Proceedings WARMICE-2012
Sudhir Kumar, et al. (eds)
I.A.H., 2012

Utilization of Sludge for Sustainable Development of Society

Vaishali Sahu
Department of Civil Engineering, ITM University, Gurgaon, Haryana-122017

Abstract : Unsustainable trend in waste generation is a cause for concern because the generation of waste can be a symptom of environmentally inefficient use of resources. Therefore, development of new technologies to recycle and convert waste materials into reusable materials is critically important for protection of our environment and sustainable development of our society. With the current emphasis on environmental health and water pollution issues, there is an increasing awareness of the need to dispose of wastewater safely and beneficially. Properly planned use of sewage effluent and its by-products alleviates a number of environmental problems. Large quantities of sludge are produced in India and disposed of by landfilling. Space limitations on existing landfill sites and problem of waste stabilization have prompted investigations into alternative reuse techniques and disposal routes for sludge. A more reasonable approach is to view the sludge as a resource that can be reused. This paper highlights the potential of dried sludge, sludge pellets and sludge ash in various construction materials. This paper provides a review of the various application areas for the water and sewage treatment plant sludge. The percentage utilization of sludge in various fields is highlighted and comparison of sludge usage in various construction materials is made to identify possible future areas of research to fully utilize these methods of sludge reuse and disposal alternatives.

Keywords: Landfill, sewage sludge ash, sewage sludge pellet, sludge.

INTRODUCTION

Sludge withdrawn from drinking water and sewage treatment plants contains a lot of putrescible organic matter and if disposed of without any treatment, the organic matter may decompose producing foul gases and a lot of nuisance, pollution, and health hazards. In India, several million tonnes of sludge is produced annually with the treatment cost being 50% of the annual operating costs of wastewater treatment.

The world is currently witnessing a rapid increase in sludge production, and this is expected to continue up to the early part of the next century. With the implementation of the CPCB municipal wastewater directive, it is expected to see the production volume of sludge to increase to 1 million tons per years. Delhi itself produces approximately 228 to 381 tons of sludge which would increase to 430 to 718 tons if the gap in the generation of sewage and treatment will be filled in the coming years. The increasing trend of sludge production in India as per CPCB is shown in the figure 1. Feasibility studies on the use of sludge to produce cement, mortar, concrete, building blocks etc. as a means of ultimate sludge disposal has been initiated. The application of sludge can significantly reduce the sludge disposal cost component of sewerage treatment.

In this paper, an attempt has been made to find out the reuse potential of sludge which itself is an end product causing much pollution. In view of the anticipated disposal problem of sludge and associated environmental concerns, recycling of

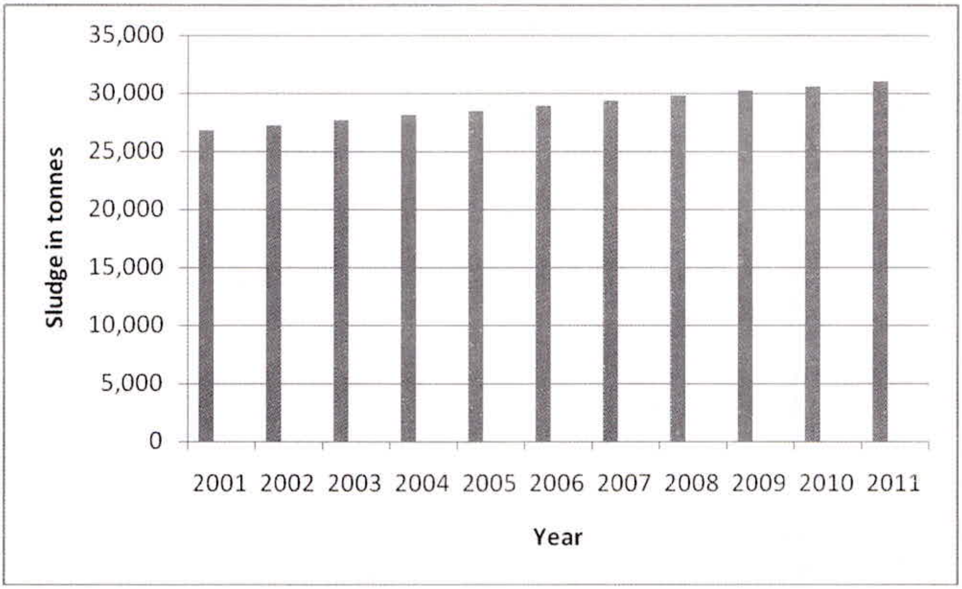

Fig. 1. Sludge production in India from 2001to 2011

sludge into useful materials is gaining due consideration as an alternative disposal option. It is actually sludge reprocessing to value-added products that holds the future key to sustainable management. Thus, the primary focus of this review is the value addition of sludge comprising recovery of different components and development of commercial products.

SLUDGE DISPOSAL METHODS

As the sewage generation is increasing to follow the stringent rules, so the sludge production and finally we have to deal with the problem of its disposal. The most common routes being in use are agricultural reuse of sludge, sea disposal, landfill disposal, etc. The sea disposal is now banned. The landfill disposal will soon be restricted with the implementation of the landfill directive. The main remaining routes are the reuse of sludge in various applications or to incinerate it and then reuse. All the alternate routes have to be judged on several levels.

On Land Application

So far in India sewage sludge has been utilised for agricultural purposes, but studies shows that sewage sludge is classified as toxic waste, due to heavy metal concentration and pathogenic microbial load. It requires extensive treatment to ensure a benign product, for reuse in agriculture or safe for land disposal which is not feasible under certain circumstances. It is needed to find opportunities for sludge. (Hospido et. al, 2010). The microorganism present in sewage observed by Kacprzak, 2005 is given in table 1.

Thus, sewage sludge may be an important cause of environment pollution. Great care is needed to prevent sludge running off onto roads or adjacent land, depending on topography, soil and weather conditions. On sloping land there is the risk of such runoff reaching watercourses and causing serious water pollution. Thus it is also not eco-friendly mode of disposal.

Table 1. Various microorganism present in sewage sludge

Microorganism	Yeast and yeast-like fungi	Mucoraceae	Penicillium	Others
Sewage sludge	19%	5%	54%	22%

REUSE POTENTIAL ANALYSIS OF SLUDGE

One solution to the crisis of sludge disposal lies in recycling this waste into useful products to replace the natural products wherever possible which will reduce the economic and environmental problem of waste disposal and also reduce the depletion of natural resources.

Dried Sludge

Sludge is bulky in nature with moisture content varying from 90 to 98%. Hence it has become increasingly important to handle it in more effective manner due to new regulations, legislation and environmental issues. Sludge should be first dewatered to make its handling easy. The various usages in building material of dried sludge are as follows:

Bricks : Joo Hwa Tay in 1987 used dewatered sludge from sewage treatment plant to make bricks. The percentages of dried sludge used for the first sample were 10%, 20%, 30%, and 40% by weight. Brick samples with dimensions of 40x20x10 mm were manufactured. They found the maximum percentages of dried sludge that could be mixed with clay for brick making is 40% by weight. For bricks with 10% dried sludge, the compressive strength was about 30% lower than control samples. Nuvolari (2002) tested soft-mud bricks with reduced dimensions (10x5x2.5 cm) and concluded that the maximum proportion of sludge that met minimum compressive strength standards was 10%. Liew, Idris, Wong, Noori and Baki (2004) tested addition of sewage treatment plant (STP) sludge in the manufacture of soft-mud brick and concluded that a proportion of 20% meets water absorption and compressive strength standards. Maria, Anaxsandra and Rubens (2011) studied the properties of the soft-mud bricks, measuring 220x105x45 mm. They were moulded in a manual press in laboratory and fired in an industrial kiln, with 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40% sludge. They concluded that the maximum concentration of sludge that can be incorporated into ceramic mass, meeting both the technical and environmental requirements, is 20%.

Concrete The direct addition of sewage sludge to concrete has been studied by S. Valls and its effect on setting, strength, leaching and so forth have been determined by them from year 2000 to 2003.

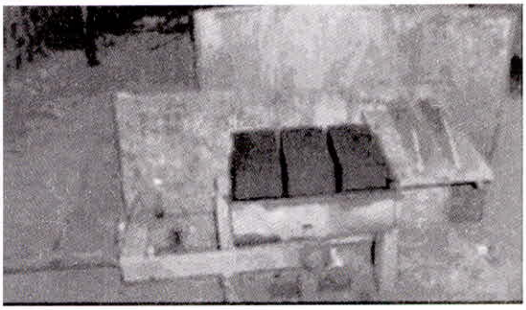

Fig. 2. Manual press for bricks moulding

Fig. 3. Bricks added with sludge

In 2004 study, it was confirmed by Valls, Yague, Vazquez and Mariscal, that upto 10% of treatment plant sludge can be added to concrete for use in certain very specific applications. They found it as a light material that can be used to meet diverse needs in the field of filling materials and compacted flooring. Almir Sales and Francis Rodrigues de Souza (2009) obtained that the production of concretes and mortars with the joint addition of water treatment sludge and aggregated from recycled construction & demolition wastes may offer a recycling alternative that is feasible from the standpoint of axial compression strength and water absorption. Sludge may be applied as a regulator of consistency and plasticity and, in suitable quantities, can even increase the compressive strength of concretes and mortars produced for a given application. The results of this study allow us to state that the application of water treatment sludge in concretes and mortars does not render the future leachate from these products harmful. Spray dried atomized sludge from drinking water treatment plants were utilized by Rodriguez, Ramirez and Flores in 2010. They prepared mortars mixed with 10 to 30% atomized sludge and found that it exhibited lower mechanical strength than the control cement and the slump was decline. In recent studies by Chen, Xianwei and HengJie (2010) revealed that water purification sludge (WPS) can replace siliceous material partially upto 10%. It was found that WPS replacements <7% increased the strength of samples. It is evident that concretes containing higher sludge contents showed better performance at longer curing times. It was found by Jamshidi and Mehrdadi (2011) that by adding 5 % of dry sludge to concrete, negligible decrease in compressive strength (less than 3%) is achieved. There were not considerable differences between compressive strength of specimens containing 10 and 20% dry sludge.

Blocks: Production of various mix ratio of hollow concrete blocks from dewatered water treatment sludge used as a fine aggregate could be a profitable disposal alternative in the future. The results of the study by Thaniya Kaosol (2010) showed that the water treatment sludge mixtures can be used to produce hollow non-load bearing concrete blocks, while 10 and 20% water treatment sludge mixtures can be used to produce the hollow load bearing concrete blocks. Economically, the 10 and 20% water treatment sludge mixtures can reduce the cost of the blocks. The 50% of water treatment sludge ratio in mixture to make a hollow non-load bearing concrete block can reduce the maximum cost at 2.35 baht per block.

Potential Application for ISSA

Incinerated sewage sludge ash may be used in ceramic products as a sand or clay substitute, in concrete mixes as a cement substitute (up to 20% replacement), as a secondary fine aggregate in concrete (replacement up to 30%) and in asphalt (replacement up to 10%) (Gunn, Dewhurst, Giorgetti, Gillot, Wishart,& Pedley, 2004).

Bricks: In 1986 Tay used the percentages of sludge ash for the brick sample as 10%, 20%, 30%, 40%, and 50% weight. Brick samples with dimensions of 40x20x10 mm were manufactured. The maximum percentages of sludge ash that could be mixed with clay for brick making is 50% by weight, respectively. The compressive strength for bricks made with 10% sludge ash is similar to that of the clay brick. Nuvolari in 2002 concluded that for the bricks manufactured with sludge ash, a concentration of up to 40% was technically feasible.

Cement mixes: Pinarli and Dhir in 2000, showed that the initial and final setting times of the concrete were longer with high percentages of sludge ash used. With 5% replacement of cement by pulverised sludge ash, the compressive strengths at all ages were higher than the control samples. With 10% replacement compressive strength at different stages were about the same as reference cubes. The water adsorption and permeability of concrete with sludge ash decreased.

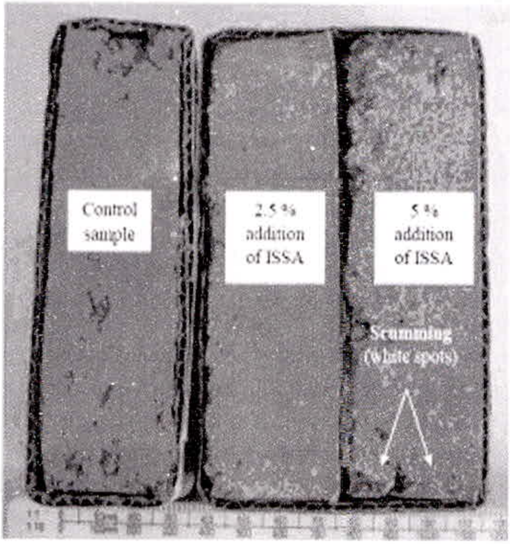

Fig. 4. Bricks made with incinerated ash

The use of a super plasticizer enhances workability of SSA mortars, and cancels the negative effect of SSA. A linear increase of workability is observed with growing percentages of super plasticizer added. The presence of SSA in mortars prepared with various cements reduces their workability; the negative influence of SSA is similar for all cements. For high replacement levels (30%), very low workability mortars were obtained in all cases. (Monzo, 2003).

Pan (2003) studied the fineness of sludge ash and concluded that when the fineness of SSA increased, the workability of SSA mortar increased due to the lubricant effect and morphology improvement. On the other hand, the compressive strength of SSA mortar increased with increase of SSA fineness, primarily due to the improvement of pozzolanic activity cause by grinding and the increase of the outer surface of SSA particles. These results show that the application of mechanical grinding to adjust SSA fineness was an effective modification to improve SSA mortar properties.

Dunster (2007) gave the characterisation data and the trial results to make aerated concrete with ash. He indicated that ISSA could be suitable for use in aerated concrete ISSA is only expected to be considered for use in aerated concrete products if alternatives are not available or un-economic.

Martin, Marie and Pierre (2007) observed that the heavy metals of SSA probably affected the cement hydration and so the setting time of the mortars. Results obtained from Vicat needle and calorimetric measurements showed delays in setting and hydration of 1 h and 30 min and 3 h for 25 and 50% SSA, respectively. The compressive strength development of mortars at early ages was also affected. The environmental impact of SSA used in mortars was checked by means of leaching tests. It was shown that the leaching behaviour of mortars containing SSA was of the same order of magnitude as the reference mortar without residue. However, it must be kept in mind that more environmental tests must be performed before any large scale use is undertaken.

Sludge Pellets

Possibilities of the reusing of SSP in the concrete manufacturing for pavements and their use as raw material in cement production, concrete, blocks, and aggregates have been analysed by many authors. Kato and Takesue during their research in 1984 produced fine lightweight aggregate from pelletized pulverized sludge ash fired at 1,050°C. Bhatty and Reid in1989, developed a range of artificial aggregates from incinerated sewage sludge ash in both pelletized and crushed form, reported that expanded lightweight aggregates can be obtained through sintering at 1,050–1,110°C. Yip and Tay (1990) in the development of coarse and fine lightweight aggregates found that the aggregates displayed thermal insulation and fire protection benefits. Khanbilvardi and Afshari (1995) also obtained successful results in the use of sludge ash as fine aggregate in concrete.

Adsorption: Research done by Garcia, Cruz and Ortiz (2006) showed that the water treatment plant sludge can be used as an adsorbent to remove zinc from waste water after pelletilization. The WTP sludge was mixed with different binders for pelletization, the cement and bentonite clay shows the better binder properties to be used on WTP sludge pelletization process. The WTP cement pellets were used to manufacture the fixed bed and the study of the downflow and upflow adsorption process. Literature reviewed by Smith, 2009 has determined that sewage sludge is a highly promising feedstock for the production of adsorbent, and its conversion represents an attractive alternative to existing adsorbent disposal and reuse routes. However, the properties of the adsorbent have been shown to be heavily dependent upon both the production/conversion method and the nature of the sludge itself. Fang, 2010 studied the sewage sludge pellets and observed that the carbonaceous adsorbent presented higher dynamic adsorption capacity than activated carbon. The adsorption data were fitted to the Langmuir adsorption model. The physical and chemical adsorption was identified on the adsorbent.

Light weight aggregate: Cheeseman and Virdi (2005) showed spherical pellets of sintered SSA rapidly fired in a rotary furnace has properties comparable to Lytag, a leading commercially available lightweight aggregate. Sintering SSA at 1060 æ%C produced pellets with mean densities of 1.35 g/cm^3, a water absorption of approximately 8% and comparable crushing strengths to Lytag. The effect of increasing the clay addition to SSA had negligible effect on sintered properties. Lightweight pellets could be formed either using a clay or 1 wt.% addition of an organic binder

The study done by Kuan, Duu and Sze (2005) indicated that it is possible to promote the development of lightweight property in artificial aggregates through careful control of firing temperature and mix proportion of the raw materials. Although the chemical composition of sludge itself does not lie within the projected good bloating area as marine clay alone is a good bloating material, a mix with 50% sludge and 50% clay exhibited a better bloating potential compared with pure clay material.

Tay (2002) revealed that the sintered aggregates of all sludge-clay combinations met the AIV requirement for use in concrete for normal purposes, and combinations of up to 80% clay content satisfy the requirement for use in concrete pavements and similar surfaces in accordance with the standards. The compressive strength test results revealed that sintered aggregates, of all sludge-clay combinations, are most capable of producing concrete of structural grade having compressive strengths ranging from 20 to 40 N/mm^2. Pellets of 100% sludge displayed a good concrete compressive strength equivalent to that of normal granite concrete.

Sludge as Bio Cement and Eco Cement

Tay (1994) come with the mixture of sludge and limestone at equal amount by weight fired at 1000^{o}C for 4 hours produces the biocement for adequate strength for general masonry work. The compressive strength test results indicate that upto 30% by weight of the Portland cement can be replaced by the biocement without deteriorating the strength. The blended cement upto 10 % replacement level shows slightly higher strength than the control strength, as well as indicating higher rate of strength development at early stage.

From the results of chemical analysis, XRD, compressive strength and TLCP tests of the water purification sludge, Hu Xing Chen found it feasible to use as a substitute of siliceous material in cement production. The heavy metals (Cr, Cu, Ni, Pb, Zn) in WPS were almost completely incorporated into clinkers, and the heavy metals were not detected in the leachates up to 28 days. They showed that WPS contributes positively to compressive strength during days. Therefore, the amounts of WPS should have an appropriate value, which is between 4% and 7% in their study.

Stabilization of Sludge

P.Samaras, Papadimitriou , Haritou and Zouboulis (2008) showed that , based on the physical–chemical parameters, the addition of fly ash to sewage sludge may be considered as an alternative sludge stabilizing agent, with or without the simultaneous presence of lime, representing an effective, environmental friendly management option for both solid by-products/wastes. However, low dosages of fly ash should be added to sewage sludge in order to produce a material with the appropriate properties in respect to the phytotoxicity and ecotoxicity effects.

Artificial Soil with Sludge

Reynold, Kruger and Rethman (1999) prepare one artificial soil by utilizing sewage sludge, fly ash and lime and give it the name SLASH. They found that SLASH showed an immense potential for agricultural application. SLASH is devoid of pathogens and can either be safely disposed in land or preferably used as soil ameliorant. This research confirms the use of fly ash as an ingredient in the pasteurization of toxic wastes like sewage sludge. Depending upon the environmental requirement of the regulatory authorities, this technology can be applied, not only to provide an innovative conduit for ash utilization but a safe and cost effective means for the disposal of sewage sludge.

CONCLUSIONS

The implementation of the directives will increase the sludge production in the near future. Yet there are solutions for a safe and acceptable disposal of them. From the above literature review the following conclusions can be drawn to provide sustainable solution for the sludge disposal. There are various alternative routes to utilise the drinking water and sewage treatment plants sludge.

1. Using sludge as a fertilizer is not permissible if harmful microorganisms are present. Final disposal in landfill sites is not the solution due to space constraint.

2. For the reuse of SSA in practical mortar production, addition of plasticizing agents is recommended. The positive influence on mechanical strength when SSA replaces 15 or 30% of Portland cement.

3. The granulometric properties of dried sludge mean that it can be used as fine sand in production. Water purification sludge can be utilised in 4-7% for the production of cement comparable to the control samples.

4. It is feasible to use water purification sludge (WPS) as a substitute of siliceous material in cement production. Up to 7% of WPS can be utilized.

5. Sewage sludge ash can replaces 30% of cement. On the other hand incineration of sludge causes air pollution and is uneconomical in countries like India. Need of the time is to utilized sludge as it is rather than converting it into ash.

6. Maximum of 20% sewage sludge can be utilized for soft mud bricks.

7. For mortar it is feasible to utilized 30% of sludge from water and sewage treatment plants and in soil stabilization process water purification sludge can be used up to 10%.

8. Sewage sludge is a highly promising feedstock for the production of adsorbent, and its conversion represents an attractive alternative to existing adsorbent disposal and reuse routes.

REFERENCES

Ahn Johng-Hwa, Seung Gu Shin, Byung-Cheol park and Seokhwan Hwang, "Comparision of municipal and coke wastewater sludges in disintegration and acidogenesis by microwave", Journal of Environmental Engineering, Vol 137, No 8, August 1, 2011.

A. Jamshidi, M. Jamshidi and N. Mehrdadi, "Application of dry sewage sludge in concrete mixtures", Asian Journal of Civil Engineering, Volume 13,No 3, 365-375, 2011.

Almir Sales and Francis Rodrigues de Souza, "Concretes and mortars recycled with water treatment sludge and construction and demolition waste", Journal of Construction and Building Materials, Volume 23, Issue 6, June 2009, 2362-2370.

Chen HuXing, Xianwei, HengJie Dai, "Reuse of water purification sludge as raw material in cement production", Journal of Cement & Concrete Composites Volume 32, 2010, 436–439.

Cheeseman C.R, G.S. Virdi, "Properties and microstructure of lightweight aggregate produced from sintered sewage sludge ash", Journal of Resources, Conservation and Recycling, Vol. 45, 2005, 18–30.

Deng-Fong Lin and Chih-Huang Weng , "Use of sewage sludge ash as brick material, Journal of Environmental Engineering, Vol. 127, No. 10, October, 2001.

Dunster Andrew M BRE, "Incinerated sewage sludge ash (ISSA) in autoclaved aerated concrete (AAC)", case study, Oct. 2007, Technological and environmental behaviour of sewage sludge ash (SSA) in cement-based materials.

Fang Ping, Chaoping Cen, Dingsheng Chen, Zhixiong Tang, "Carbonaceous adsorbent prepared from sewage slugde and its application for Hg^0 adsorption in simulated flue gas", Chinese Journal of Chemical Engineering, Volume 18, Issue 2, April 2010, Pages 231-238.

Gunn, A., Dewhurst, R., Giorgetti, A., Gillot, N., Wishart, J. & Pedley, S., "Use of sewage sludge in construction" CIRIA, C608, 2004, London.

Herek, L. C. S., Bergamasco, R., Tavares, C. R. G., Uemura, V. O., and Pancotte, L. P. (2005). "Study of the solidification/stabilization of textile sludge in ceramic material." Journal of Ceramites", Volume 10, Issue 4, 41–46.

Hospido Almudena, Marta Carballa, Maite Moreira, Francisco Omil, Juan M. Lema, Gumersindo Feijoo, "Environmental assessment of anaerobically digested sludge reuse in agriculture: Potential impacts of emerging micropollutants, Journal of Water Research, Volume 44, 2010, 3225-3233.

Kacprzak M., E. Neczaj, E. Okoniewska, "The comparative mycological analysis of wastewater and sewage sludge from selected wastewater treatment plants", Conference on Desalination and the Environment, Santa Margherita, Italy, 22–26 May 2005. European Desalination Society.

Kelley Reynolds, Richard Kruger and Norman Rethman, "Manufacture and evaluation of an artificial soil (SLASH) prepared from fly ash and sewage sludge", International Ash Utilization Symposium, Centre for Applied Energy Research, University of Kentucky, 1999.

Kuan-Yeow Show, Duu-Jong Lee, Joo-Hwa Tay, Sze-Yunn Hong, and Chao-Yu Chien "Lightweight Aggregates from Industrial Sludge–Marine Clay Mixes", Journal of Environmental Engineering, Vol. 131, No. 7, 2005.

Liew, A. G., Idris, A., Wong, C. H. K., Noor, M. J. M. M., and Baki, A. M. M., "Incorporation of sewage sludge in clay brick and its characterization", Journal of Waste Management, Vol. 22, Issue 4,2004, 226–233.

Maria P. Durante Ingunza , Anaxsandra C. L. Duarte , Rubens. M. Nascimento , "Use of sewage sludge as raw material in the manufacture of soft-mud bricks", Journal of Materials in Civil Engineering, Vol. 23, No. 6, June 1, 2011.

Martin Cyr, Marie Coutand, Pierre Clastres, "Technological and environmental behaviour of sewage sludge ash in cement based materials", Journal of Cement and Concrete Research, Vol. 37, 2007, 1278–1289.

Monzo J., J. Paya, M.V. Borrachero, A. Corcoles, "Use of sewage sludge ash (SSA) — cement admixtures in mortars", Journal of Cement and Concrete Research, Vol. 26, Issue 9 ,1996,1389–1398.

Monzo J., J. Paya, M.V. Borrachero, I. Girbe, "Reuse of sewage sludge ashes (SSA) in cement mixtures: the effect of SSA on the workability of cement mortars", Journal of Waste Management, Vol 23, 2003, 373–381.

N. Husillos Rodriguez, S. Martínez-Ramirez, M.T. Blanco-Varela, M. Guillem, J. Puig, E. Larrotcha and J. Flores, "Evaluation of spray-dried sludge from drinking water treamtnet plants as a prime material for clinker manufacture", Journal of Cement and Concrete Composites, Vol. 33, Issue2, 2011, 267-275.

N. M. Garcia, N. T. B. Cruz and N. Ortiz, "The development of pelletization process of the sludge obtained as solid waste on water treatment plant – WTP", Congress Brasileiro de Engenharia e Ciência dos Materials, 15 a 19 de November de 2006, Foz do Iguaçu, PR, Brazil.

Nuvolari, A. (2002). "Inertization of sewage sludge in soft-mud ceramic bricks: technological and environmental aspects." Doctoral thesis, Dept. of Civil Engineering, Universidad Estadual de Campinas, São Paulo, Brazil.

Pan S.C, D.H. Tseng, C. Lee, Influence of fineness of sewage sludge ash on the mortar properties, Journal of Cement and Concrete Research, Volume 33, Issue 11, November 2003, page 1749–1754.

Petavratzi Evaggelia, Scott Wilson, "Characteristics of mineral wastes, resources and processing technologies-integrated waste management for the production of construction material", case study, Oct. 2007.

Pinarli V., R.K. Dhir, et al., (Eds.), Sustainable Waste Management— Studies on the Use of Sewage Sludge Ash in Construction Industry as Concrete Material, Sustainable Construction: Use of Incinerator Ash, Thomas Telford, London (UK), 2000, pp. 415–426.

P. Samaras, C.A. Papadimitriou , I. Haritou , A.I. Zouboulis, "Investigation of sewage sludge stabilization potential by the addition of fly ash and lime", Journal of Hazardous Materials, 2008, Vol. 154, 1052–1059.

Show Kuan-Yeow, Duu-Jong Lee, Joo-Hwa Tay, Sze-Yunn Hong, and Chao-Yu Chien, "Lightweight aggregates from industrial sludge and marine clay mix", Journal of Environmental Engineering, Vol. 131, No. 7, July 1, 2005.

Smith K.M., G.D. Fowler, S. Pullket and N.J.D. Graham, "Sewage sludge-based adsorbent: A review of their production, properties and use in water treatment applications", Journal of Water Research, Volume 43, Issue 10, June 2009, pages 2569-2594.

S. Valls, A. Yague, E.Vazquez, and C. Mariscal, "Physical and mechanical Properties of Concrete with Added Dry Sludge from a Sewage Treatment Plant", Journal of Cement and Concrete Research, Vol 34, 2004, 2203-2208.

Tay Joo-Hwa and Kuan Yeow Show, "Innovative Civil Engineering Material from Sewage Sludge: Biocement and its Use as Blended Cement Material", Journal of Material in Civil Engineering, Vol 6, No. 1, Feb 1994.

Tay Joo-Hwa, "Bricks Manufactured from Sludge", Journal of Environmental Engineering, Vol.113, No. 2, 1987.

Thaniya Kaosol, "Reuse water treatment sludge for hollow concrete block manufacture", Journal of Energy Research Vol.1, Issue 2, 131-134, 2010.

Tay Joo-Hwa; Kuan-Yeow Show; and Sze-Yunn Hong, "Concrete Aggregates Made from Sludge-

Marine Clay Mixes", Journal of Materials in Civil Engineering, Vol. 14, No. 5, October 1, 2002.

Tsadilas .C. D., V. Samaras, P. Kazai, and J. Sgouras, "Fly ash and sewage sludge application on an acid soil and their influence on some soil properties and wheat biomass production" , 12th ISCO Conference Beijing 2002.

Zou Jin-Long; Ying Dai; Xiu-Juan Yu; and Guo-Ren Xu, "Structures and metal leachability of sintered sludge-clay ceramsite affected by raw material basicity", Journal of Environmental Engineering, Vol. 137, No. 5, May 1, 2011.