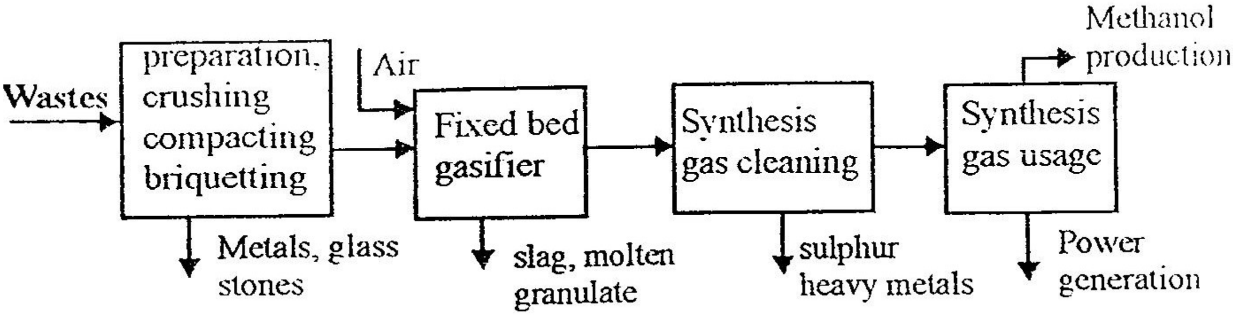

Fig. 5 flow diagram of SVZ technology

Apart from pure gasification process, waste disposal technologied such as *Noell Conversion Process* and *Thermoselect* combine pyrolysis and gasification. The **Noell** Conversion Process consists of a gasifier, operating at a pressure of up to 35 bar and a temperature of 2000 °C, Fig. 6. The wastes are crushed, pyrolysed at 550 °C and thereafter the larger parts consisting of metals, stones and other inorganic matter are removed. The remaining materials are pulverised and fed into the gasifier. The pyrolysis gas, cleaned of the condensable vapours, is compressed. Both the gas and the condensate are fed seperately into the gasifier. For co-gasification, pre-dried sludge, is pulverised and then pneumatically fed and fired into the gasifier. A 130 MW large scale plant has been operating in Berlin since 1988 and produces a high quality synthesis gas consisting mainly of CO and H_2, which can be used in gas turbine for power generation.

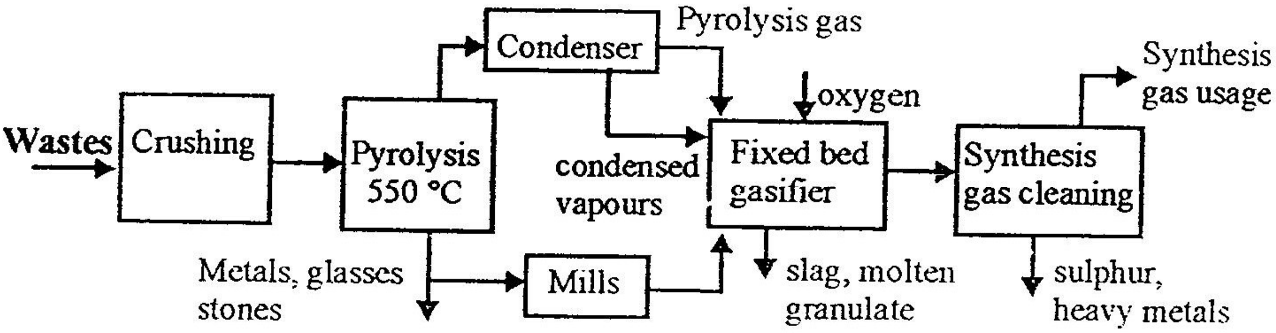

Fig. 6 Simplified flow diagram of the Noell Conversion Process

For *Thermoselect* technology, the process of pyrolysis and gasification are carried in a single unit, Fig. 7. The waste including sewage sludge are compressed using hydraulic press in a long canal heated from outside and maintained at temperatures higher than 600 ^{0}C. As wastes move through the air-tight canal, they are heated, dried and completely pyrolysed by the time they reach the end of the canal. The products of pyrolysis then enter in the gasification zone where the materials are gasified with oxygen at a temperature of around 2000 ^{0}C. A high quality sythesis gas and a molten by-product is formed, cleaned and made available for use in power generation or as raw material for chemical processes.

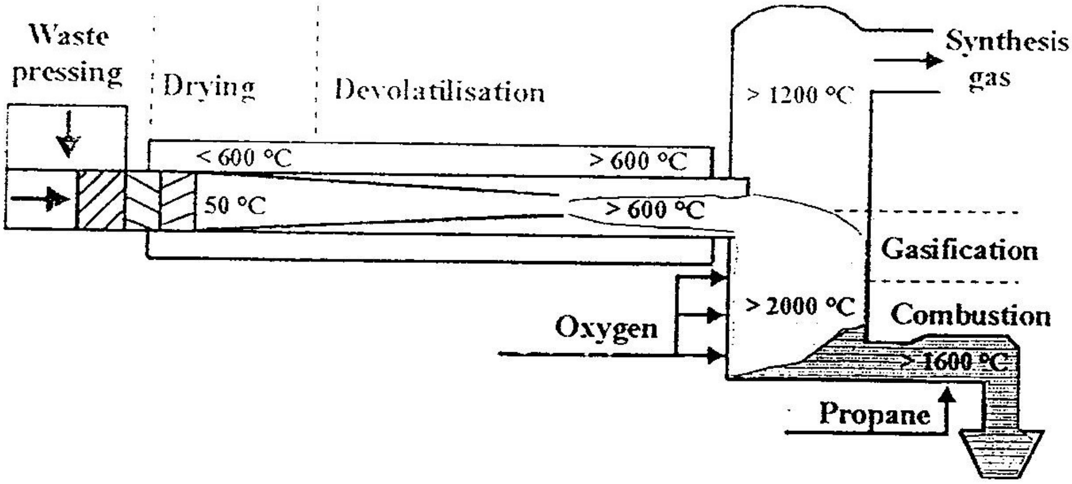

Fig. 7 Thermoselect process

Since 1992, thermoselect company has acquired experience from their pilot scale plant, capacity 100 t/d located in Italy and in 1997 started the construction of a large-scale plant, capacity 225.000 t/a in Kalsruhe, Germany.

Conclusion

In the current paper, the potential of various new and alternative technologies for sludge processing have been discussed. Technologies such as co-firing in coal power plant, in waste incinerators, in brick production as well as wet oxydation processes and others have been tasted in large-scale operation.

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