The utilisation of sewage sludge in the manufacture of clay bricks†

JA Slim* and RW Wakefield
City Engineer's Department, PO Box 7, Port Elizabeth 6000, South Africa

Abstract

The dewatered sewage sludge produced at the Fishwater Flats Water Reclamation Works in Port Elizabeth has for a number of years been successfully used in the manufacture of clay bricks on a commercial scale. This paper describes the processes employed in the manufacture of these bricks, their quality, and the considerable benefits to both the brick manufacturer and the local authority.

Introduction

The clay brick has been used as a constructional and architectural unit for several millennia. Excavations at Ur of the Chaldees, the city of Abraham, revealed clay bricks inscribed with details of life some 6 000 years ago and the Old Testament indicates that the Tower of Babel was constructed of brick:

> "They said to one another, 'come let us make bricks and bake them in the fire' — for stone they used bricks, and for mortar they used bitumen" (Genesis 11:3).

The ancient Egyptians realised that the addition of chopped straw to the wet clay improved the structural strength of the product, and since that time other additives such as shale and broken brick fragments have been used to improve both strength and durability.

In an endeavour to reduce the energy demand for the firing of raw bricks the calorific value of several organic substances, generally regarded as waste products e.g. sawdust, coal dust and waste oil, has been utilised by adding them to the clay. With proper use these products can also result in the production of bricks with enhanced mortar adhesion properties due to the presence of interstitial voids created by the combustion of these organics (Alleman and Berman, 1984).

In 1899 Thomas Shaw of Manchester, England, patented the process of using sewage sludge as just such an organic supplement in brick manufacture (Fig. 1); however, the authors have been unable to discover any record of the process being used in practice until 1984 when Alleman and Berman reported on the production of "Biobricks" in the United States of America. In 1987 Joo-Hwa Tay published details of similar work carried out in Singapore at the Nanyang Technical Institute. Prior to this however, in 1979, development work commenced independently in Port Elizabeth, resulting in the full-scale production of bricks incorporating sewage sludge.

Sludge production

The Port Elizabeth Municipality's Fishwater Flats Water Reclamation Works, commissioned in 1976, is currently receiving 68% of its design flow of 112 Mℓ of sewage per day. The sewage is of medium to high strength, having a COD of from 1 000 to 1 500 mg/ℓ, and after reception and preliminary treatment, is settled in primary sedimentation tanks prior to secondary treatment by a conventional activated sludge process. Most of the purified effluent is discharged into the adjacent Indian Ocean; however, part of it, following tertiary treatment by sand filtration and further chlorination, is supplied to local industries for use as a process and irrigation water.

Primary sludge is de-gritted and thickened in two continuous flow circular tanks. Surplus activated sludge is pumped directly into 2 separate identical thickening tanks. The thickened sludge withdrawn from the 4 tanks is then blended in approximately equal volumes, before passing through in-line macerators to the heat-treatment plant.

The heat-treatment plant employs the Zimpro wet air oxidation process and comprises 2 identical streams each designed to treat 33 t of dry solids per day in a continuous operation. The sludge in admixture with compressed air is raised to a temperature of 187°C using steam in a reactor operating at a pressure of 2 200 kPa. The combination of temperature and pressure sterilises the sludge and greatly improves its dewatering characteristics.

Following further gravity thickening the sludge is transferred by pumps to centrifuges for final dewatering. Four centrifuges are installed, 2 rated at a capacity of 20 m^3/h, and 2 at 10 m^3/h. Each is fitted with in-line chemical dosing equipment and consumption of polyelectrolyte is 0,6 kg per ton of dry solids processed.

At present approximately 45 t of dewatered sludge are produced daily. The average composition of this sludge is given in Table 1.

Disposal of dewatered sludge

The initial concept in the design of the Fishwater Flats Works was to treat and dispose of the sludge on site, which necessitated the use of incineration (Slim, 1977). Of the two types of incinerator considered the fluidised bed type was chosen as, at the time, the capital cost was lower than that for the alternative multiple hearth furnace.

The incinerator installed was a Dorr Oliver Fluo-solids reactor having a capacity of 76 t of dry solids per day at 35% dry solids in the feed sludge, operating at temperatures between 750°C and 800°C.

As daily sludge production was considerably less than the design capacity of the reactor, insufficient heat was produced by the combustion of the sludge to maintain the required fluidised bed temperature without the addition of diesel oil as a supplementary fuel. At present day prices the cost of fuel required to operate this incinerator is estimated to be in the order of R2 000 000/a.

As a result of difficulties experienced in maintaining continuous operation, breakdowns, and rapidly escalating fuel prices, it was decided, early in 1979, to shut down the incinerator and initially to dispose of the centrifuge sludge as a landfill on site and subse-

---

†Revised paper, originally presented at Symposium on Sludge Handling, 15 November 1988, Pretoria.
*To whom all correspondence should be addressed.
Received 8 August 1990; accepted in revised form 21 February 1991.

N° 12,623 A.D. 1889

Date of Application, 10th Aug., 1889—Accepted, 2nd Nov., 1889

COMPLETE SPECIFICATION.

Improvements in Utilizing the Waste Product from Sewage Works for the Manufacture of Bricks, Tiles, Quarries, Building Blocks, Slabs, and the like.

I Thomas Shaw of No. 46 Mode Wheel Road, Weaste near Manchester in the County of Lancaster Engineer do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The object of this invention is to utilize the sludge, sediment or waste product from the precipitating tanks of sewage works, to form bricks tiles, quarries, slabs, blocks or other similar solid forms for building and other purposes.

The sewage as pumped up or otherwise taken in a liquid state from the sewers is ordinarily mixed with lime and other ingredients and is left to settle in the precipitating tanks; the solid refuse matter settles to the bottom of the tanks in the form of sludge and the supernatant clear liquid (comparatively pure water) is allowed to flow away either back again into the sewers or into a brook, river, or other water course, being limpid, inodorous, and otherwise innoxious.

The precipitated sludge has to be removed from the tanks from time to time and hitherto it has been considered as a valueless waste product, the accumulation of which has been a great drawback to the adoption of the precipitating system at sewage works.

This waste product or sludge contains various ingredients more or less valuable, and I have discovered that by mixing the said refuse with common clay a plastic composition may be obtained which possesses valuable properties and is capable of being moulded into the shape of bricks, tiles slabs, blocks or other similar solid forms, and after drying and burning in the ordinary manner is suitable for utilization for building and other purposes.

According to my invention I take the sludge or refuse from the sewage precipitating tanks and I add thereto about an equal quantity of common clay, and these ingredients I mix well together by means of any suitable machine such for instance as an ordinary pug mill.

The material if too wet is then semi-dried and afterwards forced into or through dies in the ordinary manner of making bricks tiles slabs or similar articles from clay or other plastic materials; which when subsequently dried and burnt in the usual manner will be found to possess valuable qualities such as hardness durability and color far superior to ordinary bricks and other articles made from clay alone, and may be used with advantage in place of the latter for building and for a variety of other useful purposes as a substitute for ordinary clay.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed I declare that what I claim is:—

The utilization of the sludge or waste product, from the precipitating tanks of sewage works, by mixing therewith about an equal quantity of clay and forming from the mixture or plastic composition thus obtained bricks, tiles, slabs, blocks or other similar articles which when dried and burnt are suitable for building and other useful purposes.

Dated this 9th day of August 1889.

GEORGE DAVIES,
4, St. Ann's Square, Manchester, Agent for the Applicant.

London: Printed for Her Majesty's Stationery Office, by Darling & Son, Ltd.—1889.

Figure 1
Patent for use of sludge in brick manufacture

TABLE 1
COMPOSITION OF HEAT-TREATED DEWATERED SLUDGE

	Heat-treated sludge (1986-88)		
	High	**Low**	**Average**
Total solids %	43,0	31,7	35,2
Ash content %	35,4	13,6	21,7
Calorific value MJ/kg	-	-	16,77
Total nitrogen (N) %	3,6	2,3	2,8
Total phosphorus (P) %	2,4	0,5	1,0
Potassium (K) %	0,23	0,09	0,18
Magnesium (Mg) %	0,38	0,14	0,24
Calcium (Ca) %	2,38	0,65	1,36
Sodium (Na) %	0,14	0,06	0,09
Iron (Fe) %	1,41	0,45	1,03
Zinc (Zn) mg/kg	1535	651	1153
Lead (Pb) mg/kg	1936	231	750
Chromium (Cr) mg/kg	3141	366	1877
Copper (Cu) mg/kg	287	133	210
Nickel (Ni) mg/kg	48	28	37
Manganese (Mn) mg/kg	165	88	125
Cadmium (Cd) mg/kg	2,8	0,6	1,7
Cobalt (Co) mg/kg	5,0	0,6	2,5

All results, except total solids, are expressed on dry solids

quently by transporting it to a sludge tip some 11 km from the works.

Early in 1981 2 local farmers expressed interest in the use of sludge from the works, one to improve the poor quality pasture on his sandy coastal land, and the other to enhance turf production. Following normal tendering procedures agreements were entered into between the City Council and the farmers for the removal of the total production of sludge from the Fishwater Flats Works for a period of 2 years. The success of both of these applications has been reported by Vail and Devey (1984).

During 1979, when sludge was being used as a landfill on the sewage works site, there were occasions when it caught fire. The owner of a local brickworks saw one of these fires and with the knowledge that certain brickmakers in the Transvaal added coal dust, or 'duff', to their clay in order to reduce fuel costs in the firing process, realised that there could be a similar fuel value in sludge. On request he was given a quantity of sludge for experimental purposes.

Brickmaking

Initial trials

Initially small quantities, in the order of 5% by volume of sludge, were mixed with the clay from which batches of bricks were made using the normal production methods. Over a period the proportion of sludge was gradually increased, but it was found that at levels of sludge above 45% problems were experienced with both distortion and cracking of the bricks and control of kiln temperatures. However, at approximately 30% sludge the bricks were of the manufacturer's normal standard and appearance, temperatures were controllable, and substantial fuel saving were indicated.

Although the kiln used in the process was fired mainly by heavy furnace oil (HFO), supplementary fuel in the form of sawdust and waste rubber was added. As the sludge had an obvious fuel value it was also tried as a direct additive into the kiln. Although it burned well, the sludge produced excessive amounts of ash which built up on the rail track in the kiln causing uneven trolley movement and resultant brick fractures. For this reason the use of sludge as a direct additive to the kiln was abandoned.

By early 1983 enough experience and confidence in the use of sludge had been gained by this brick manufacturer and when the Council again called for tenders he was awarded a contract to take the entire output of sludge from Fishwater Flats for a period of one year, with an option for a second year. This option was subsequently taken up and was followed by a further contract awarded in 1985 for a period of 5 years.

Removal of sludge from site

Dewatered sludge is discharged from the centrifuges onto a belt conveyor which delivers it to a covered storage area from which it is loaded by means of a front-end loader into high sided tipping lorries and transported to the brickworks 15 km away.

Because of the high solids concentration and granular nature of the sludge no special modifications have had to be made to the loadbeds of the vehicles to prevent spillage and the material is free-tipping.

On delivery to the brickworks it is either used immediately or stockpiled. Both loading and transportation of the sludge is the responsibility of the brickmaker.

Brick production

The clay used is a grey marine deposit of the Sundays River formation. Clay winning from the quarry is performed with self-elevating scrapers which transport the material to the clay store at the head of the process.

Sludge and clay are blended from variable speed box feeders, equipped with rotating tines, discharging onto a conveyor.

Currently 30% by volume of sludge is added to the clay for the production of stock bricks (commons), and between 5% and 8% for face bricks. Recent tests conducted on the face bricks indicate that this percentage can be considerably increased without affecting their quality.

The mixture of clay and sludge is conveyed to the crushing plant where it first passes through a disintegrator which reduces the lumps of clay into fragments of less than 12 mm in diameter. This is followed by a high speed roller mill which further reduces the fragments to a grain size not exceeding 2,5 mm diameter.

The crushed clay and sludge then pass to a double-shafted mixer where it is kneaded into a homogeneous mass after the addition of water to give the 20% moisture content required for the extrusion process. The amount of water added is dependent on the original moisture content of the mixture. Without the addition of sludge the water required is in the order of 280 ℓ/1 000 bricks. When stock bricks are being manufactured the sludge eliminates the need for any additional water.

The clay mix is then extruded through a metal die to produce a continuous column of the required cross section and pattern. This is guillotined into 'slugs', 1,15 m long, which are in turn sliced by wires to produce 15 bricks of conventional height.

These 15 'green' bricks are then set on laths which are in turn placed in rows of 5 and stacked 10 high on mobile transfer trolleys which transport them to the air-drying area.

Air drying takes place under cover at ambient temperatures for a period of approximately 2 weeks or by drying in heated chambers where the bricks remain for 48 h at an average temperature of between 60° and 65°C. There are 18 chambers, each having capacity for 10 000 bricks. The dried, unfired bricks are then removed from the trolley and transferred by conveyor belt to the setting station where they are stacked on tunnel kiln cars ready for firing.

The tunnel kilns used at this works are straight, ceramic lined chambers of rectangular cross section, 1,8 m high by 2,2 m wide, and approximately 100 m in length having a steel door at each end.

From the setting station the loaded kiln cars are pushed on rails through the kiln by means of a hydraulic ram. They first enter a pre-heating zone ahead of the kiln door, where they are heated to approximately 100°C by means of hot exhaust air drawn from the kiln. This causes some of the moisture still remaining in the brick to be removed.

The trolleys are indexed forward in increments of 1,3 m every hour when using clay alone, at which speed the journey through the kiln takes some 76 h. However, it has been found that the frequency of indexing, and hence the throughput, can be almost doubled when using sludge in the clay. This is directly attributable to the fuel value of the sludge.

With each trolley movement the kiln door automatically opens, allowing one stack of bricks to enter the heating zone which forms the initial stage in the firing process. Here the remaining moisture in the brick is removed and at a temperature of about 150°C the organic matter in the sludge begins to burn. This causes a rapid increase in temperature up to 800°C which is reached at a point some 18 m into the kiln. By this point the sludge has been completely burned and the temperature gradient decreases over the next 35 m until the firing zone is reached.

Fuel in the form of HFO is injected through overhead nozzles over a distance of 5 m in order to raise the temperature to 960°C, required for the vitrification of the clay. When no sludge has been added to the clay, 80 ℓ of HFO are required to provide sufficient heat for the firing of 1 000 bricks. The addition of sludge has reduced this requirement to 25 ℓ per 1 000 bricks, and it is anticipated that this figure can be further reduced to 10 ℓ per 1 000 bricks by a small increase in the percentage of sludge added.

After firing, the bricks move into the cooling zone where, over a distance of some 25 m, the temperature is slowly reduced to 600°C in order to avoid cracking. The rate of cooling is then increased by air which is blown into the kiln and the bricks exit at ambient temperature.

Air required for the firing is blown in at the exit end and is drawn out near the inlet end of the kiln.

A diagrammatic temperature profile of the firing process is shown in Fig. 2. The broken line illustrates the approximate temperature gradient before the use of sludge when the initial heating depended on the hot air flowing from the firing zone. The addition of sludge to the clay has considerably altered the temperature profile in the first half of the kiln, as shown by the solid line. This change in the temperature gradient has allowed brick production from the kiln to be increased by almost 100%.

Finally the bricks are removed from the kiln trolleys and conveyed to the stack yard ready for sale.

Properties of the bricks

The appearance of both face and stock bricks made from clay mixed with sludge is excellent, being uniform in colour and texture and free from extensive cracks. They are indistinguishable in both appearance and odour from conventional clay bricks.

The bricks conform to the nominal standard dimensions of 220 x 106 x 73 mm. Shrinkage occurs throughout the manufacturing

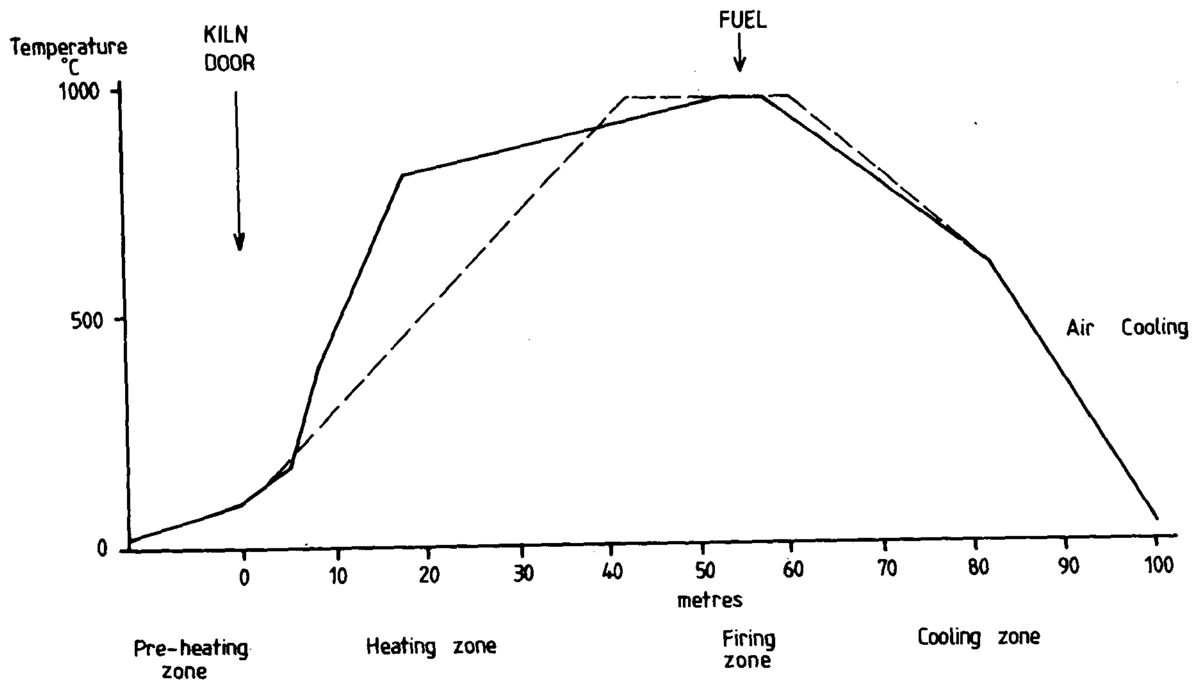

Figure 2
Kiln temperature profile

TABLE 2
TYPICAL VALUES OF PERCENTAGE SHRINKAGE IN SLUDGE BRICK VOLUME

	Face bricks	Stock bricks
After air drying	9,8%	11,1%
After firing	4,3%	3,6%
Total shrinkage	13,7%	14,3%

process and allowance for this is made in the extrusion stage. Typical values of percentage shrinkage in sludge brick volume are shown in Table 2.

The average weight of a stock brick made from 30% sludge/clay mixture is 2,36 kg, and a face brick containing 5% and 8% sludge weighs 2,60 kg. This compares with a 'conventional' stock brick which weighs 3 kg. The lighter weight of a 'sludge' brick provides obvious advantages in transportation costs and also makes the task of bricklaying less arduous.

In an effort to increase bricklaying productivity, certain manufacturers have produced a "Maxi-brick" with nominal dimensions of 222 x 90 x 115 mm. When these are made from a 30% sludge mix, they have the distinct advantage of only being 10% heavier than a conventional stock brick.

The average compressive strength, measured according to the method specified by the South African Bureau of Standards (SABS, 1986), was 40,7 MPa for the face bricks and 38,3 MPa for stock bricks. These figures show that the bricks easily comply with the SABS standard of 17,0 MPa and 14,0 MPa respectively. They also compare favourably with the results given by Alleman and Berman (1984) of 43,2 MPa, and Tay (1987) of 39,5 MPa for stock bricks manufactured with 30% sludge.

The degree of firmness and compaction of clay bricks, as measured by their water absorption characteristics, varies considerably depending on such factors as type of clay and methods of production.

The 24-hour water absorption test (SABS, 1986) gave average figures of 13,1% for the face and 14,2% for the stock bricks. These figures are some 30% higher than those obtained from similar locally made bricks which do not contain sludge. However, the absorption is not high enough to present problems in the use of the bricks and in fact is advantageous as it is considered that this will lead to better mortar adhesion.

Kiln stack emissions

Initially the flue gases from the kiln passed to a stack from which they were discharged into the atmosphere. As the production of bricks containing sludge increased the plume from the stack took on a dense white appearance and there was a definite irritating smell of 'burning' in the area. Heavy deposits formed on the inside of the stack and on occasions these ignited, causing serious fires at the top of the stack. On analysis this deposit was found to contain almost 60% NH_4Cl with the remaining 40% consisting of partially burned sludge and pyrolysis products.

Samples of the gas taken from the stack contained the following percentage volumes:

Hydrogen	0,01%
Oxygen	18,02%
Nitrogen	79,29%
Carbon monoxide	trace
Carbon dioxide	2,18%
Sulphur dioxide	trace

The plume also contained approximately 140 mg NH_4Cl/m^3 gas. Partially burned organic matter was also present.

In order to improve the quality of the flue gases, a sludge fired afterburner has recently been installed. This consists of a conventional underfed coal burner which has been modified to burn air-dried sludge (90% dry solids) taken from the stockpile. The sludge burns without any additional fuel. Ash falling from the hearth is removed by means of two screw conveyors.

Gases previously discharged directly to the atmosphere via the stack are now drawn by means of a large fan across the firebox of the afterburner, consisting of a refractory lined chamber 2,25 m diameter and 8,0 m long. The burning sludge raises the gas temperature to between 700° and 750°C after which it cools to approximately 180°C before being used to heat the brick drying chambers prior to discharge through the stack.

Since the introduction of the afterburner there has been a considerable improvement in the quality of the stack emission, organic matter has been completely eliminated and the NH_4Cl content has been reduced to approximately 7 mg/m^3.

Conclusions

Since full-scale production of bricks incorporating sludge began in Port Elizabeth in 1979, over 120 million "sludge bricks" have been produced. They are of good appearance, comply with the relevant standards regarding strength, and have been readily accepted by the building industry.

The use of sludge provides a number of advantages for the brickmaker, among these are:

- Savings on water consumption; at current production levels of 27 million bricks per annum, a saving of some 7 Mℓ of water per year is achieved.
- Savings on fuel consumption; this has been reduced by 69% with further reductions being anticipated.
- Reduction in transport costs; the reduced weight of the bricks allows more to be carried on each vehicle load.
- Increased kiln throughput; the fuel value of the sludge contained in the brick has effectively extended the firing zone within the kiln, resulting in an increase in the throughput by almost 100%.
- Provision of heat for drying; sludge burned in the afterburner provides a very cheap source of heat for the drying chambers.

For the Municipality, the use of sludge in brick manufacture provides a cheap, safe, and trouble-free method of disposal.

The development of the use of sludge in brickmaking has led to a viable commercial manufacturing process which is an example of the close co-operation and liaison which can exist between a public authority and a private industrial undertaking, to their considerable mutual benefit.

Acknowledgements

The authors wish to thank the City Engineer and City Council of Port Elizabeth for permission to publish this paper.

They also wish to sincerely thank Messrs Eric and Wout Offerman, directors of the Algoa Brick and Tile Company of Port Elizabeth, for their enterprise and enthusiasm in the conception and development of the process described in this paper.

References

ALLEMAN, JE, BERMAN, NA (1984) Constructive sludge management: Biobrick. *Environ. Eng.* **110**(2) 301-311.

SHAW, T (1989) Patent No. 12623. Her Majesty's Stationery Office. London.

SLIM, JA (1977) Sludge treatment at the Fishwater Flats Water Reclamation Works, Port Elizabeth. Presented at the Symposium on the Treatment and Disposal of Sludges Deriving from Municipal Sewage. Pretoria. October 1977.

SOUTH AFRICAN BUREAU OF STANDARDS (1986) Standard Specification for Burnt Clay Masonry Units. *SABS 227-1986.*

TAY, JOO-HWA (1987) Bricks manufactured from sludge. *Environ. Eng.* **113**(2) 278-284.

VAIL, JW, DEVEY, DG, (1984) Controlling metal uptake from heat-treated sludge applied to grasslands. *Water Sci. Tech.* **17** 599-610.