Effects of Using Arsenic-Iron Sludge in Brick Making

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Abstract

Leaching of arsenic from brick manufactured from arsenic and iron sludge has been investigated in this study. TCLP result shows that leached metal concentrations are far below the regulated TCLP limits and the quantities of metal leached from sludge are less than those from dried sludge. The results of Atterberg limits tests of moulded sludge-clay mixtures indicated that both plastic index and dry shrinkage decrease with an increasing amount of sludge in the mixture. Results of tests indicated that the sludge proportion and firing temperature were the two key factors determining the quality of brick. Increasing the firing temperature and decreasing the amount of sludge in the brick resulted in a decrease of water absorption. The appropriate percentage of sludge content for producing quality bricks was in the range of 15 to 25% by weight with a 15 to 18% optimum moisture content prepared in the moulded mixture and firing at 1000^{0}C for 6 hours. This study showed that arsenic and iron sludge could be used as brick material.

INTRODUCTION

The serious arsenic problem of Bangladesh has led to massive concerted efforts of Government, NGOs and donor agencies in mitigating the crisis.

Most of the focus has been on awareness building and the development of water treatment system removing arsenic from drinking water. The disposal of arsenic rich sludge generated from the treatment processes is one of the issues that have received little attention from the sponsors of the technologies and the users (Eriksen et al., 2001). Different treatment technologies are available at present, which may offer solutions to this menace. Among them arsenic removal by coagulation and co-precipitation (Alum Coagulation and Iron Coagulation) and sorption (Activated Alumina, Iron Coated Sand and Ion Exchange Resin) techniques are well-known systems. In arsenic affected areas where the contents of naturally occurring iron and or manganese in groundwater is high, one may be tempted to remove arsenic together with iron and manganese by using the co-precipitation technique. The precipitation (Iron-Manganese removal) process produces sludge with considerable arsenic content of up to 10% by weight. No proper disposal method for the highly toxic arsenic sludge waste has been developed yet. Uncontrolled disposal of the arsenic sludge may lead to the pollution of the surface water and ground water system and create serious problem for the environment. Different researcher like Pal (2001) emphasised on safe disposal of arsenic contaminated sludge.

There is a strong demand for environmentally safe reuse of and effective disposal methods for iron and arsenic contaminated sludge out of water treatment plant due to the increasing amount of sludge generated by the water treatment plants in Bangladesh. At present, 18 number of large scale Arsenic and Iron Treatment Plant are in Bangladesh. Each treatment plant generates about 60000-cft arsenic rich sludge in a year (DPHE, 2002). While landfills are commonly used for disposal of sludge in Bangladesh, rapid urbanization has made it increasingly difficult to find suitable landfill sites (Lin et al., 2001). At places, it is disposed off to nearby rivers or low laying areas, which is likely to pollute surface and groundwater.

As environmental regulations become more stringent and volume of sludge generated continues to increase, traditional sludge disposal methods are coming under increasing pressure to change. Incineration is costly and contributes to air pollution and landfill space is becoming scare. A possible long-term solution appears to be recycling of the sludge and using it for beneficial purposes. One technique that is available to treat hazardous waste is solidification that stabilizes and solidifies components of waste. The solidified product is disposed off to a secure landfill site or it can be recycled as construction material like bricks if it meets the specific strength requirement and can be shown to leach toxic pollutants within acceptable limits (Rahmat, 2001).

MATERIAL AND METHODS

Raw materials (Arsenic and Iron sludge) were collected from Manikganj Arsenic and Iron Treatment Plant. Upon collection, sludge sample was oven dried for 24 hours 105^0C. Basic physicochemical characteristics, including moisture content and pH were also analyzed. Heavy metal content i.e. Arsenic, Iron, Chromium and Lead was determined by acid digestion with a HNO_3: HCl volume of ratio of 1:3. The Toxicity Characteristics Leaching Procedure (TCLP) in accordance with USEPA Method 1311 determined toxic characteristics of sludge.

A clay sample of normal bricks was collected from Mirpur Ceramic and Brick manufacturing area. Upon collection, it was grind with a crushing machine. Because water content is an important factor affecting the quality of the brick, tests including Specific Surface Area (SSA) analysis, Atterbergs limits and AASHTO (1982) was conducted to obtain the plastic nature of the sludge-clay mixture and to establish the optimum moisture content (OMC) in the brick making process. Using this OMC, the mixtures with various proportions of sludge (5%, 15%, 25% and 50%) and clay was prepared in batches (3 samples for each proportion). After a 24 hours maturation followed by another 24 hours 105^0C oven-drying period, mixtures were heated in Carbolite heavy-duty electric furnace at the design temperatures of 950^0C, 1000^0C and 1050^0C respectively for 6 hours. Leaching test of all these burnt samples was carried out by TCLP (USEPA Method 1311) and Column Leaching procedures.

A total of 15 brick samples (length 12.25 cm, width 5.85 cm and height 3.81 cm) of sludge-clay mixture in varying proportion (5%, 15%, 25% and 50%) at OMC were prepared in the laboratory. A clay only mixture sample was prepared as a reference specimen. All these samples were heated in Carbolite heavy-duty electric furnace at the design temperatures of 950^0C, 1000^0C and 1050^0C respectively for 6 hours. The produced bricks then received a series of tests including firing shrinkage, weight loss on ignition, water absorption and compressive strength, to determine a suitable condition for producing qualified bricks. Flow chart of the experimental procedures for this study is shown in Fig.1.

RESULTS AND DISCUSSION

Sludge and Clay Characteristics

Experimental result shows that the sludge has a pH of 6.5, indicating that the sludge can be treated as neutral material. Moisture content of raw sludge is 901.89% and stabilized sludge is around 473.68%, which expose sludge as quick sand with poor bearing capacity. As shown in Table 1, arsenic content in raw sludge is almost double than that of stabilized sludge. Further it is observed that total arsenic concentration in both type of raw sludge is much higher than Environmental Protection Agency (EPA) hazardous waste concentration limit. Soil sample collected is observed to be dark brown, silty clay, high plastic and with no organic compound in it.

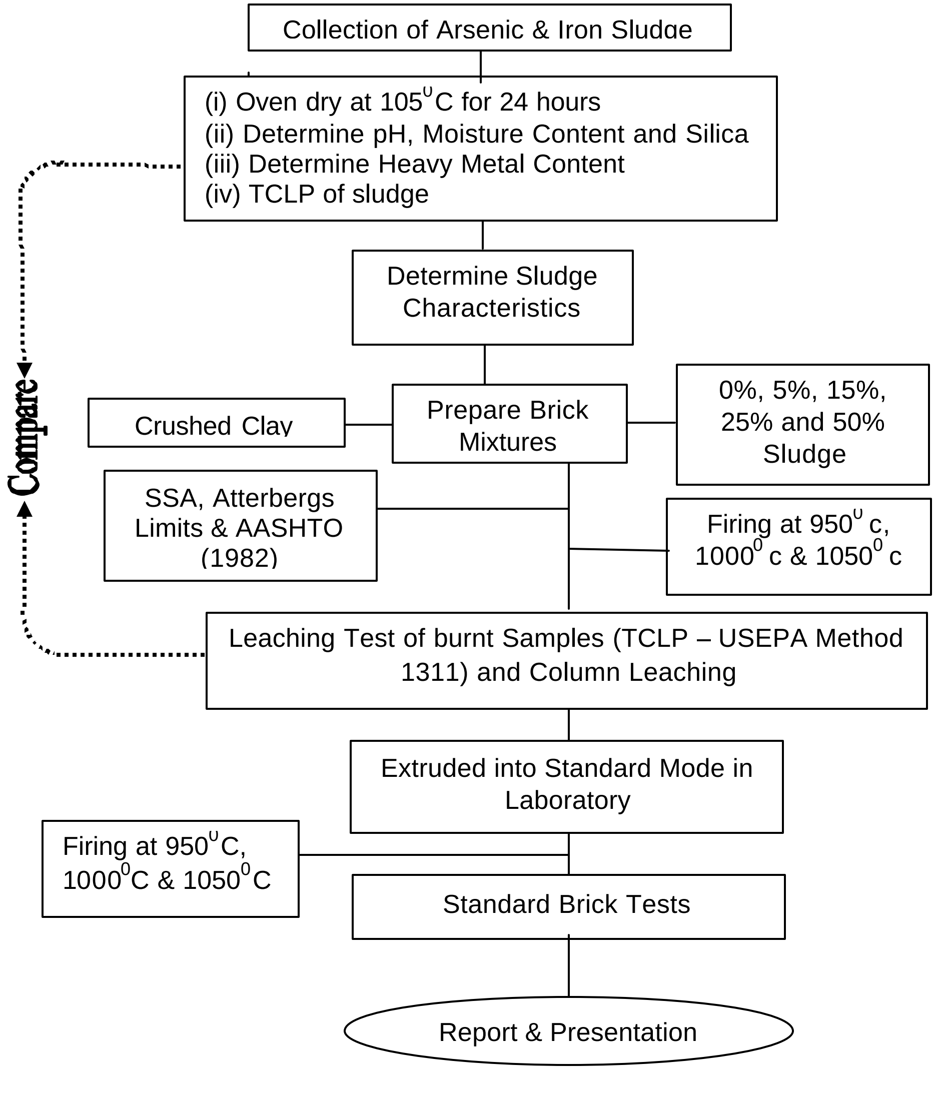

Figure 1: Flow-chart describing study methodology

Table 1: Heavy metal concentration in the sludge

Constituent	Concentration Present (mg/kg) (105^0 oven dry)
Arsenic[1]	1450.2
Arsenic[2]	2372.2
Leached Arsenic[1]	3.5588
Leached Arsenic[2]	2.1916
Iron[1]	123615.3
Iron[2]	161730.4
Lead[1]	0.018
Lead[2]	0.011
Chromium[1]	0.031
Chromium[2]	0.022

Note: 1 Stabilized sludge (from landfill site)
2 Raw sludge (from collection pond)

Toxicity Characteristic Leaching Procedure (TCLP)

The toxicity characteristic leaching procedure (TCLP) test is designed to identify wastes likely to leach hazardous concentration of particular toxic constituents into the groundwater as a result of improper management. During the TCLP, constituents are extracted from the waste to simulate the leaching actions that occur in landfills. If the concentration of the toxic constituent exceeds the regulatory limit, the waste is classified as hazardous.

The results of TCLP tests from Fig. 2 indicate that leaching of arsenic from original sludge is more than that from burnt bricks. Further it observed that leached arsenic from stabilized sludge is more than that from raw sludge. However leached arsenic content is less than hazardous concentration limit (5mg/kg). Further it shows that leaching decreases linearly with the increase of sludge mix and firing temperature. However, the decrease is prominent with 5% to 15% sludge mix. In the brick making process, the sludge and clay are all fired up to 950 to 1050^0C. At such temperatures, the formation of metal oxides minimizes the leaching of metals. As shown in the results of TCLP tests from Table 2, the quantities of arsenic leached from burnt sludge are all less than those from in the dried sludge. This can be attributed to the metal form (Fe) in the sludge that has been converted to oxides during heating at high temperature. Arsenic co precipitate with iron and a process of cementation occurs between these two substances.

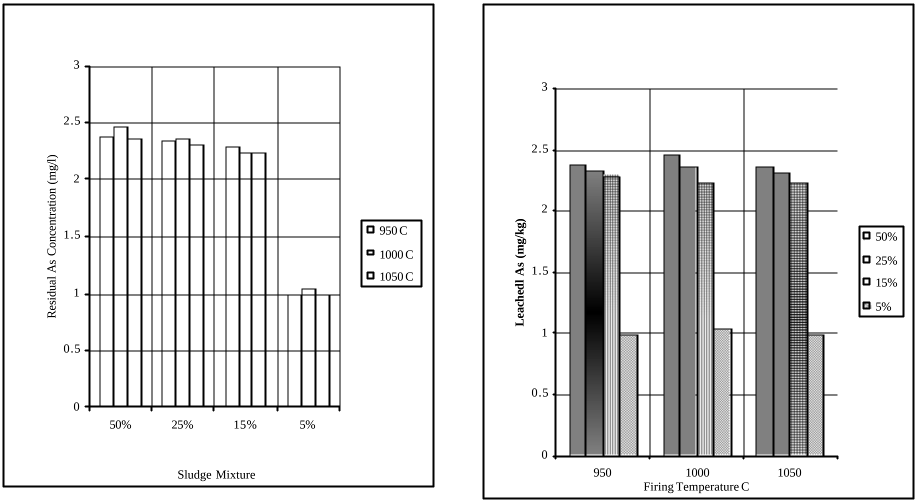

Figure 2: Effect of firing temperature and sludge mix on TCLP test results

Table 2: Result of TCLP tests of sludge and bricks samples

Mix Proportion (%)	Heating Temp. (^{0}C)	Leached As (mg/kg)	Mix Proportion (%)	Heating Temp. (^{0}C)	Leached As (mg/kg)
100[1]	105	3.558	25	1000	2.3668
100[2]	105	2.1916	15	1000	2.2384
50	950	2.3844	5	1000	1.0388
25	950	2.3376	50	1050	2.36
15	950	2.292	25	1050	2.3148
5	950	0.9864	15	1050	2.234
50	1000	2.4696	5	1050	0.996

Crushed burnt bricks sample were also leached through different media using vary extraction fluid e.g., tap water, rainwater, fluid containing anion bounds (PO_4^{3-}, SO_4^{2-}, NO_3^- and Cl^-). Range of pH values were maintained in between 6 to 7.5. The results of TCLP tests from Fig. 3 indicate that leaching of arsenic from burnt bricks sample varies in different media condition. Leaching of arsenic is more in rainwater than ground water. Further higher leaching is observed in case of fluids containing phosphate and chloride compared to those containing nitrate and sulphate.

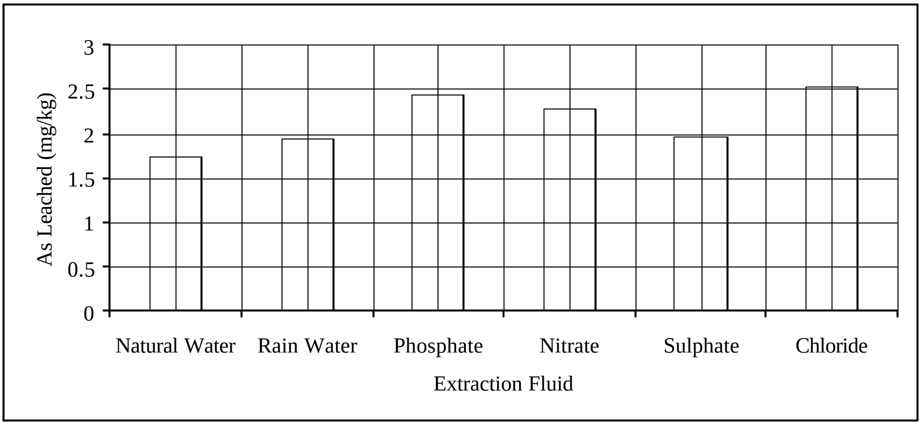

Figure 3: Results of TCLP tests performed with different extraction fluids

Column Leaching

Leaching is dependent on contact time, contact area and pH. Column leaching is aimed at carrying out leaching for longer period as long as waste constituent continue to leach. An endeavour has been made to prepare a column leaching plant with the help of available local materials by adopting improvisation technique. Fluids of varying composition are allowed to drip through 100 ml burette from 9-litre plastic water container placed at higher elevation on a table being connected by plastic tube. Burette is filled up with sludge and crushed burnt brick samples with filter arrangement at the bottom of burette made with stone chips comprising size 4,8 and 16. Extraction fluids are being collected at 6-litre water bucket placed beneath each burette. Solutions of anion bounds are prepared by trial and error mixing proportions with a view to adjust pH within normal range in between 6 to 7.5. Continuous flow of fluids is maintained by regular refilling of container in each week as and when necessary.

The results of column leaching tests from Fig. 4 indicate that leaching of arsenic from burnt bricks is much higher than that of original sludge at initial stage. However, leaching from brick samples sharply decreases and continue to decrease further as duration of leaching progresses. In case of leaching from sludge through different media, it is observed that leaching concentrations from sludge moves in a bandwidth as duration increases. However within the bandwidth leached arsenic concentration in extraction fluid containing PO_4^{3-} was maximum.

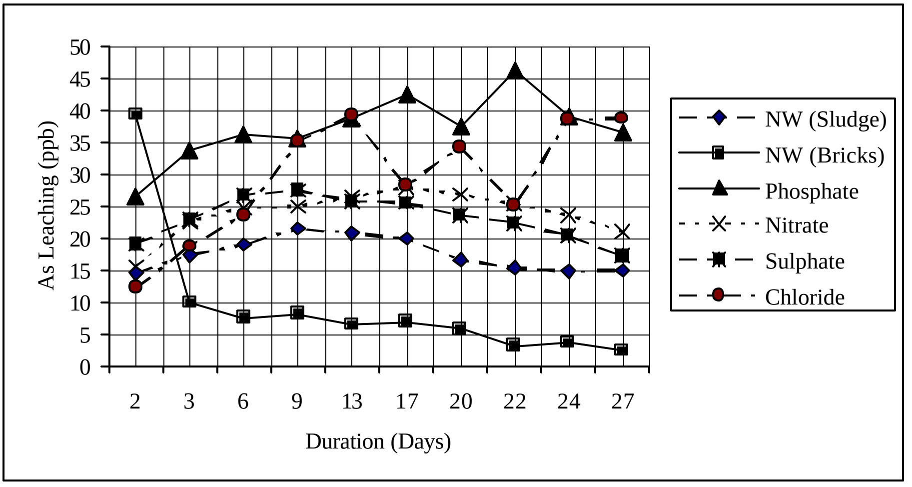

Figure 4: Results of column leaching

Cumulative amount of arsenic generated from column tests are shown in Fig. 5. It indicates that leaching from brick samples continue to increase, but at a much lower rate compared to that from sludge samples. As duration progresses, rate of increase of leaching (of arsenic) from bricks sample leads almost to negligible value and maintains a steady state. In case of leaching from sludge sample, it is observed that rate of increase of leaching for fluids containing PO_4^{3-} and SO_4^{2-} is much higher than compared to those containing NO_3^- and Cl^-.

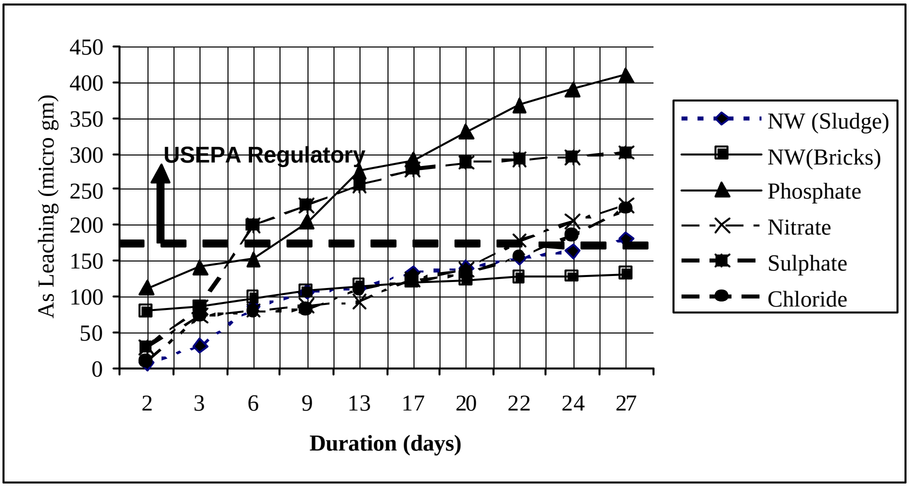

Figure 5: Cumulative arsenic leached from columns

Specific Surface Area (SSA) of Clay-Sludge Mixtures

The high SSA of the mixtures indicates the need for more water in the brick making process. The results of SSA obtained for the clay-sludge mixtures are shown in Table 3. As the amount of sludge is increased in replacement of clay, the SSA of that corresponding mixture increases proportionally. Table 3 also indicates that the overall particle fineness increases with the increasing percentage of sludge in the mixture.

Table 3: Effect of sludge proportions on specific surface area and plastic index of mixtures

Sludge Proportion (%)	Specific Surface Area (cm^2/g)	Liquid Limit (%)	Plastic Limit (%)	Plastic Index
0	5152	36.26	18.29	17.97
5	5225	39.54	22.86	16.68
15	5495	42.25	27.07	15.18
25	5906	47.08	34.65	12.43
50	6201	56.08	44.22	11.86

Atterbergs Tests

The effect of moisture on the plastic behaviour of the pulverized materials is evaluated by the Atterberg limits test. Normally, nonplastic soil has a plastic index (PI) value ranging from 0 to 5 and 15 to 30 for a low-plasticity soil. If the PI value is greater than 35, it is classified as having high plasticity. The results of Atterberg's tests of sludge-clay mixtures indicate that the value of PI is inversely proportional to the amount of sludge in the brick. A PI value of 17.97 for clay alone shows the clay can be classified as low–plasticity material. The PI values shown in Table 3 indicate that up to 15% of sludge can be applied to brick making without losing the plastic behaviour.

Compaction Test of Clay-Sludge Mixtures

In order to determine the OMC, which is an important factor affecting the properties of brick, a standard AASHTO compaction test was used in this study. The OMC of different mixtures was based on the moisture requirement in which maximum bonding among the mixture particles are retained. The results of AASHTO clay tests from Fig. 6, shows that OMC is directly proportional to the increases sludge mix in the brick and corresponding density is inversely proportional to sludge mix.

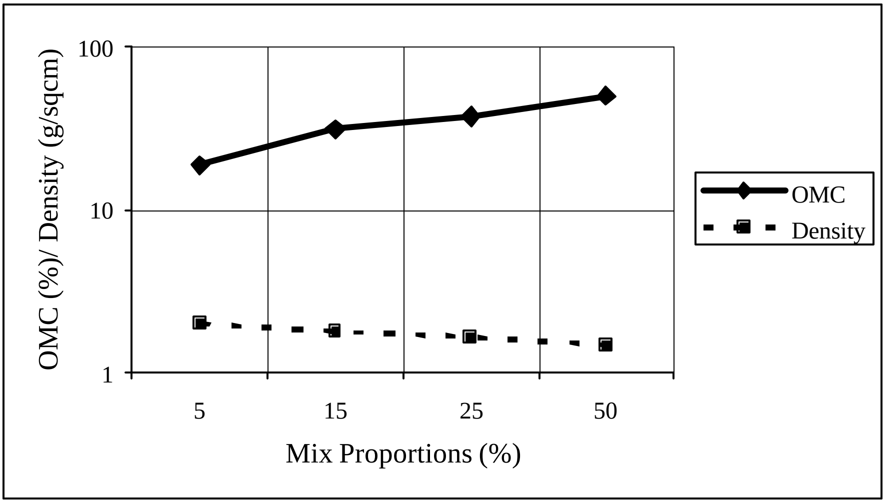

Figure 6: OMC and density of mixtures

Brick Firing Shrinkage

The quality of brick can be assured according to the degree of firing shrinkage. Normally a good quality brick exhibits shrinkage below 8%. As shown in Fig. 3, the percentage of shrinkage increases as the amount of sludge is added in the mixture increases. For a normal clay brick, the shrinkage is 8.42, 10.49 and 13.9 at firing temperatures of 950, 1000 and 1050^0C, respectively. Firing shrinkage increase rapidly up to 15% mix proportion. However, a linear relationship between the shrinkage and the sludge proportion is observed for 15 to 50% sludge added. Because the swelling of the clay is much lower than that of sludge, an addition of sludge to the mixture widens the degree of firing shrinkage. The firing temperature is another important parameter affecting the degree of shrinkage. As shown in Fig. 7, in general, increasing the temperature results in an increase in shrinkage.

Brick Weight Loss on Ignition

The brick weight loss on ignition is not only attributed to the organic matter content in the clay, but it also depends on the inorganic substance in both clay and sludge being burnt off during the firing process. In order to avoid the uneven surface texture of bricks, both sludge and clay was oven dried at 105^0C for about 24 hours. Upon drying these samples were crushed into powder and then mixed well in required proportion by weight. Fig. 8 shows a linear relationship between the amount of sludge to the mixture and the percent weight loss on ignition at all three temperatures. As shown, increasing the percent sludge resulted in an increase in brick weight loss. The weight loss on ignition criterion for a normal clay brick is 15% (AASHTO 1982). The bricks made for this study meet all weight loss criteria.

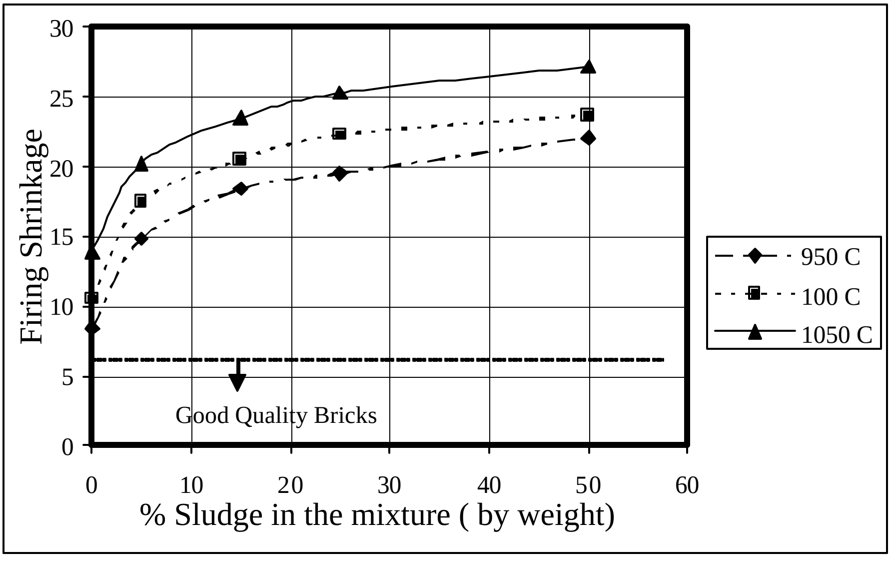

Figure 7: Firing shrinkage of bricks

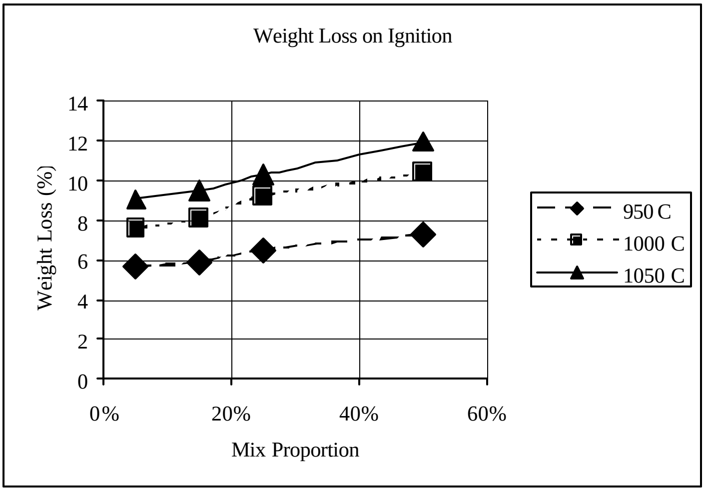

Figure 8: Weight loss on ignition

Density of Bricks

The bricks made with clay normally have a bulk density of 1.8 to 2.0 kg/cm^3. The measurements of bulk density for different proportions of sludge fired at three temperatures are demonstrated in Fig. 9. As shown, the bulk density of the bricks is inversely proportional to the quantity of sludge added in the mixture. A linear relationship between the bulk density and sludge proportion in the mixture for all three temperatures is observed. This finding is closely related to the quantity of water absorbed as demonstrated in Fig.10. When bricks absorb more water, it exhibits a large pore size than the one with less water absorption. As a result, the bulk density becomes smaller. The firing temperature can also affect the bulk density of the bricks. The results show that increasing the temperature results in an increase in bulk density.

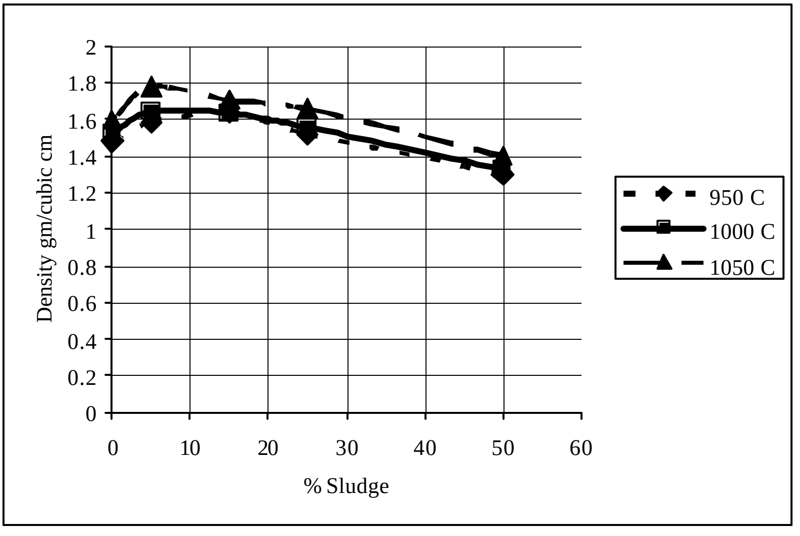

Figure 9: Density of bricks

Brick Water Absorption

Water absorption is a key factor affecting the durability of brick. The less water infiltrates into brick, the more durability of the brick and resistance to the natural environment are expected. The water absorption was determined by using the procedures described in ASTM C67-60 (1998). Fig. 6 shows the results of the water absorption tests for various sludge-clay mixtures fired at three different temperatures. As shown in Fig. 10, the value of water absorption is directly proportional to the quantity of sludge added. Increasing the firing temperature resulted in a decrease of water absorption, thereby increasing the weathering resistance. According to the criterion of water absorption of bricks in ASTM C67-87 (1998), the ratio is below 17% for first- class brick and 17 to 22% for second-class brick. According to this guideline bricks with 15% sludge burnt at 1000 to 1050^{0}C are first class category and bricks with 15% sludge fired at 950^{0}C fall within second-class category. Further, bricks with 25% sludge burnt at all temperature fall within second-class category.

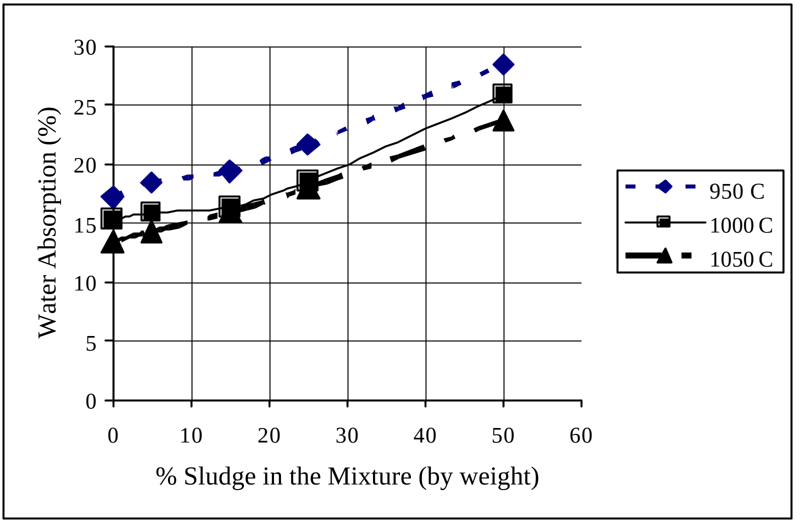

Figure 10: Water absorption of brick samples

Compressive Strength of Bricks

The compression test is the most important test for assuring the engineering quality of a building material. The results of the compressive strength test on the bricks made from both clay and sludge mixtures are shown in Fig. 11. The results indicate that the strength is greatly dependent on the amount of sludge in the brick and the firing temperature. Compressive strength of bricks decreases with increase of sludge mix in the bricks but increases with the increase of fifing temperature. As shown, with up to 25% sludge added to the bricks, the strength achieved at all temperatures can be as high as that of normal clay bricks. With up to 50 % sludge in the bricks at 1050^{0}C, the strength is even higher than that of normal clay bricks. The results indicated that the optimum firing temperature at which maximum compressive strengths occurred was 1000^{0}C for sludge mix up to 15% in the bricks. Beyond 15%, optimum firing temperature for maximum compressive strength was 1050^{0}C. The compressive strength of brick made from sludge –clay mixtures all meet

AASHTO standards for brick requirements: 150 kg/cm^2 for a first-class brick. It is concluded that arsenic and iron sludge can be blended with clay in different proportions to produce a good quality brick under a certain temperature.

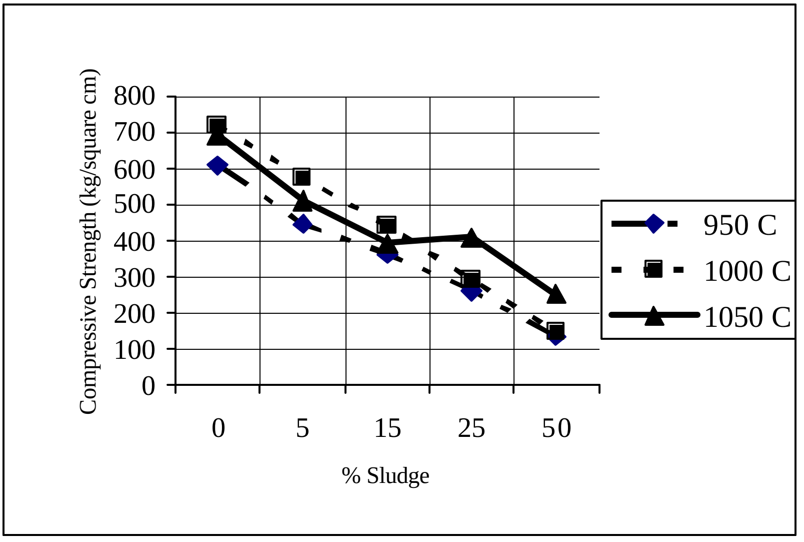

Figure 11: Compressive strength of bricks

CONCLUSIONS

This work has demonstrated a feasible way of using arsenic and iron sludge as a clay substitute to produce quality bricks. Different measurements of both clay-sludge mixture and bricks were carried out to evaluate the factors that could affect brick quality.

Arsenic content in the raw sludge was found to be almost double than that present in stabilized sludge. However, in case of leaching it was seen that leaching of arsenic was more in case of stabilized sludge. TCLP test of sludge indicated that leaching of arsenic from sludge is more than that of burnt bricks. Though TCLP result of both sludge and burnt bricks don't indicate it as hazardous waste but leaching values are far more than drinking water arsenic concentration. Increasing the firing temperature resulted in decrease in leaching of arsenic. However, leachate concentration at varying temperature indicates it to be independent of temperature and mix proportion down to 15% since TCLP simulates the leaching actions that occur in landfills. Arsenic co precipitate with iron during water treatment and process of cementation occurs between these two substances. This can be attributed to the metal form (Fe) in the sludge that has been converted to oxides during heating at high temperature.

Leaching of arsenic from column tests indicate higher leaching of arsenic from brick sample at initial stage, indicating leaching of residual free arsenic content present in bricks. However, with progress of time leaching of arsenic decrease sharply and maintains a steady state indicating very negligible leaching. Apart from bricks sample leaching of arsenic from sludge in different media progresses in a bandwidth. Within the bandwidth, extraction fluids containing phosphate and chloride produced higher leaching. Analysis of flow rate of extraction fluid and its arsenic concentration suggest that leaching is dependent on contact period. Leaching of arsenic from column tests were found to be significantly higher than that from TCLP tests.

The results of compressive strength tests on the bricks indicate that the strength is greatly dependent on the amount of sludge in the brick and the firing temperature. The optimum amount of sludge that could be mixed with clay to produce good bonding of bricks was 15% by weight firing at 1000^0C. With up to 25% sludge added to the bricks and fired at 1050^0C, the strength can be as high as that of normal clay bricks. The compressive strength of bricks made from sludge–clay mixtures all meets the BDS 208 (1980) brick standard.

Increasing the amount of sludge in the clay, the SSA of that corresponding mixture increases proportionally. As a result, the overall particle fineness and water requirement for mixing increase with increasing percentage of sludge in the mixture. Increasing the amount of sludge added in the mixture results in a decrease in its plastic behaviour.

The brick manufactured did not show any deformation or uneven surfaces occurring at all firing temperatures with OMC applied in the mixtures of varying proportions. Increasing the firing temperature and decreasing the amount of sludge in the brick resulted in a decrease in water absorption.

In order to yield a good quality brick, the proportion of sludge and the firing temperature are the two key factors controlling the shrinkage in the firing process. Firing shrinkage increase rapidly up to 15% mix proportion. However, a linear relationship between the shrinkage and the sludge proportion was observed for 15 to 50% sludge added. A good quality brick can be produced under the following conditions fewer than 15% sludge used and fired at 1000^0C.

Increasing the percentage off sludge resulted in an increase in brick weight loss. The bricks made for this study all meet the criterion of 15% weight loss on ignition for a normal clay brick. The bulk density of brick was seen to be inversely proportional to the quantity of sludge added in the mixture. This finding was closely related to the quantity of water absorbed in the brick. When bricks absorb more water, it exhibits a large pore size than one with less water absorption. As a result bulk density becomes smaller.

In all, the recommended proportion of sludge in brick making is 15 to 25% and fired at 1000 to 1050^{0}C to produce a good quality brick. We revealed that addition of sludge up to 25% retain the original characteristics of normal clay bricks. Further, leaching of arsenic is largely reduced when sludge mix is burnt at high temperature in the brick making process.

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