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Design of a Rotary Kiln for Production of Sarooj

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تصميم فرن دوار لانتاج الصاروج

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الخلاصة: الصاروج اسم محلي للبوزولان كان يستعمل على نطاق واسع كأسمنت هيدرولكي في البنايات و التجهيزات الهيدروليكية و الحصون و القلاع وفي ترميم الاثار التاريخية. وينتج الصاروج بإحراق أنواع معينة من التربة الطينية التي تحتوي على كميات كافية من السيليكا و أوكسيد الحديد وأوكسيد الألمنيوم. في الماضي كان ينتج الصاروج باستخدام كميات كبيرة من الطاقة يضيع أغلبها بفعل الرياح نتيجة حرق التربة في الهواء الطلق. كما كان نظام الحرق المستعمل غير كفء حراريا عادة، ونادرا ما يعرض الناتج لأي فحوصات للتاكد من النوعية. كما ان الصاروج المنتج باستعمال الطريقة التقليدية قد يكون ذا نوعية رديئة بسبب الاحتراق غير الكافي او بسبب الأحتراق الزائد عن الحاجة، حيث لم تكن هناك وسيلة للتاكد من درجة الحرق. وفي هذا البحث، تم إجراء دراسة شاملة على طريقة إنتاج الصاروج لتقرير العوامل التي تؤثر على نوعية الصاروج. وبالإستناد على هذه العوامل، تم اقتراح طريقة جديدة لانتاج الصاروج، وذلك بتصميم فرن دوار متنقل لإنتاج الصاروج يمكن تركيبه خلال ساعة واحدة من وصوله في الموقع. والفرن يمكن أن ينتج حوالي مائتي كيلوا غراما من الصاروج في الساعة، كما يمكن سحبه بواسطة جرار أو عربة سحب الى الموقع المطلوب، ثم يوصل بتجهيزات الغاز الطبيعي و الطاقة الكهربائية. ويمتاز الفرن المقترح بخفة الوزن وبساطة مكوناته وسهولة تشغيلة. وفي هذه الورقة، تم عرض تصميم الفرن بالتفصيل، كما تضم عرضا لبعض النتائج التمهيدية للإختبارات التي اجريت على الصاروج المنتج بواسطة الفرن المقترح، وسيتم نشر التفاصيل الكاملة للإختبارات على منتج الفرن في ورقة لاحقة.

المفردات المفتاحية: صاروج، بوزولان، اسمنت هيدروليكي، فرن نقال، مواد إنشائية.

Abstract: Sarooj is a local term used for pozzolana. It has been used extensively as a hydraulic binder in buildings, hydraulic installations, forts and castles, and in the renovation of historical monuments. It is produced by burning specific clay soil that possesses adequate quantities of silica, alumina and iron oxides. In the past, the material was produced using a large amount of energy most of which is wasted by blowing winds. The burning system was usually thermally inefficient, and the output is rarely checked for quality. Test on products produced by using the traditional method may yield poor quality Sarooj due to inadequate burning or over burning or even insufficient grinding in the end. In this research, extensive experimentation has been performed on the method of production of Sarooj to determine the factors influencing Sarooj quality. Based on these factors, a new method of production is proposed. In this method, a fully mobile kiln was designed to produce Sarooj on the site. The kiln can produce 200 *kg*/*h* of Sarooj, and can be installed within one hour of arriving on the site. It can be towed by a tractor or a normal vehicle to the desired location, connected to the natural gas supply and the electric power. The construction is light, compact, and easy to start and shut down. In this paper, the plant is described in detail, together with some preliminary results of testing done on Sarooj produced by the kiln. Full details of tests on the product of the kiln will be given in a subsequent paper.

Keywords: Sarooj, Pozzolana, Hydraulic binder, Mobile plant, Building materials

1. Introduction

The traditional method that the Omanis has used in the past for producing the Omani Sarooj can be summarized in the following steps (Hago and Al-Rawas, 1999):

1. The soil used in producing Sarooj is usually brought from farms and lands used for agricultural purposes, and perhaps other specific bare lands. However, it should be noted that the soil used differs in its clay content, and chemical and mineralogical composition from one area to another. This soil is sieved in order to remove gravels and other undesirable materials.
2. The sieved soil is mixed thoroughly with water to form "Ghailah" (soil paste) which should be left for one day. This step is repeated for two consecutive days and finally circular disks of soil are made and left to dry. The process of drying the circular disks may take a week.
3. Dry logs of date trees are arranged in three layers. Small openings are left between the logs of trees to allow for air circulation. Dry leaves are placed between logs of dates trees to help in the burning process. This arrangement, shown in Fig. 1, is known as "Mahabba".
4. The prepared soil disks are packed on the top of the third layer of the dates trees. They can reach a height of one meter.

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5. A layer of white Wadi limestones is placed between the soil disks for the production of "Al-Nourah" which will be mixed with the soil during the burning process and gives it its white colour.
6. After completing all the preparation of the Mahabba, the burning process starts. Copious fumes are produced in the process (Fig. 2) and with time they disappear. The Mahabba is to be visited after four days from burning, no traces of fire could be seen, but the burned soil disks will still be hot. The logs of the date trees will be completely destroyed by the fire, turning them into ashes. Water is then sprayed over the Mahabba, in order to extinguish any fire that could not be detected.
7. The sarooj must be left at the site for a period of about two months, before it can used. It is believed by Sarooj experts who worked with the traditional method that this period would give the Sarooj more strength. After that, Sarooj is ground into a powder form.

Figure 1. Sarooj Mahabba

Figure 2. Sarooj Burning

In this method of Sarooj production, temperature recording is not possible and the period of calcination cannot be observed or controlled. The calcined product is pulverised through two operations: primary and secondary. The primary operation is done manually, using tamping rods and shovels which involve a considerable amount of effort and time, while the secondary operation is done mechanically using compacting rollers which are hand driven, see Fig. 3. The end product is screened to get the required fineness. Although the capital cost of production is not usually high, high thermal efficiency cannot be obtained due to the small size of the work and the intermittent operation.

Figure 3. Grinding of Sarooj

The proposed design should consider these aspects. The calcination process involves baking the raw material in a heat transfer apparatus like a kiln. The feed for a kiln is required to be of a particular size, shape and density according to the likely breaking down of the feed during its travel through the kiln. A variety of fuels can be used to obtain the required calories of heat per kilogram of charge to be calcined. However, in the process of the design of the kiln, the following aspects should be considered:

1. Feed size, shape, density and moisture content;
2. Hoisting and charging arrangement;
3. Thermal efficiency in terms of tons of Sarooj produced per ton of fuel;
4. Control of temperature and duration of burning;
5. Operational efficiency.

In order to meet a local small demand, small capacity plants have been developed, using different heaters as vertical shafts furnaces or rotary kilns of fluidized beds (Thate and Patel 1978; Gupta and Rao, 1978). In all of these kilns, the installations are fixed in position, which increases the cost of production for a small intermittent plant operation. To reduce the cost, a semi mobile flash/dryer calciner unit was proposed by (Salvador and Pons 2000). Still the size of their plant was too big for small demand production. The overall size of their kiln was 14.5 *m* long, 3 *m* wide and 4.5 *m* high weighing 23 tons. Clearly such a plant cannot be fully mobile.

2. A Better Design

The review of the existing method given above indicated a need for a new design which will incorporate the following improvements:

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1. Hoisting and emptying of the feed into the kiln can be mechanized;
2. Easy firing and efficient use of energy will be provided by the use of natural gas burners;
3. Kiln shell should be structurally strong and be designed for temperature and hoop stresses;
4. In the shell, a non-conductor lining should be designed to withstand the high temperature of the kiln;
6. Reduction of heat losses so as to reduce cost of production;
7. Good utilization of space of the kiln as reusable. The traditional method abandons the area where the Mahabba is established until Sarooj is removed. This could take more than two months to allow reuse of the place occupied by one firing operation;
8. The continuous calcination temperature recording through thermocouples can help control the movement of the calcination zone;
9. Easy handling and movement of the kiln.

Specifically, the designed kiln should meet the following specifications:

1. Operating temperature = 750^{o}C;
2. Maximum temperature not to exceed 1000^{o}C;
3. Temperature on the outside surface of the kiln not to exceed 50 ^{o}C;
4. Rate of feed to the kiln = 200 *kg*/*h*;
5. Natural gas pressure = 3 bars;
6. Volume of air for combustion = 16 m^3/h;
7. Speed of rotation of kiln = 30 *rpm*.

3. Raw Material Processing And Handling

The excavated material from the clay bed comes in the form of fine soil varying in size from 20 *mm* to fine powder. The material can be hard desiccated clays and shale, or it can be granular soft clays. Two methods can be used for preparing the material for burning in the kiln, depending on the hardness of the raw material:

3.1 Hard Desiccated Clays and Shales

Desiccated clays and shales of sizes ranging between 5 *mm* to 10 *mm* can be fed directly to the kiln without processing. These materials are usually stiff and unsolvable in water. They can withstand rolling in the kiln without disintegration. Particles larger than 10 *mm* have to be separated by sieving and broken to a size roughly less than 5 *mm* or can be excluded all-together if it was in small quantities.

3.2 Soft Granular Clays Soluble in Water

Such soils cannot withstand the rolling that takes place inside the kiln and can easily disintegrate into powder. Once disintegrated, they can stick to the sides of the kiln and hinder the easy flow of the material. They can also create lumps in the kiln which require more time for complete burning. In order to overcome these effects, such soils have to be mixed with about 12% water and molded in a form of balls or pellets before putting in the kiln, to facilitate their movement inside the kiln. The pellets are obtained by using a pelletizer designed specifically for the purpose, see Fig. 4. The pelletizer is composed of a cylindrical drum 600 *mm* in diameter and 2 m long, rotated about its longitudinal axis which is supported at its ends by roller bearings. It is rotated at a speed of 20 *rpm* by an electric motor. The moistened soil is introduced into the pelletizer drum through a side opening. After the soil is loaded the opening is closed with a cover, and the motor is started to set the drum in rotation. In three minutes, pellets start to form. The size of the pellets is controlled by changing the moisture content of the soil. The moisture content of the soil can be increased by spraying water through end openings in the drum. When all of the soil has changed into pellets, the motor is stopped, and the palletized soil is extracted from the drum through the side opening. The pellets are then spread in the sun and left to dry. After drying, they are ready to be loaded in the kiln.

Figure 4. Pelletizer

3.3 Loading of the Material into the Kiln

The feed to the kiln, whether processed or unprocessed material can be loaded into the kiln by using a manual procedure, or by using a hoist. The hoist, Fig. 5, consists of a steel bucket 2 *mm* thick having dimensions 30x30x40 *cm* and can hold 40 kg of soil. The bucket rolls over a pair of mild steel channels 160 x 80 mm, each made by welding 2 angles 80x80 *mm*. The supporting rails have an inclination of 80^{o} with the horizontal, and are tied to the frame supporting the kiln. A pair of guide wheels attached to the bucket roll inside the channels. The bucket is pulled along the rails by means of a 5 *mm* diameter wire rope tied near the bottom on either side. The wire rope is passed over a series of pulleys and is pulled by means of a manually operated winch. The bucket rolls over the rails till they curve downwards at the top of the kiln. The guide rollers stop at the end of the rails and the winch winds up some more length of the wire rope to haul up the bottom of the bucket and turn, it upside down in the chute. After emptying the bucket, the winch pulls out the rope which puts the bucket down on rails again right side up. The empty bucket slides along the rails to the bottom of the lifting rails where it is filled again.

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Figure 5. The hoist

4. The Kiln

Depending upon the heat transfer unit selected the cost of calcinations forms 40 to 60 % of the total cost of manufacture of Pozzolana. A mobile cylindrical double-coned rotary kiln was proposed for this design. Various alternative shapes could be have been adopted for the kiln, but the selected shape was favored for several reasons viz. minimum wear and tear of lining due to sliding of charge; minimum choking and clinkering; more uniform burning and a better distribution and flow of the charge through the kiln. The kiln was designed to give the required optimum temperature (750^{o}C) and a period of calcination of two hours.

The designed kiln was built from 6mm steel plates of, and consisted of three parts: a central cylindrical drum 1200 mm external diameter with a length of 15 *mm*, and two truncated cones at the ends, see Fig. 6. Each cone was tapered from a diameter of 1200 mm at the mating end with a central cylindrical portion to 300 mm at the free end. The overall length of the kiln was 3170 *mm*.

Figure 6. Parts of the rotary kiln

The fire brick used in the lining of the kiln was manufactured in the laboratories of the College of Engineering at Sultan Qaboos University. A fire clay containing a high percentage of alumina was used for this purpose. Special molds constructed from steel plates were manufactured for casting the fire bricks. Fire clay for making the bricks was imported from Pakistan and was supplied by Skylark Company for Building Materials in Sharjah. A hydraulic compression machine was used for pressing the clay in the moulds. The mortar used in building the fire brick inside the kiln was made of high alumina cement with sand. The mortar courses were only about 5 *mm* thick, so as to reduce thermal volume changes in the mortar when subjected to a high heat input/discharge. The thickness of the brick lining in the kiln was 170 *mm* in the cylindrical portion where the fire was concentrated, and 120 *mm* in the conical portion, Fig. 7.

Figure 7. Lining the kiln with fire bricks

The kiln was built over a trailer made of steel rolled sections with four wheels to facilitate movement both during manufacturing and operation stages. It can be dismantled, moved over land (road network) and sea, and assembled within few hours. It rests on four roller supports fixed over the trailer. The four rollers allow free rotation of the kiln. The kiln rotates about its longitudinal axis with a speed of 30 rpm. The rotation is provided by a 10 *hp* electric motor through a steel shaft, two pulleys and three belts, Fig. 8. When dragged in place, the trailer was supported by four jacks on the ground to anchor the wheels against rotation. Because the front two jacks were shorter than the rear, the overall body of the kiln became tilted about 1 to 2 degrees with the horizontal to facilitate withdrawal of the product at the end.

Figure 8. Kiln mounted on a trailer

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One gas burner was used to provide the required heat energy. The burner was BP7 premix type manufactured by Australian Combustion Company. The burner uses natural gas at a pressure of 3 bars and with a rate of 16 m^3/hr. It includes an automatic ignition of the flame and flame safety detection. The detection system utilizes the flame rectification principle. For complete combustion, an air blower was needed to supply the burner with air. Air and gas are mixed in the burner at a well calculated ratio by the mixer itself, depending on the temperature of the burner. A small processor unit controls the operation of the burner, and the whole process is automatic. Assuming a calorific value of natural gas of 38 MJ/m^3, this means that heat is input to the system at a rate of 608 MJ/hr. Attempts to estimate the necessary heat requirement to produce sarooj from clayey soils by field experimentation gave an estimate of 5579 *MJ*/ton of soil (Hago, *et al*. 1995 and Hago and Al-Rawas, 1997). Thus for a given size of feed, the duration of burning can approximately be determined. A batch of 0.2 ton, needs 2 hours calcination time. Figure 9 shows the burner and blower mounted in the kiln.

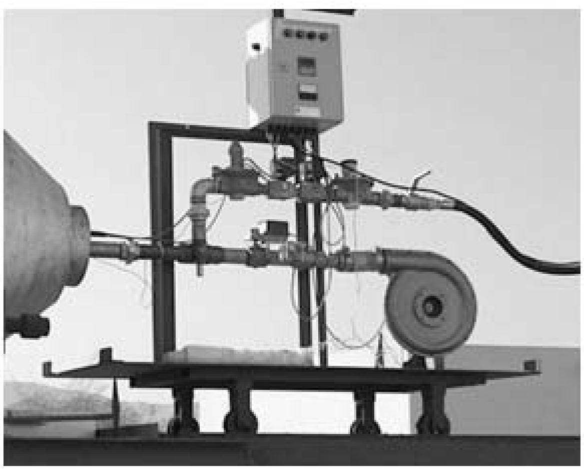

Figure 9. Burner and blower mounted in the kiln

The operation of filling the kiln will be done in batches of five buckets each. The volume of the calcination zone was designed to hold one batch's production.

Temperature in the kiln was monitored by means of thermocouple inserted through the kiln drum. The arrangement enables the monitor to read the temperature on the display of the burner control unit.

The shell of the kiln is designed to serve three purposes. viz., withstand the calcination temperature and structural stresses as well as minimize heat losses. Inside, a 170 *mm* thick fire brick lining made of fire claim was used.

The desired calcination temperature was 750°C. However, structural components were designed to take up a maximum temperature of 1000°C which may happen due to accidental rise in temperature. The temperature on the outside of the outer shell will be slightly higher than the ambient temperature. The thickness of each component of the kiln was selected to minimize the heat loss through conduction as much as possible. Most fire bricks withstand a temperature of 1500°C.

5. Structural Design of the Kiln and its Supports

The design was carried out on lines of that adopted for steel structures. It was checked for combined stresses due to internal load and temperature. Tensile stress in steel (hoop tension) was assumed at 460 N/mm^2; compressive stress in brickwork was assumed at 14 N/mm^2, with cement-lime mortar grade IV according to BS 5628-1, 1992. Unit weight of charge of loose clay soil was taken as 14 kN/m^3. The coefficient of thermal expansion of brickwork and steel was assumed to be $6x10^{-6}$ and $11x10^{-6}$ per degree centigrade respectively. The total downward load includes the dead weight of the kiln shell plus the estimated soil charge plus the weight of the supporting frame itself. Due to the small size of the installation, wind load was neglected in the design of the supporting structure. Safety factors on all loads were taken as 1.4. Full detailed set of drawings for the construction the kiln is given in Figs. 10(a) and (b).

6. Pulverising

After allowed to cool in natural air, the calcined product drawn out from the kiln can be carried in 2-wheel trolleys straight to the pulverizer. The crusher used for this purpose is a disc mill used for batch or continuous fine grinding of soft to hard material (hardness grades up to 8 Mohs), having a capacity of 150 kg/hr. It can be adjusted to any desirable size of the final product.

7. Sample Results of Tests on the Kiln Product

Clay samples were produced from 3 sites in Oman and were burnt in the kiln to produce Sarooj. Mixes were produced from Sarooj and lime and were designated as Fanja (K), Al-Fulaij (K) and Bahla (K). For comparison, the soil from the same sites was used to produce sarooj in the laboratory and mixes produced in this way were designated as Fanja (L), Al-Fulaij (L) and Bahla (L). Results of the initial setting, slump, consistency, density, compressive strength tests on the two series are compared in Table 1. The initial setting times of the laboratory-burnt and kiln-burnt samples for each site show differences of 1.5, 3.0 and 5.5.0 hours for Fanja, Bahla, and Al-Fulaij samples, respectively. The initial setting time was maximum (11 hours) for Fanja (K) and Al-Fulaij (K) samples, and minimum (3.5 hours) for Bahla (L) sample. The slump values for the laboratory-bunrt and kiln-burnt samples of all sites are similar and consistent. Bahla (K) sample has the highest slump value (55 *mm*) whereas Fanja (L) sample has the lowest value (14 *mm*). Al-Fulaij samples show intermediate slump values (25-28 *mm*).

Table 1 also shows that the consistency values of Fanja

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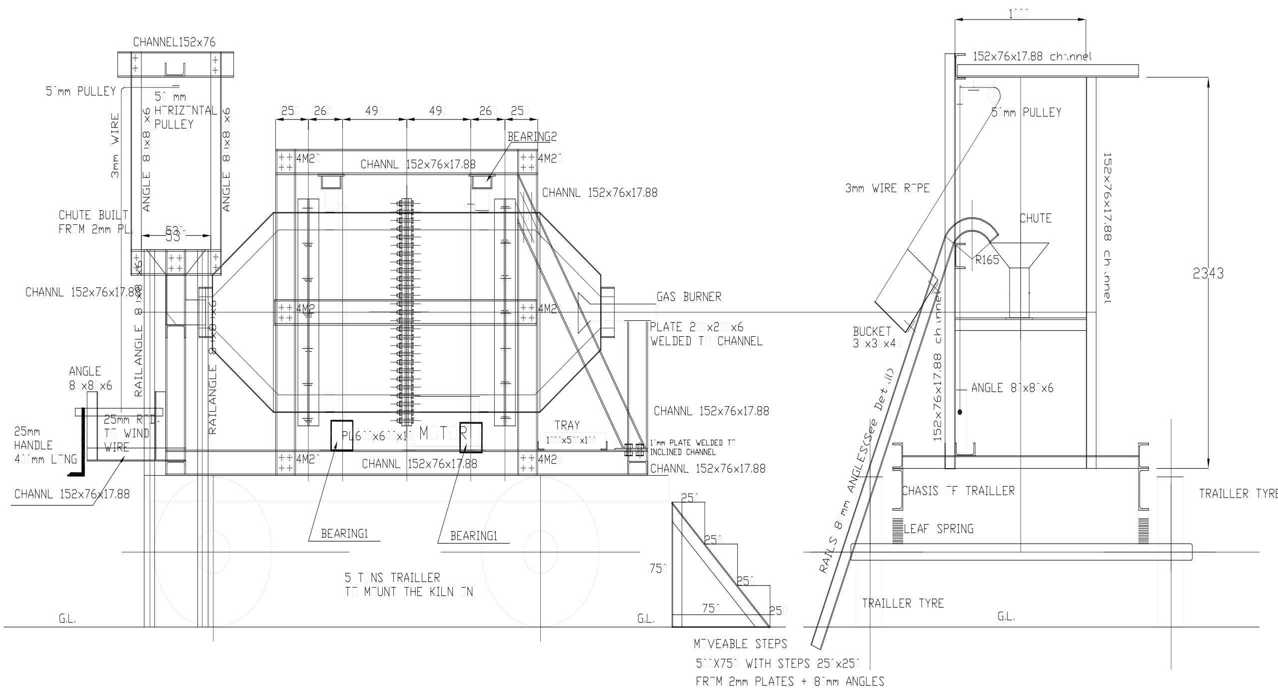
Table 1. Results of the engineering tests of Sarooj

Sample Designation	Temp./ Duration, °C/hour	Initial Setting Time, hours	Slump, mm	Consis-tency, %	Density, kg/m^3	Compressive Strength, MPa			
						7 days	14 days	28 days	90 days
Fanja (L)	740/2	9.5	14	31	1985	5.04	11.11	17.63	26.50
Fanja (K)	740/2	11	15	30	1964	4.39	10.37	18.36	23.80
Al-Fulaij (L)	740/2	5.5	28	35	1989	5.52	6.64	8.63	11.98
Al-Fulaij (K)	740/2	11	25	33	1952	4.07	5.46	7.58	11.82
Bahla (L)	740/2	3.5	53	37	1990	5.84	6.29	7.33	8.79
Bahla (K)	740/2	6.5	55	46	1953	1.83	2.54	3.05	4.82



ELEVATION LEFT VIEW

Figure 10a. Details of the mobile rotary kiln for Sarooj production, Drawing 1/2

and Al-Fulaij samples are comparable. The density values showed slight differences between the laboratory-burnt and kiln-burnt samples for all three clays. Al-Fulaij and Bahla showed a difference in density of only 1.8% while Fanja samples showed a difference in density of only 1.1%. Results of the compressive strength showed an agreement between the laboratory-burnt and kiln-burnt samples for Fanja and Al-Fulaij clays. However, notable differences were recorded for Bahla samples. Fanja (L) sample attained the highest strength of 26.50 MPa at 90 days whereas Bahla (K) sample showed the lowest strength of 4.82 MPa for the same duration. Al-Fulaij (L) and Al-Fulaij (K) samples exhibited strength of 11.98 and 11.82 MPa, respectivley. All samples showed development of strength with time. Compressive strength and consistency results showed a similar trend.

8. Conclusions

Based on the research findings, a new method of production of Sarooj was proposed. A fully mobile kiln was designed to produce Sarooj on the site. The kiln can produce 200 *kg*/*h* of Sarooj, and can be installed within one hour of arriving to the site. It can be towed by a tractor or a normal vehicle to the desired location, connected to the natural gas supply and the electric power. The construction is light, compact and easy to start and shut down.

Preliminary tests showed that the designed kiln could

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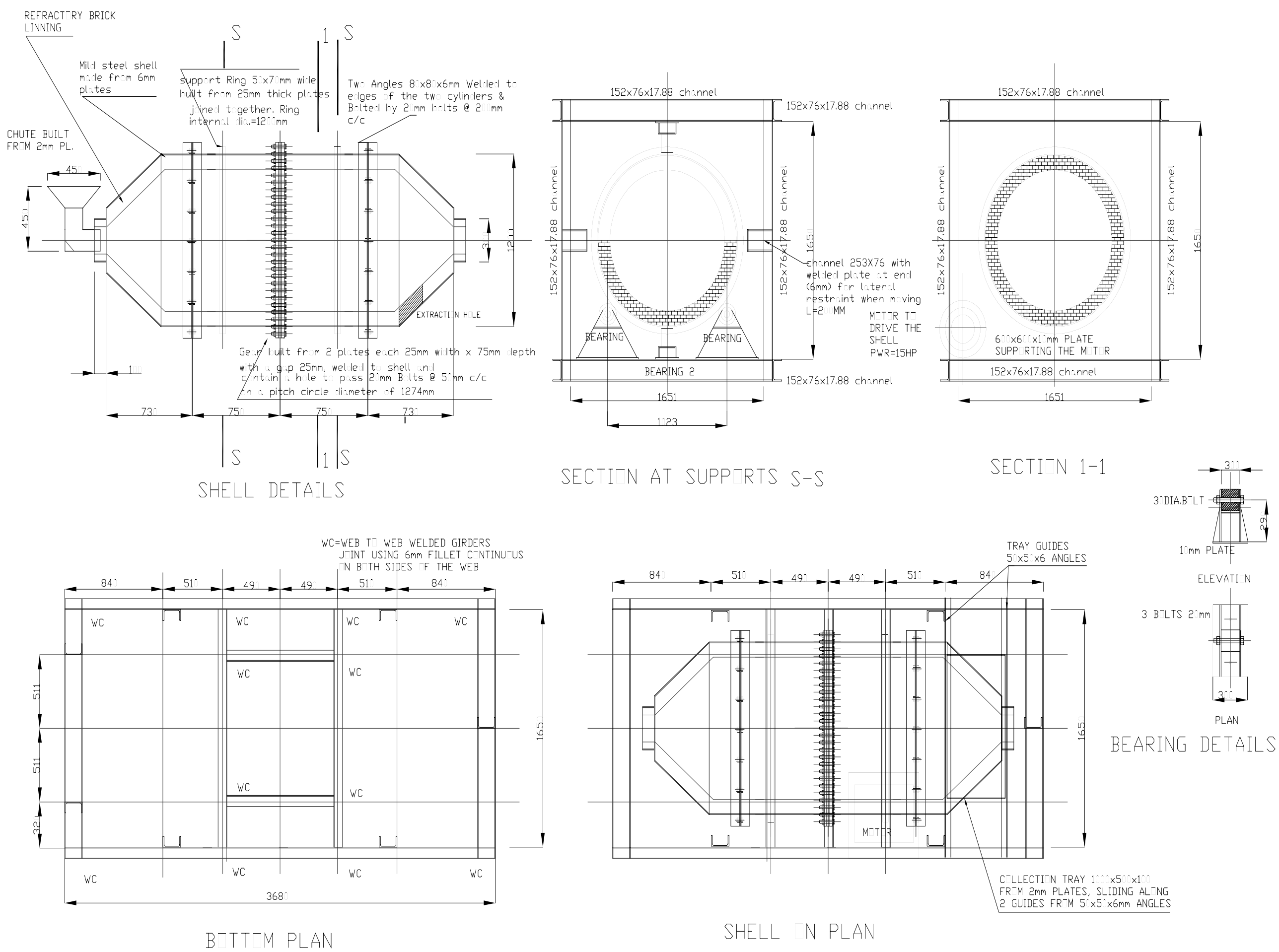

Figure 10b. Details of the mobile rotary kiln for Sarooj production, Drawing 2/2

produce Sarooj with properties comparable to those of Sarooj produced under controlled conditions in the laboratory.

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