EFFECT OF KAOLIN ADDITION AND CLAY MIX PROPORTIONS ON TECHNOLOGY OF BRICK PRODUCTION

CASE STUDY
(SOBA BRICK PLANT)

THESIS SUBMITTED FOR PARTIAL FULFILLMENT FOR THE DEGREE OF M.Sc IN BUILDING TECHNOLOGY

BY

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- : بانتقه

(الإيمان بالإخلاص والصلاة والسلام)
(۱۲ من الزعاماء)

(الإيمان بالإخلاص والصلاة والسلام)
(۱۴ من الزعاماء)
Dedicated to My Mother and to the soul of my Father
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Abstract

This work summarizes the immeasurable research work and studies previously undertaken in the field of fired clay-brick as produced by local and modern methods especially the work undertaken by Building and Road Research Institute (BRRI), University of Khartoum.

This research work aims at upgrading the present quality of Soba Plant bricks, which is one of the existing modern brick factories in Sudan, by determining optimum mix proportions of ingredients in order to minimize the percentage of breakage per batch.

To this end extensive field studies comprising soil profiles and laboratory studies ranging from soil and kaolinite clay characterization to the effect of adding kaolinite on the overall characteristics of the Blue Nile silt at Soba and on the drying and firing behavior of bricks so produced.

*The outcomes of experimental results were used to produce full size bricks using Soba plant production line, to confirm the obtained experimental results.*

The results of these studies are considered to furnish good grounds for setting up local directives and guidelines for mechanized production of bricks.
الخلاصة

玻璃的化学成分分析

玻璃的化学成分分析旨在探讨玻璃在不同温度下的行为，以便更好地理解其在生产过程中的性能。

1. **化学成分**
   - 如表所示，玻璃的化学成分主要包括：
     - 二氧化硅 (SiO₂)
     - 三氧化二铝 (Al₂O₃)
     - 四氧化三铁 (Fe₂O₃)
     - 二氧化钛 (TiO₂)
     - 三氧化二硼 (B₂O₃)
     - 氧化钠 (Na₂O)
     - 氧化钾 (K₂O)

2. **温度对化学成分的影响**
   - 温度的升高对玻璃的化学成分产生显著影响，具体表现在：
     - 二氧化硅 (SiO₂) 的比例增加
     - 三氧化二铝 (Al₂O₃) 和四氧化三铁 (Fe₂O₃) 的比例降低
     - 氧化钠 (Na₂O) 和氧化钾 (K₂O) 的比例保持相对稳定

3. **结论**
   - 研究结果表明，玻璃的化学成分可因温度的不同而有所变化，这对其性能和应用有重要影响。

通过深入分析这些数据，我们能够更好地了解玻璃的性质，为优化生产过程提供依据。
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<tr>
<td><strong>T.P</strong></td>
<td>Test Pit</td>
</tr>
<tr>
<td>L.L</td>
<td>Liquid Limit</td>
</tr>
<tr>
<td>P.L</td>
<td>Plastic Limit</td>
</tr>
<tr>
<td>P.I</td>
<td>Plasticity Index</td>
</tr>
<tr>
<td>L.S.</td>
<td>Linear Shrinkage</td>
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<tr>
<td>S.L.</td>
<td>Shrinkage Limit</td>
</tr>
<tr>
<td>Sf</td>
<td>Firing Shrinkage</td>
</tr>
<tr>
<td>Sd</td>
<td>Drying Shrinkage</td>
</tr>
<tr>
<td>St</td>
<td>Total Shrinkage</td>
</tr>
<tr>
<td>m.c</td>
<td>Moisture Content</td>
</tr>
<tr>
<td>AV.</td>
<td>Average</td>
</tr>
<tr>
<td>S.D.</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>C.V.</td>
<td>Coefficient Of Variation</td>
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Chapter One

1. Introduction

1.1 Historical background:
The Nile sediments have been used as a building material along the Nile valley since earliest history.

There is evidence that the Egyptians used the Nile sediments in building their homes, at first just to reinforce the walls, which had been built of bamboo, then they used it in the production of green bricks, which were used in building of small pyramids in the Northern part of the valley.

After wards, they knew how to use the Nile sediments in the production of fired –clay bricks and other fired products.

From the northern part of the valley, the knowledge of the production of fired –clay product was transferred to the southern part of the valley i.e. to the Northern Sudan.

The old Sudanese used fired-clay bricks in building of small pyramids in “bajrawia “ and in some other places.

During the first half of the last century, the British and Egyptian Colonist used large quantities of fired-clay bricks in building of a large number of offices and houses in Khartoum area and other large towns in Sudan. With time, building with fired –clay bricks became popular and a large quantity was demanded (1).

Later on small industrial unit was established in soba west about 20 Km. south west of Khartoum on the Blue Nile river bank (The present site of the pilot brick plant of University of Khartoum)

The exact time of the establishment of this small unit is not known, and the production, reportedly stopped in the late fifties due to unknown reasons.
This small unit seems to be the first semi-mechanized unit for the production of fired-clay bricks in Sudan.

The raw material was the Blue Nile sediments, shaping was done by pressing and firing of the dried units was done in an open top Hoffman kiln using charcoal as fuel. The produced bricks were of good quality and were used in so many existing buildings as load-bearing bricks (1).

In 1949, a second industrial unit was established at Burri to cover the consumption of the ministry of public works from the fired-clay bricks. In this unit the Blue Nile sediments were transported by special rail cars to a rotary mixer, and then the solid bricks were formed by hand.

The formed bricks were dried under sun and fired in Hoffman kiln. The production was stopped in 1958(2). Many trials were made to rerun this factory but the trials were not successful.

In 1949, the Sudan railway department established a small unit for the production of fired-clay bricks at “ELAKAD VILLAGE” near Atbara, at the northern region of Sudan. It seems to be the first mechanized unit for the production of fired-clay bricks in Sudan. Nile sediment was formed into the desired solid shapes by extrusion and wire cutting technique. Drying carried out in chamber driers and firing was in Hoffman kiln using mazout as a fuel (2).

1.2 Present situation of brick production:

At present fired-clay bricks are produced mainly by traditional method which is common in most part of the Sudan, about 98% of brick production come out of this method (3).

The annual production of bricks is estimated to be 2.8 billion bricks used mainly in walls and partitions in reinforced concrete frames and flooring. Their
use for loadbearing has been limited to one storey when mud mortar is used and to two-storey building if cement mortar is used (3).

In the near past the production of these traditional units was of good quality, but later on the production became of lower quality as bricks became irregular in shape, had low crushing strength, high water absorption and there was a high percentage of breakage per batch.

This situation is due to the high demand on fired-clay brick accompanied with uncontrolled production technique, and due to the fact that production technique is by a traditional method that does not worth any development.

1.3 Soba Demonstration plant:

1.3.1. Establishment of the plant

Realigning the deteriorating and problematic situation of building materials and that improved red bricks production has good potential to solve the problem to a considerable extent, the Building and Road Reach Institute (BRRI) Of University of Khartoum (U of K) has undertaken the task of promoting the production of fired-clay bricks in Sudan. A number of research programmes were formulated with the objective to improve the production quality. Results of these programmes were so positive to warrant the idea of establishing a demonstration plant for the production of fired clay bricks.

In order to fulfill that idea, BRRI made contacts with the Ministry of Industry, National Council of research, UNIDO, and other local organizations and units concerned with red brick development. In the light of the positive response and interest aroused by these contacts, BRRI prepared a project paper to be discussed in the Solidarity meeting of ministers of industry for cooperation in the industrial development of Sudan held in Khartoum in 1981 organized by UNIDO (4).

The project found acceptance from the former Yugoslav Government, where a grant of $ 900,000 in form of equipment was offered for Sudan Government and Sudan government agreed to meet the remaining cost of the project implementation, such as transport and erection of equipment, building and civil work, commissioning and start up of the project.
The main objectives of the project are:

* To assist in the development of the present production of red brick by producing good quality bricks.

* To provide facilities for experimentation work on appropriate technology transfer and, hence, to act as a research and consultation centre.

* To act as a project of excellence so as to demonstrate to potential investors the practical possibilities of producing good quality bricks.

* To play the role of a training centre in the brick production technology for training artisans and technicians.

This demonstration plant was decided to be at the western bank of the Blue Nile at Soba locality, 20 km south of Khartoum at the place of the mentioned brick factory, which closed fifty years ago.

The project is intended to produce 10 million bricks annually.

The project was completely erected in 1994 and then commissioned.

1.3.2. Technology of production

The Yugoslav offer includes machinery and equipment for extrusion process. This means the manufacturing process was determined beforehand i.e. before proper testing of raw materials, because production technology should match with the available raw material.

Nevertheless Blue Nile silt although not a true brick making clay can be used for production of quality bricks, which could meet the general demand after some treatments.

The method of shaping adopted in Soba brick Plant is extrusion process.

The manufacturing process of Soba Plant starts by winning of raw materials. Here multi bucket excavator running in rails excavates the clay. The excavated
clay is transported to plant site by a tractor with a tipping truck to the box feeder the clay then taken by slat conveyor.

At first sand was added instead of kaolinitic stone, which was proposed by Yugoslav, because kaolinitic stone was found expensive since it was brought from distant areas. The sand was placed in a steel hopper and taken by small rubber conveyor belt to join the clay at slat conveyor, which takes them to the wet pan mill, where preliminary mixing and grinding took place. After wet pan mill, the material (i.e. the mix) is transported by a rubber belt conveyor to coarse differential roller mill and then to fine differential roller mill for final grinding. The mix was then conveyed by a rubber belt conveyor to a mixer on the top of extruder for further mixing and watered if necessary. The material was then entered the vacuum chamber of the extruder for de-airing and then compressed, pressed and formed through the mouthpiece. The extruded column is cut into desired shape by a wire cutting machine. The formed bricks were taken manually from horizontal conveyor and set in hand driven carts. The carts took bricks to the dryer to be set on shelves for drying.

The bricks produced by this mix of sand and clays were found to be brittle and had high percentage of breakage. Instead of sand brickbats (grog)s were used. They were crushed by jaw crusher and joined the clay at slat conveyor and then passed in the process line as indicated previously. But it was found that the grog did not ground properly well and there were big lumps present in the formed bricks. For this reasons grogs were ground separately in a hammer mill and then placed in the silo or hopper which was used previously for sand.

Bricks from grog/clay mix were also found brittle and had high percentage of breakage. This is why thoughts went back to the Yugoslav proposal of using kaolinitic stone as additive especially the clay soil at factory location was found to have great deficiency in clay fraction and addition of kaolinitic stone
will raise the percentage of clay fraction and help in reducing shrinkage, which is responsible of cracking of bricks.

At first drying took place in closed dryer by passing hot gas from kiln for two days in order to slow down the rate of drying and then dryers were opened for further drying. This natural drying proceeds for another two days. This method of drying was found unsuitable because there were high percentage of breakage. This process was then reversed. Natural drying took place first but the doors were completely closed. Then hot gases from kiln were introduced.

Also this combination of natural and artificial drying did not solve the problem although it improved it. Further investigation was carried out to improve the drying both through improving mix proportion as outlined previously and by improving the methods of production.

After drying dried bricks were taken from dryers by hand carts to be stacked manually outside the kiln into certain stacks and then carried by forklifts and placed inside the kiln for firing. But this was faced with many problems, first forklift did not handle stacks properly especially when placing one stack over the other.

This was why this procedure was changed and the dried bricks taken directly to the Kiln and stacked manually inside the kiln. Firing was carried out in circular rectangular Hoffman kiln by special burners set at the top of the kiln and injected the mixture of fuel and air inside kiln. The fuel used is mazout (furnace).

The first firing temperature tried was 950°C, but later changed to 900°C as some bricks melt. But this was also further changed to 875°C.

There was no control on temperature propagation especially when slow rate of heating was required or soaking temperature is required to be maintained for certain period of time. For these reasons there was high percentage of breakage and cracking in bricks at firing stage.
This problem was minimized by increasing the firing cycle to give time for some physical and chemical reaction to take place such as evolution of steam of both mechanically and chemically combined water, phase transformation of silica and re-crystallization reaction and by improvement of mix, as outlined previously.

Finished products were taken manually by hand carts to the brickyard ready for dispatch. Figure (1.1) shows the flow process chart of the plant.

Table (1.1) compares the properties of bricks of Soba plant with Sudanese military standard for machine made bricks as tested by the author.
Table (1.1) Physical and Mechanical properties of Soba brick Plant bricks as compared with Sudanese military standard for machine made bricks.

<table>
<thead>
<tr>
<th>Property</th>
<th>Properties of Soba Brick plant bricks</th>
<th>Military Standard Specifications</th>
</tr>
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<tbody>
<tr>
<td>Dimesion(mm)</td>
<td>Length 22.9</td>
<td>Width 11.1</td>
</tr>
<tr>
<td></td>
<td>23 or 25</td>
<td>11 or 12</td>
</tr>
<tr>
<td>Water absorption</td>
<td>14.5</td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>Average</td>
<td>-</td>
</tr>
<tr>
<td>------------</td>
<td>---------</td>
<td>------------</td>
</tr>
<tr>
<td>Compressive strength Mpa</td>
<td>Average</td>
<td>27</td>
</tr>
</tbody>
</table>

- Not specified

### 1.4 Objective

Fore-mentioned facts reveal that the demonstration plant of Soba suffers from some problems, which can be summarized as follows:

- Nile deposit shows deficiency in clay fraction coupled with high variation in clay content.

This deficiency in clay fraction requires suitable additives to increase clay fraction and to minimize problems incurred by drying and firing

* Problems of drying, which are accompanied by cracking and breakage of bricks

* Firing problems, which also accompanied with high percentage of breakage and uneven colour of bricks due to uneven heat distribution.

So the objective of this study is to overcome some of these problems through the study of the present Nile deposit at the plant location in order to determine the clay fraction and then to find suitable additives and suitable means to increase the clay fraction. These additives coupled with proper mixing and aging of clays might lessen variations in clay content. Since the ultimate goal of this study is to minimize the cracking and breakage that took place during drying and firing, then effects of additives, mixing and ageing were studied.
through drying and firing behavior of bricks (models and full size) made from these mixes.

1.5 **Scope of work**

It is envisaged to include the following:

1.5.1 **Clay deposit investigation:**

- Preparation of geological mapping of borehole at different Locations of quarry.
- Manual drilling of test Pits (T.P) (each 4.0m. deep)
- Collection of samples from every 1.0m. depth of each T.P and collection of average sample from whole T.P.
- Collection of average sample from a specified location and a specified depth.

1.5.2 Ceramic Test for Individual samples

1.5.3 Ceramic Tests For Composite samples

1.5.4 Characterization of the Kaolinite clay additive

1.5.5. **Technological Tests:**

It includes:

1. Selection of mixes
2. Preparation of mixes
3. Shaping of model and full size bricks to study drying, and
4. Firing behavior.
Chapter Two

2. Literature Review

2.1 Review of research-work on bricks:

BRRI has been involved in so many research projects aiming to investigate the quality of the locally produced bricks, and to determine an appropriate technology for the development of this industry.

In 1966 a programme for research with three phases was set up:

2.1.1 General survey of bricks production in Khartoum

A general survey of fired clay bricks in Khartoum area was carried out in 1970, so as to assess the physical and mechanical properties of bricks produced by traditional methods namely: dimension, water absorption and compressive strength.

The investigation also includes the methods of production in traditional kilns in Khartoum province. The outcome of this phase can be summarized as follows (5):

- The average dimensions and their variations are not within the acceptable limits specified by standards (or accepted local standards).
- The average compressive strength is very low, and the variations in this compressive strength are very large.
- The average water absorption and its variations are rather high.
- The average values and variations of compressive strength, water absorption and dimension confirm the poor degree of control in production.

Table (2.1) shows deterioration of physical and mechanical properties of bricks.

Table (2.1) Physical properties of local bricks for the period 1970-1984 (5).
<table>
<thead>
<tr>
<th>Particulars</th>
<th>S.S 1974* (Requirements)</th>
<th>Year</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>1970</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>230 or 250</td>
<td>208</td>
</tr>
<tr>
<td>Width (mm)</td>
<td>110 or 120</td>
<td>100</td>
</tr>
<tr>
<td>Depth (mm)</td>
<td>60 or 70</td>
<td>53</td>
</tr>
<tr>
<td>Water absorption %</td>
<td>Not more than 30%</td>
<td>29.2</td>
</tr>
<tr>
<td>Compressive Strength (N/mm²)</td>
<td>Not less than 2.0</td>
<td>6.0</td>
</tr>
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</table>

* Sudanese standard for common burnt bricks.

### 2.1.2 Development of brick production:

Development of existing methods of production in order to improve the physical characteristics of bricks. The work in this phase include:

1- Laboratory work to determine the effects of different additive (agricultural and animal waste) to the Nile sediment. The additives investigated were” Saw Dust”, ”Zibala”, “Garad” and “Ground nut shells”. Also cotton stalks were tried as both additive and firing fuel. This has been done in collaboration with Gazira Board. The result of this study was:

a) Mixing Blue Nile clays with Zibala have yielded the highest average strength value. Next to Zibala is the Groundnut shells third saw dust. Garad has yielded the lowest record of the average strength.

b) Possibilities of using simple and manually operated pressing machines for shaping the clay should be looked into.
c) Cotton stalks powder was suitable as additive to the clay for green brick shaping and also to check the effectiveness of using cotton stalks in burning of the sun dried bricks.

d) Effect of method of drying of bricks, whether under direct sun rays or under shade, on the physical properties of bricks has insignificant effect on the physical characteristics of bricks when a reasonable proportion of the additive was used (6).

2- Use of hand-operated pressing machines in order to improve the shape of bricks. In this respect a field trials were carried out in co-operation with Prison Department so as to view the effect of pressing on bricks shape and to find optimum moisture content (m.c). It was found that a ratio of 4:1 by volume Nile sediment to water is the best mix with an ageing period of 5-7 days. In 1971 a great effort was exerted in the BRRI in co-operation with the Ministry of construction and Public Works towards re-running of Burri Kamina and also an Egyptian expert was entrusted to study the possibility of re-running Burri brick factory (7). The results of these studies emphasized the suitability of Nile sediments at Burri for brick production. He recommended for further development of this industry to investigate the suitability of other localities. Similar efforts were exerted with Sudan Railways Co-operation to re-establish their deserted brick factory at El Akad near Atbara.

2.13 Suitability of clay for brick production:

This phase deals with investigation on suitability of clay for the manufacture of fired-clay bricks aiming thus to introduce modern technology into production of bricks and other ceramic elements.

In 1974 the Industrial consultancy corporation of the Ministry of Industry entrusted Interkiln Company to determine whether suitable clays were available in sufficient quantities for the establishment of a factory to
manufacture structural clay products. The results of these studies are summarized as follow:

1. The only suitable and available clay in sufficient quantities for production of fired clay bricks was the Nile sediment. However, these clays are not the best type for production of other ceramic articles.

2. These clays are not suitable for extruded bricks due to the serious difficulties in drying stage. Therefore, they recommended the use of the soft-mud forming process. However, so far the manufacturers of the equipment of this process are dubious about the success of such an operation. The machines available require a considerable skill in maintenance, and their operating costs are very high.

Furthermore, as plastic clay is desired to give good results, they recommended adoption of mechanized hand moulding operation using modern mixing and conveying equipment.

3. For further progress in this industry, they suggested the use of dry pressing machines (8).

In June 1979 Battelle –Institute of Frankfurt, on Main Federal Republic of Germany issued a 3-volume report to the Ministry of National Planning, Sudan Government. This report contains a survey of building materials in the Sudan based on the Six Year plan 1977/1983 and the assessment of the possibilities for industrialization of these building materials. This survey includes an assessment of consumption of fired-clay bricks and a reproduction of data on physical properties of the traditionally produced bricks (1).

In 1983 a study was carried out by Mr. Adel M. Abbas on fired clay production. The outcome of this study was:

1. The main problems in using the Blue Nile sediment in the production of fired-clay bricks were associated with its high sensitivity for drying due to presence of montmorillonite clay mineral, and high variation in the physical properties of its constituent (i.e. sand, silt and clay).
2. In order to improve the quality of traditionally produced bricks the following remarks were pointed out:
   a. A mixture composed of Balabaty, Gureira and Zafota in proportion of 1:1:2 by weigh respectively was proposed to be used.
   b. The drying problem could solved by lowering the quantity of water added.
   c. Alteration of grain size would affect the physico-mechanical properties of the mixture.

3. Another way of improving the quality of the produced Blue Nile sediment bricks was by addition of up to 30% by weight of clays from Soba East, Esaggai and Jebel Aulia to Blue Nile sediment.

   Bricks models made from Soba East and Soba West in the percentage of (30%: 70% respectively) gave better results.

   One of the disadvantage of blending the Blue Nile sediment with the above mentioned superficial clay deposit was the appearance of light efflorescence in bricks.

In 1982, a technological test of raw materials for Soba brick plant was carried out by the Institute for Materials Testing Centre For Structural Ceramics Belgrade, Yugoslavia. The outcome of this study was as follows (9):

   1. The silt deposit of Soba was very heterogeneous. This necessitate homogenization of raw material at both exploration and production stages.

   Moreover this deposit was found to contain appreciable amount of sand, which render it difficult for shaping.

   2. These silts deposits were also found sensitive to drying.

   3. The deficiency of clay content and sensitivity to drying implies addition of other type of clay to improve both workability and mechanical properties of the end product. The optimum percentage of added material was found to range between 10-25%.

In 2002 at the time when this study was carried out the Sudanese Organization For Building Material and Construction introduced Liquefied Petroleum Gas (LPG) as new type of energy instead of firewood in traditional brickmaking, the outcome of this study was as follow (10): -
1. Traditional brick kilns could be burnt with LPG without any difficulty.
2. The structure of the kiln was left as it was; only simply constructed chimney was introduced at the back of the Kiln.
3. Use of LPG in brickmaking reduce the cost of firing by more than 50% when compared with wood.
4. High utilization of heat was achieved when using LPG unlike wood.
5. Use of LPG in brickmaking would reduce use of wood and this restore the forest resource of the country, beside LPG was considered to be a clean fuel with very low Co2 emission and this all had positive effect on environment.

2.2 Brick production: -

2.2.1 Old brick factories:

In Sudan, as well as in most developing countries, the mechanization of the brick industry was introduced in the first half of the last century for the construction of buildings serving the direct interest of the colonizers. After independence, and due to diversified reasons, the acquired techniques were lost and the whole technology deteriorated. The buildings constructed with that bricks still stand.

At that time a small industrial unit was established in Soba West about 20 Km. South of Khartoum on the Blue Nile bank which was called (Soba Ceramic Company). The exact time of the establishment of this small unit is not known, and the production, reportedly, stopped in the late fifties due to unknown reasons. This small unit seems to be first semi-mechanized unit for the production of fired-clay bricks in Sudan. The raw material was the Blue Nile sediment, shaping was done by pressure and firing of the dried units done in a large Hoffman’s kiln using charcoal as fuel. The produced bricks were of good quality and were used in so many existing building as load-bearing bricks.
In 1949 the Sudan Railways Department established a small unit for the production of fired-clay bricks on “ELAKAD” near Atbara, at the Northern region of Sudan. It seems to be the first mechanized unit for the production of fired-clay bricks in Sudan. Nile sediments were formed into the desired solid shapes by extrusion with wire cutting technique. Chamber driers were in use, and firing was carried out in Hoffman’s Kiln using mazout as fuel, but the production was stopped in 1955 due to increasing cost of production and the inferior quality of produced bricks and increase of percentage of breakage and failure of part of the roof of the new Kiln (2). Later in 1969 the Railway department decided to rerun the Factory again after reconstruction of the failed part of the Kiln but to shape the mix of clay and animal dung manually without using the machines, and firing the produced bricks in the circular Hoffman Kilns using the mazout oil as a fuel. But the cost of produced bricks was high and the percentage of the breakage was also high and the quality of the brick was worse than the traditional products, therefore the Factory was stopped completely in 1970(2).

In 1949, the Ministry of public works in joint venture with Egyptian Structural Engineering Company established a second industrial unit at Burri on an area of about 15 hectares (the site of the Khartoum Fair) to cover the consumption of the ministry from the fired–clay bricks due to the inferior quality and high cost of the traditionally produced bricks. The Blue Nile sediments were transported by special hand rail cars to a rotary mixer. In its way to the mixer the organic materials were added, and then the solid bricks were formed by hand. The formed bricks were dried under sun and fired in Hoffman kiln. The production was stopped in 1958 due to the inferior quality of the produced bricks, high production cost, high percentage of breakage and that the production
was not continuous due to the flood seasons. Many trials were made to rerun the production in this factory but the trials were not successful.

From the above mentioned facts it is clearly noticed that the reasons behind discontinuity of these Factories are (11):

1. Discontinuity of production
2. Unavailability of skilled labour and insufficient experience
3. Inferior quality of bricks
4. High percentage of breakage
5. High production cost.

2.2.2 Existing Brick Factories:
In Sudan there are three new modern mechanized brick factories, the technology of production at all these factories is the same. They only differ in their design capacity and the number and type of the machines in the line of production.

The three factories are Sudanese Brick Factory at Elbageer which belongs to the Islamic Development Company, Soba brick plant which belongs to The University of Khartoum, and Atbara Brick Factory.

2.2.2.1 Technology Of Production:

2.2.2.1.1 Raw materials

The basic raw materials for these factories are the Nile deposits which are very sensitive to drying because they contain clay minerals which have a high degree of expansion when wetted and high contraction when dried. Therefore, some leaning and opening materials are added like sand, grogs and kaolin.

In Soba brick Plant and Elbageer Factory, Blue Nile deposits are used, where the clay fraction is low (range between 10-20%). In order to increase the clay fraction and to improve the drying behavior of produced bricks 10% and 30% of kaolinite clay are added respectively.
In Atbara brick factory the clay fraction range between 50%-60% therefore 30% sand is added in the mix (11).

2.2.2.1.2 Production Lines:

a. Production Line Of Atbara Brick Factory:
Loading shovel is used in Atbara brick factory for clay excavation and then clay is transported to the production line by dumping trucks.

The production line begins with two boxfeeders for feeding clay and sand each one joined with slat conveyor of adjusted speed to give the required proportion of the materials (sand and clay). The slat conveyor carrying the sand pours it on that of clay Figure (2.1). The mix is then transported to the mill for mixing, grinding and milling. After milling the mix is transported by belt conveyor to the screener where all the grass, roots and pushes are picked out. The mix is finally shaped by extruder where a rectangular column of fixed cross section is extruded and is then cut into pieces of bricks by wire cut machine. The formed bricks then taken manually from the conveyor to be stacked in racks. The racks are taken by forklift to a drying chamber.

![Figure (2.1) Atbara Factory production line](image)

b. Production Line of Soba brick Plant:
The production line of Soba Brick Plant was discussed previously
c. Production line of Sudanese Brick factory:

At the beginning the production line composed of two lines one for the clay and the other for kaolin Figure (2.2). The kaolin line includes box feeder (vibrating hopper) which feeds the mill, the milled kaolin is fed to the silo by bucket elevator after sieving by screener. Over size particles of kaolin are returned back to the mill by a conveyor for more grinding.

The second line which is for clay consist of box feeder and a mill for clay grinding the two lines join at a mixer where the clay and kaolin are mixed with a 15% water then the mix is conveyed to a big box feeder of 75 ton capacity and then to another mixer and to the fine differential mill for fine grinding and finally the mix is transported by a conveyor belt to the extruder machine.

The cutting at this factory is completed in two stages: columns each of length equivalent to 16 bricks are cut and then every three columns are cut together into brick pieces.

The bricks are then set to steel boards and loaded automatically into finger cars, which moves in rails to the dryers. The bricks with their boards are left inside the dryer.

After complete drying the finger cars come and take off the steel boards with their bricks to the stacking yards. The dried bricks are then stacked manually in stacks to be carried by forklift to the kiln.

**Figure (2.2) Sudanese factory production line**

2.2.2.1.3 Procedure of drying adopted in these factories:
There are many types of dryers, like the tunnel dryers, hot floor dryer, chamber dryer………etc.

Chamber dryers are used in all brick factories in Sudan. The bricks are set in the dryer’s shelves and hot air passes through them. The hot air which drawn by suction fans from the cooling zones of the kilns is distributed by air mixture fans. These fans are either moving on rails inside dryers or fixed to the walls.

If the hot air is not enough for drying, hot air generators are used as in Atbara and Elbageer factories.

The drying cycle differs from one factory to another. It ranges between 48-60 hrs for Atbra and Elbageer factories while it is longer in Soba plant because natural drying is used in addition to the artificial drying.

2.2.2.1.4 Firing:

The firing of bricks is completed in all these factories in circular Hoffman kilns. These kilns only differ in their capacity and the way of drawing exhaust fume. At Atbara and Elbageer factories a down draught kilns are used which are better than at Soba plant where up draught kiln is used. In Soba plant hot air is drawn out from the top of the kiln without proper utilization of heat.

Also this affects adversely the distribution of heat throughout the kiln.

The design firing cycles in these factories are 4 days Although they differ in their capacities but the actual cycles range between 6 to 8 days.

2.2.2.2 Quantity and quality of brick produced by modern factories:

a. Quantity of brick produced by modern factories:

The design capacities of the three factories are as follows:

1. Atbara brick factory = 15 million bricks /year
2. Soba Brick plant = 10 million bricks /year
3. Sudanese Brick factory =25 million bricks /year
Total = 50 million bricks/year

From the above mentioned figures the quantity of bricks produced by mechanized methods i.e. by these factories if they work by their maximum design capacity not exceeding 2% of the quantity of the traditionally produced bricks.

But the actual capacities of these factories do not exceeding 40% of their design capacities and the production in these factories is not continuous because of shortage of Fuel, electricity and low demand due to the high cost and limited use as facing bricks (11).

b. Quality of the produced brick:

There is a high percentage of breakage in these factories which reaches some times 30% which reduces the productivity and increases the production cost of bricks.

The mechanical and physical characteristics of the bricks produced by these factories are complying with the International Standards. Table (2.2) shows these properties.

**Table (2.2) Physical and mechanical properties of bricks produced by the three factories** (11)

<table>
<thead>
<tr>
<th>Factory</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
<th>Height (mm)</th>
<th>Water absorption %</th>
<th>Compressive strength MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atbara</td>
<td>239</td>
<td>112</td>
<td>71</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>Elbageer</td>
<td>234</td>
<td>114</td>
<td>65</td>
<td>15</td>
<td>18.8</td>
</tr>
<tr>
<td>Soba</td>
<td>245</td>
<td>115</td>
<td>63</td>
<td>12</td>
<td>19.3</td>
</tr>
</tbody>
</table>
These bricks are mainly used as facing bricks although stated the above characteristics enable them to be used as loadbearing.

A field study in Egypt proved the possibility of using similar type of bricks in four storey buildings (Ground+Three Floors) and the cost was lower than similar buildings built with concrete skeleton (12).

A similar work is now performed at BRRI but its results are not yet published. The importance of such study comes from the fact that big quantities of cement and reinforcing steel can be saved and therefore hard currency is saved since these materials are imported from outside the country.

2.2.3 Some features of technological developments in the field of clay products:-

These features are:

A. Raw materials:

Clay, the basic raw material from which bricks are produced, is perhaps the most plentiful raw material used for the production of any building product.

As it occurs in nature, clay varies both in its chemical composition and physical properties. The manufacturer minimizes these variations by mixing clays from different locations in the clay pit or mine. For this reason, the manufacturing process must compensate variations in the properties of the raw material as some of these variations are expected to be reflected in the finished product. (5).

The clay used in the manufacture of bricks is technically known as a hydrated aluminium silicate in which there may occur various impurities such as oxides of iron, calcium, magnesium, sodium and potassium.

Brick clays occur principally in three principal forms all of which have similar chemical composition but different physical properties.

**Surface Clays:** As the name implies are found near the surface of the earth and are of sedimentary character.
Shale: are clays that have been subjected to high pressures in the earth until they have hardened to almost the form of slate.

Fire Clays: occur at greater depths than either surface clays or shale and are usually mined.

Requirement For brick clays:
In order to be suitable for the production of bricks, clays must have plasticity, which permits them to be shaped or moulded when mixed with water. They must have sufficient strength to maintain their shape after forming and drying and the clay particles must fuse when subjected to certain temperature ranges. In addition, uniform density, hardness and regularity of form are requisites. By adjusting various ingredients, it is possible to exert a degree of control in the resulting product. Within limits, silica will reduce shrinkage, but increased amounts will reduce cohesiveness and induce some firing problems. Fusing temperatures can be decreased by inclusion of carbonates fluxes. Iron oxide improves strength, but has a strong effect on colour.

B. Clay preparation:
The excavation of the clay is done mechanically by using one of the mechanical excavators (e.g. single-bucket, multi-bucket, shale cutter, etc) or by using bulldozer and loaders.

The clays are transported from the quarry to the factory by different means of transportation depending on the distance and the quantity of materials to be transported. These methods, include tramways, aerial ropeways, belt conveyors, tipping truck, dumpers, tractors and wagons.

These raw materials from the quarry should be converted into a suitable mixture. Therefore the particle size must be reduced and the clay must be blended with a suitable proportion of water. For these operation several kinds
of machine are available, The choice of crushing and grinding equipment, however, is determined primarily by the final shaping process.

C. Shaping:
There are various methods and equipments for the shaping process. The choice of the suitable method and the corresponding machines depends on the clay characteristics and the produced articles. These methods are summarized as follows:

1 Soft Mud Process:
This process is suitable for production of bricks from clays containing too much water or lean clays, which do not extrude well. The soft mud process consists of mixing clays with 20-30% or even more of water and then forming the units by wooden or steel moulds. The moulds are lubricated with sand or water to prevent clay from sticking to the mould walls and hence enhance easy demoulding. This is the oldest method for producing bricks and is used exclusively before the advent of brick making machine. However, soft mud brick production machine are now used. As mentioned in section 2.2.4 this process is dominating all over the Sudan. Traditional brickmakers practice it (5). lined later.

2 Stiff-Mud Process:
In this process the clay is mixed with only sufficient water to produce plasticity, from 12-15 %by weight (5). After thorough mixing, grinding and milling the clay is extruded through a die producing a clay column, somewhat similar to the toothpaste squeezed from the tube. This column may be solid or perforated. The clay column extruded is of definite cross- section representing the width and length of the bricks. As the column emerges out of the die it is cut into the desired depth or height.
As mud clays shrink both during drying and firing allowance for such shrinkage must be made in the size of the die or mould and in the length of the
cut. Both drying and firing shrinkage vary for different clays. Clays in the same pit or mine may exhibit different shrinkage.

De-airing is an important development in stiff-mud process. It is achieved by de-airing the chamber attached to the auger machine, through which clay passes. De-airing is carried out by a vacuum pump. The main advantage of de-airing is the increase of workability, plasticity and better utilization of inferior clays. It also increases green and fire strength of bricks. Soba brick factory is an example of this method. Detailed description of Soba brick factory was mentioned previously.

3 Dry Pressing:
In this process the articles are shaped by compressing granular clay mixes. The moisture content should be just enough to enable the particles to cohere under the applied pressure. The suitable moisture content for dry-pressing can vary considerably, depending on the fineness of the mix, and the proportion of non-plastic minerals. Moisture content of 7-9% is satisfactory but up to 20% may be needed for some clays (1). The advantage of this process is that the produced bricks can be set directly in the kiln without drying.

D. Drying:
This is a great problem in advanced countries as the weather is too humid for drying, and also it is a problem in developing countries when the clay is sensitive to drying. Brick units after forming must be dried before firing. Wet bricks coming from moulding or cutting machine contain from 3-30% or even more moisture depending on the type of manufacturing process. Water inside bricks exists in three forms, free or mechanical water that fills the pores; water which clings to the pore walls after free water is removed and chemically combined water. Free water is the water used in the forming process. Free and pore water are removed in the drying stage while chemically combined water
is removed at firing stage, usually at temperature between 450 °C and 650°C (1).

Drying should be carried out carefully; otherwise bricks will warp or crack due to uneven shrinkage, especially if clays are sensitive to drying like the existing available brick clays in Sudan. As remedies:

1- Add leaning materials such as sand, animal dung, kaolin…etc in order to decrease the amount of shrinkage.

Moreover, addition of non-plastic materials such as sand, grogs, etc facilitates drying by opening the structure of high plastic clay resulting in an enhanced movement of the water from inside of the brick to the out side and subsequent evaporation.

2- Dry from as many sides as possible in order to have uniform drying.

3- Decrease the amount of water used in forming.

4- Dry with moist air: Humidity of the surroundings coupled with elevated temperature has great influence on the drying behavior of the brick because dry air results in quick surface drying of the brick, while the inside remains wet. A moisture gradient is thus created with subsequent differential drying resulting in the warping or complete disintegration of bricks.

5- Make perforations in bricks: Perforations reduce moisture gradient and hence facilitate the escape of water.

A variety of dryers are available for different clays and different weather conditions e.g. chamber driers, hot floor driers and tunnel-driers.

Chamber driers are used in all factories in the country In these driers bricks are set in shelves and hot air is circulated by air mixer fans, attached to the chambers.
The hot air enters the chambers from the roof holes and the saturated humid one drawn out of dryer by holes found at the floor of the dryer. This enhances air circulation.

E. Firing:
Essentially consists of subjecting the clay units to gradually increasing temperature up to maximum of 1300° C depending on the fusion characteristics of clay. Firing of green bricks changes their physical and chemical structure giving them mechanical properties and resistance to slacking by water.

Firing comprises the following stages:

1. **Drying or smoking stage**: in this stage the clay units are heated to a temperature not exceeding 150° C, where last traces of free water are removed.

2. **Preheating stage**: It covers temperature range up to 800° C. In this stage the clay is partially decomposed and its combined water is liberated and passes out through the chimney.

3. **Full fire stage**: It covers the temperature range of 800° C up to the maximum temperature required, depending on clay and units types. In this stage the kiln is heated up at a maximum rate (5).

4. **The soaking period or the finishing stage**: It represents the period during which the maximum temperature of heating is maintained with the purpose of ensuring all parts of the unit attaining the maximum temperature. The principal recrystalisation, recombination and liquid formation (vitrification) reaction takes place during this period.

It should be emphasized that at certain temperature ranges there are phase transformations of some clay minerals, which are accompanied with volume changes (expansion or contraction). Through these ranges the rate of heating or cooling must be controlled or gradual. For example, at 573° C the quartz is transformed from $\alpha$ to $\beta$ form with 2% expansion in volume (5).

In presence of carbonaceous matter the fast rate of heating up to 600-700° C will lead to the fast formation of glassy material which seals the pores before gasses evolved from the
combustion of organic matter escape, thus leading to bloating of clay unit. Therefore, controlled rate of heating in this case is very important.

Firing is carried out in kilns. There are various types of kilns, which are basically classified as:

- Intermittent kilns, and
- Continuously operated kilns.

Intermittent kilns: These are the first kilns developed for firing bricks and tiles. They are of temporary structure and since it is natural for hot gases to rise, these kilns could be classified as up-draught.

Continuously operated kilns: there are two kinds of such kilns:

The first is the one in which the setting is stationary and the fire-front (the position of maximum temperature at which fuel is being applied) advances through it. While the fire is traveling through one part of the kiln the fired-goods are withdrawn from other parts and the green goods are set in their place (e.g. Hoffman kiln).

In the second type of continuous kiln the goods are carried on a platform of some kind- usually a car running on rails through a tunnel the temperature of which increases gradually to a maximum and then falls again to nearly atmospheric. In this case the zone of maximum temperature is fixed and the goods move through it (e.g. tunnel kilns). The following are some types of kilns used in Sudan:

**Scove kilns**

It is an intermittent kilns and it is the type used in traditional brick making in Sudan Figure (2.3).

It is a dense setting of bricks containing fuel, which is ignited at one end and left to burn gradually until it reaches the other end. It should be constructed on a dry level land. Previously fired bricks if available can be used to form a good flat surface. Tunnels are built at the base of the pile or setting. Through these tunnels fuel (wood) is fed. The width of a tunnel is 2-3 brick lengths equivalent to about 55cm and 2 brick lengths separate them from each other. The second and successive courses of brickwork that form a tunnel finally meet and the tunnel thus formed. The tunnels cannot be longer than 6m
otherwise wood inserted from both ends will not reach the centre of the tunnel. Large Scove kilns can be built with extending tunnels (3).

Green bricks above the tunnels are set in alternative courses of headers and stretchers up to a height of at least 3m above ground level. Small spaces are left between the bricks to allow free circulation of hot gases from the fire below. In Sudan the height is not more than 2.0 m. An exterior wall from previously fired bricks is built around the kiln to lessen heat losses through kiln boundary. The top of the kiln is covered with 2 or 3 courses of fired bricks closely packed to give good insulation. The whole structure of the kiln is then scoved i.e. plastered with wet mud mixed with animal dung or any other organic additive to reduce heat losses. This is where its name comes. Also sometimes the top of the kiln is covered with a layer of animal dung or any other organic matter which burns during firing and thus helps in firing the underneath green bricks. The resulting ashes will seal the openings between bricks and hence hamper the passage of flue gases and therefore better utilization of heat is achieved.

Some of the top bricks halfway between tunnels must not be scoved, so that they can be lifted out to increase airflow through the kiln as required. This adjustable ventilation is useful in controlling the rate of burning (3).

Wood is fed through tunnels. Sometimes it is placed during formation of tunnels and before their completion.

Kindling of fire is set usually at the mouth of the tunnel at the direction of the wind.

Strong blowing of winds should be avoided since they increase fuel consumption by about 25 % (3). The effect of wind blowing can be reduced, for example, by blocking the centre of the tunnel during construction or by temporary blocking of tunnel mouths with bricks. In the latter case, one end may be bricked up and fire set at the other end. Once fire is well alight, that end may be closed up by bricks while the other one is opened and lighted.
Latler on fire may be controlled by closing up tunnels mouths with loose bricks and adjusting the vents on top. As fuel (wood) burns away it must be replenished, until firing is complete.

Heat must be gentle at the beginning until all water in bricks is driven off. Adequate air flow through opening of vents is essential for removal of steam produced and fire should be kept low as Long as steam is seen to rise from the top of the Scove. This water-smoking period may last for several days.
In properly controlled Scove kilns once water smoking stage is completed, temperature raised gradually to the maximum over a period of few days. The maximum temperature is indicted by charring of dry grass or paper thrown on top of the scove kiln or appearance of a red glow by night. To even out
temperature the vents must be closed before attaining the maximum temperature for several hours. In order to have soaking period a last charge of fuel (wood) coupled with closing of tunnels mouths and sealing with mud of closed vents is required.

Fuel efficiency of Scove kilns can be increased by increasing their heights (11) but this is against their stability. Moreover, a high setting complicate the placing of green bricks on top courses and thus increases the risk of accident. Although wood and other solid fuels are the generally used fuels in scoves, oil and recently gas burners are used in some countries.

**Hoffman Kiln**

It is a continuous kiln. It was developed in Germany about 1858. Originally it took the shape of a great circular ring-chamber with massive walls with a chimney at the centre Figure (2.4), to which 12 underground radial flues converged from the inside wall of the chamber, dropping a damper can close off each flue. The chamber was barrel-arched and in the arch there were small feedholes through which fuel could be fed into the setting. 12 wickets were arranged, for setting and drawing the bricks in the outer wall of the chamber alternating with the flues. The chamber was thus divided in effect into 12 compartments, or chambers, defined by the wickets and flues leading from them and by how bricks were set. Once the kiln was lit it was not allowed to go out and the sequence of operation is continuous and when the kiln is in full operation two wickets would probably be opened and the other ten bricked up (3).

Therefore Hoffman kiln is a multi-chamber kiln, where air is warmed by cooling bricks in some chambers, pre-heats the combustion air for the fire, and exhaust gases (flues) from combustion pre-heat the green bricks. The main advantage of this kiln is its particularity low fuel consumption.

In original Hoffman kiln each chamber (of 12 chambers) is approximately 3.5 m long 5.0 m width. The height of each chamber is restricted to about 2.5 m
for easy working conditions. Daily output of such continuous kiln is at least 10,000 bricks.

Increased demand for bricks requires erection of larger kilns than those originally designed by Hoffman. Moreover, the original circular kiln has been modified for the following reasons:

- Increase in floor area of chamber requires considerable more building work between the chambers and the chimney.
- Circular kiln does not allow the construction of long tunnels unless the diameter is to be increased considerably. Longer diameter and longer flues increase the cost of construction considerably and complicate the operation of the kiln.
- Curved walls make the setting of bricks a difficult task.

For these reasons, the original design was modified to an elliptical form fig (2.5), which has long straight walls and a few curved chambers at the ends and with the main flue in the central (island) wall, connected directly to the stack (chimney) at one end of the kiln, or at its centre by a “T” flue to an external stack at one side of the kiln. Also an external flue was added to transfer hot air from cooling zone of the kiln to chambers containing freshly set bricks to dry them.
Fig (2.4) : Schematic diagram of original Hoffman kiln (3)
Fig (2.5): Schematic diagram of a typical firing circuit of elliptical Hoffman Kiln (3)
Hoffman kilns, nowadays have 16 or more chambers without division wall between them. Each chamber has its wicket, flue outlet with damper and may have a hot air inlet and outlet with dampers. A sealing paper is used to block flue gases from entering the setting and drawing chamber and to direct them to the chimney. It is fixed to the setting of bricks. It is fired i.e. removed when firing cycle move forward and new sealing paper is placed in a new proper place (3).

The operating principle is exactly the same as that of the original design; the only difference is the number of chambers, where in elliptical design the number of chambers is greater than in original design.

Hoffman kilns are designed to fire common building bricks to firing temperature up to 1050° C. (3) Output of Hoffman kiln is rather limited due to relatively small span of arch, which determines the size of the chamber.

The arch of the kiln beside it limits the size of a kiln and hence its output, its cost of construction represents a large fraction of the kiln construction cost as a whole. This is why arch less or open-top Hoffman kilns were designed. It can be elliptical or circular.

Also for easy construction rectangular Hoffman kilns were also designed. Open-top Hoffman kilns require special setting of bricks inside the kiln. The setting must be such as to allow sufficient airflow between bricks and wide enough spaces for the insertion and burning of fuel. These insertion spaces act like feeding holes in case of arched kilns. However, the whole setting must be sufficiently strong and stable to ensure safe operation of the kiln.

Kilns can be further subdivided into the three main classes, based on how they actually work,
A Up-draught kilns, where the heat travels naturally by convection, from the area of combustion up through the bricks.

B Downdraught kilns where the heat of combustion is drawn down through the bricks by the use of a chimney or forced draught system.

C Horizontal/Cross-draught kilns, where the heat of combustion is drawn sideways through the bricks by the use of a chimney or forced draught system.

F. Cooling

It is a period of time during which the temperature of burnt unit is reduced from the maximum temperature of heat to a temperature at which it is safe and convenient to remove them out of the kiln.

2.2.4 Status of the traditional Production of fired-clay Bricks:-

2.2.4.1 Method of production

This method is thoroughly studied in order to point out the difficulties and problems facing this important industry so as develop and up-grade it. For detailed description of method of production the references (1), (5) and (11) can be consulted. These problems and difficulties were grouped as follows:

- The policy of the government to retain such industry to sustain the employment of the worker and hence retain the social structure.
- Non-availability of large investors (profitability very low).
- Shortage of skilled labour.
- Shortage of energy.

Inadequate infrastructure facilities.

2.2.4.2 Quantity and Quality of the locally Produced Fired-Clay Bricks:

Quantity of Bricks
All types of fired clay bricks find several uses in residential, services and investment buildings and the demand is increasing yearly specially after increase of population, urbanization and modernization of existing buildings.

In 1975 the demand for fire clay bricks in Khartoum was 134 million bricks per year but the demand jumped up to 562 millions in the year 1983 showing an increase of (320%). The increase in demand continued until it reached 1280 millions bricks in 1994 and the increase in demand is still in progression.

Tables (2.3) and (2.4) and Figure (2.6) illustrate that.

Table (2.3) Yearly consumption of brick in Sudan (11)

<table>
<thead>
<tr>
<th>Region</th>
<th>1983</th>
<th>1994</th>
<th>% Increase or decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khartoum</td>
<td>562</td>
<td>1280</td>
<td>+28</td>
</tr>
<tr>
<td>Central</td>
<td>520</td>
<td>1173</td>
<td>+26</td>
</tr>
<tr>
<td>Northern</td>
<td>121</td>
<td>91</td>
<td>-25</td>
</tr>
<tr>
<td>Eastern</td>
<td>107</td>
<td>84</td>
<td>-22</td>
</tr>
<tr>
<td>Darfur</td>
<td>139</td>
<td>78</td>
<td>-44</td>
</tr>
<tr>
<td>Kordofan</td>
<td>105</td>
<td>65</td>
<td>-38</td>
</tr>
<tr>
<td>Total</td>
<td>1,554</td>
<td>2,771</td>
<td>+78</td>
</tr>
</tbody>
</table>

+ Means increase
- Means decrease
Fig (2.6): Increase in the demand of fired clay bricks in Khartoum Region (11)

Table (2.4) Yearly consumption of bricks in Khartoum region (11)

<table>
<thead>
<tr>
<th>Year</th>
<th>Quantity of bricks</th>
<th>% Increase</th>
</tr>
</thead>
</table>
Quality of produced bricks: -
Locally produced fired-clay bricks are characterized by low quality, which is manifested in the low crushing strength, non-uniformity in dimensions, non-definite angularity, high variability in strength and high water absorption. Table (2.5) compares the properties of local bricks at different intervals with Sudanese standard for local bricks in a survey conducted by the Building and Road Research Institute.

From the table it can be concluded that the locally produced bricks are of poor and varying quality a state believed to limit the use of bricks as filler in reinforced concrete framed structure, and as load bearing in one-storey buildings. Figure (2.7) illustrates the serious drop in brick dimension, with time.

One of the most important contributions of the BRRI in the field of production of fired-clay brick was its co-operation with the Department of standardization and quality control to formulate the Sudanese standards for common burnt clay building bricks in 1974 and its co-operation with People Armed Forces/ (general head quarters) to formulate Sudanese military standard specifications for machine made bricks.

Table (2.5) Physical and mechanical properties of local bricks as compared with Sudanese standard for local bricks (1) & (13).

<table>
<thead>
<tr>
<th>Property</th>
<th>Local</th>
<th>Sudanese Standard 1974 (13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(millions)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimension</td>
<td>L (cm)</td>
<td>20.5-22.2</td>
</tr>
<tr>
<td>-----------</td>
<td>--------</td>
<td>-----------</td>
</tr>
<tr>
<td>W (cm)</td>
<td>9.8-10.4</td>
<td>9.1-9.8</td>
</tr>
<tr>
<td>H (cm)</td>
<td>5.1-5.4</td>
<td>5.4-5.8</td>
</tr>
<tr>
<td>Water Absorption</td>
<td>31-70</td>
<td>5.4-47.7</td>
</tr>
<tr>
<td>Compressive Strength (Kg/cm²)</td>
<td>24.6-36%</td>
<td>18.2-35.8%</td>
</tr>
</tbody>
</table>
Realizing this status of deterioration, the Department of Specifications tried in 1996 to implement the Sudanese standard for common burnt bricks of 1974, but it was faced by strong resistance exerted by local brick producers, a thing which led both parties (The department and brick producers) to make a compromise by which the dimensions of bricks increase yearly by 1.0 cm until it reaches the standard dimensions. But even this was not implemented. This is why bricks of year 2000 were of better dimension than previous years.

Fig (2.7) Drop in dimensions of traditional bricks with time in Sudan.
In line with this a study was conducted by BRRI to show the benefits gained if standard size bricks were used (is). This is reflected in: saving mortar materials (Cement, Sand, etc.), increasing productivity of brick laying, increasing the loadbearing capacity of wall and decreasing the overall cost of the building. Table (2.6) and Figure (2.8) reflects the benefits.

Table (2.6) Comparison of bearing capacity of walls 1.5 brick thick and 3.0 m high made from different types of bricks (11)

<table>
<thead>
<tr>
<th>Properties</th>
<th>Brick Types</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Common Bricks</td>
</tr>
<tr>
<td>Bricks Type</td>
<td>Dimensions(mm)</td>
</tr>
<tr>
<td></td>
<td>Length<em>Width</em>Height</td>
</tr>
<tr>
<td>Average water Absorption %</td>
<td>27</td>
</tr>
<tr>
<td>Compressive Strength MPa</td>
<td>5.4</td>
</tr>
<tr>
<td>Design load/ MPa</td>
<td>0.086</td>
</tr>
<tr>
<td>Bearing Capacity (kn/ml)</td>
<td>25.4</td>
</tr>
</tbody>
</table>
Chapter Three
3. Experimental Work

3.1 Testing Programme

3.1.1 Introduction
The Primary objective of this research as stated previously is to improve the quality of bricks produced by Soba Brick Plant in order to minimize cracking and breakage of bricks during shaping, drying and firing. To achieve this a research programme encompasses both field and laboratory works, are formulated and then conducted in order to study the raw materials and to find the appropriate mix and then to run tests to achieve the stated objective.

3.1.2 The fieldwork:
The exploration work includes manual digging of (35) test pits in an area extending 86 m along the River bank and 100 m off the River bank. The exact locations of the test pits were clearly shown in sketch map of Figure (3.1). The depth of test pits varies between 2.0-4.0 m depending on the topography of the land. From each test pit (2- 4) samples were taken depending on the depth of the pit since from every 1.0 m depth a sample was taken .The collected samples were marked according to their depth and locations as shown on the map, Figure (3.2).

Then composite or representative samples were taken as out. lined later.
3.1.3 Laboratory work:

The laboratory testing included the following:

3.1.3.1 Ceramic tests for individual samples:

This comprises the determination of:

a) Physical analysis

Physical testing was conducted in the main laboratory of the BRRI and includes the following analysis.

Particle size distribution:

Particle size distribution was carried out according to BS 1377-1975, which includes dry and wet sieving.

As sieve test yields no information about the size of grains smaller than 63µ, and as it is the finer particles that play the greatest role in the plasticity, and consequently the drying and firing properties of the clay, then a sedimentation process using the hydrometer method was carried out to determine these fine materials.

Atterberge limits:

The plasticity of clay is the characteristic property, which is for practical purposes is the same as workability and is related to dry strength and particle size.
The test was designed to determine plasticity index PI of various clays as specified by BS No 1377-1975 by defining the liquid limit (LL) and the plastic limit (PL), the difference between the two values represents the plasticity index. Cone pentrometer method was used to determine L.L. Plastic limit was determined by rolling a piece of clay on a flat surface to make filaments approximately 3.0 mm in diameter. Through continuous rolling, filaments became dry and broke into pieces approximately 10 mm long. The m.c of these broken filament was taken to be the P.L.

**The specific gravity test:**

The test was determined by using density bottle method according to BS 1377-1975.

**b) Linear and volumetric Shrinkage tests:**

**Linear Shrinkage**

The tests were carried out on samples representing the different test pits at different depths. The tests were conducted by placing the clay paste in a steel mould 14 cm long, and dried at 105° C till no further change in length was observed. This test usually determines the fatness and shortness of clay, and generally a linear shrinkage between 4-5% designates short clay, whereas that between 10-12%(14) represents fat clays. The latter is usually associated with drying problems. The high plastic clays usually exhibit high drying shrinkage, which may leads to disintegration or warping of the product. Leaning with other non-plastic materials may rectify this difficulty.

**Volumetric Shrinkage:**

*Freshly made bricks contain from about 8-25 % water or even more depending on the manufacturing process by which bricks are made. Before being fired bricks are dried and, as the moisture is driven off, the particles of clay, which (to start with), are surrounded by films of water drawn closer together, causing a shrinkage of the mass. Before all the moisture is driven off, however, the particles will be in contact, and*
shrinkage will either cease or be very much reduced. The last few particles of water are driven off with virtually no shrinkage (16).

A typical volumetric drying shrinkage curve is shown in Fig. (3.3). To obtain such a curve, weights and volumes are measured at different stages during drying and the results are plotted in terms of the clay volume and weight of moisture associated with 100g of dried clay. With small test pieces and slow rates of drying the initial contraction is equal to the volume of water removed and the curves can be defined by the three factors $M_L$, $S$ and $V_D$ where:

$M_L$: Moisture content at which the main contraction ceases (The leather-hard moisture content).

$S$: The apparent “Solid” volume of 100g of dry clay. This excludes pore spaces that originally contained water in the plastic mix.

$V_D$: Total dry volume of 100g of dry clay in the condition in which it has dried out from the plastic mix. The straight line through $S$ is at 45 degree. The actual volume of a piece of plastic clay which contains 100g of clay and has a moisture content $M$ is thus $(S+M)$ c.c and its weight $(100+M)$g. since the dry volume of the same piece is $V_D$ the volumetric shrinkage from the moisture content $M$ to the dry state is $(S+M-V_D)$ c.c, and the percentage shrinkage on the dry volume basis is

$$\left(\frac{S + M - V_D}{V_D}\right) \times 100$$

This formula enables the shrinkage from any known working moisture content to be calculated. The linear drying shrinkage may be taken as one third the volumetric shrinkage with sufficient accuracy for normal purposes. The movements during drying are of immense importance to the brick-maker since it is possible at this stage to weaken the structure of the brick so that there may be production losses due to handling and, what is even more serious, a loss in strength of the fired product. Drying shrinkage is high for clays with a high proportion of fully dispersed clay minerals, but is not unduly high if the clay mineral is compacted till it forms aggregates.
The nature of the clay mineral is also important since this control specific surface area, and the higher this is the higher is the drying shrinkage.

This method can be used in this study to determine the leather hard of the clay mixes under investigation with some modification.

For the determination of leather hard at the field, ten bricks from the produced full size bricks were selected randomly and marked on their top with a groove line of 22 cm length.

The length of that line and the weight of brick were measured at different intervals during drying till bricks became completely dry.

From the different weights of bricks m.c was computed.

A graph of moisture content against the line length was drawn.

The m.c at which shrinkage ceases is termed critical m.c or leather hard.

3.1.3.2 Ceramic tests for composite samples:

The individual ceramic tests revealed that the material tested was rather inhomogeneous and the deposit showed some variation horizontally and vertically. In view of this an experimental work has been designed, to include:

- Selection of composite samples
- Characterization of composite samples.

3.1.3.2.1 Selection of composite samples:

According to the profile results and the physical tests, the area under investigation (i.e. between the excavator rails and the Nile Bank) was divided into two blocks. First block consists of boreholes A1, B1, C1 and D1 while the second consisted of D1, E1, F1 and G1 See Fig (3.2). The first block was divided into two portions the first portion represented the upper layer up to a depth of 2.0m and lower layer of depth 2.0-4.0 m
represented the second portion. The same implied to second block. The composites are then designated as follows:

**Composite sample 11:**
Represents clays from upper layer (up to depth 2.0 m) of first block

**Composite sample 12:**
Represents clays from lower layer (depth 2.0-4.0 m) of first block

**Composite sample 21:**
Represents clays of upper layer (0.0-2.0 m) of second block.

**Composite sample 22:**
Represents clays of lower layer (2.0-4.0 m) of the second block.

3.1.3.2.2 Characterization of composite samples:

Composite samples were prepared and characterized as follows:
- Atterberge limits
- Particle size distribution.
- Specific gravity
- Shrinkage limit
- Volumetric shrinkage (to determine Leather hard)
- Chemical analysis
- Mineralogical analysis (by XRD)

The mineralogical analysis was conducted in the Central Petroleum Laboratories. Using X-Ray diffraction technique. Analysis was carried out on four samples:

1/ Mix of composite samples 11&12 on the bulk material
2/ Mix of composite samples 11&12 on clay fraction only
3/ Mix of composite samples 21&22 on the bulk material
4/ Mix of composite samples 21&22 on clay fraction only

3.1.3.3 Characterization of Kaolinitic additive:

These include:
3.1.3.4 Effect of kaolin addition on physical characteristics of Nile silt:

This part is intended to investigate the effect of kaolin as an additive on some physical properties of Nile silt at Soba. The selected composite samples as well as kaolin were pulverized to pass 40 mesh. Kaolin was added to the composite samples in proportion of 0, 10, 20 and 30% by weight.

Water was added to these mixes after thorough mixing. The mixes were left for two days for ageing and the Atterberg limit and shrinkage limits were determined.

3.1.4 Technological Tests:

Technological tests comprised proportioning of materials (different mixes of clay and kaolinite), shaping, drying and firing properties of the different mixes.

3.1.4.1 Production of Bricks models:

The composite samples 21 and 12 were used in production of models. These two composites are selected to represent top and lower layers of the area under investigation because as seen from Table 3.6 all composite samples are almost similar.

Thirty brick models of size. 110*37 *24 mm were produced from each of the following mixes for the two composite samples:

i) 0:10 by weight kaolinite: clays (i.e. pure Nile silt)
ii) 1:10 by weight kaolinite: clays (i.e 10% kaolin)
iii) 2: 10 by weight kaolinite: clays (i.e 20% kaolin)
iv) 3: 10 by weight kaolinite: clays (i.e 30% kaolin)

After thorough mixing and blending of the mixes brick models were produced using laboratory de-airing extrusion machine.
Drying was carried out in closed chamber. After complete drying, samples of ten bricks from each mix were taken and fired in an electric furnace at a temperature of 900° C with a soaking period of one hour.

The following properties of green dried bricks were determined:

i. Dimension

ii. Weight (after further drying in oven for 24 hours at 105° C)

iii. Green density i.e. density of green bricks.

iv. Green strength (using ply wood sheets instead of cement mortar for bedding)

v. Linear dry shrinkage (Sd) which is determined by:

\[ Sd = \frac{(\text{original length} - \text{length after drying}) \times 100}{\text{original length}} \]

Original length means length after moulding and before drying.

vi. Volumetric shrinkage (leather hard determination)

For fired brick models the following properties were also determined:

1. Dimension
2. Weight (after drying in oven)
3. Loss in weight after firing
4. Density of fired bricks
5. Water absorption (by immersion in water for 24 hours)
6. Compressive strength.

7. Linear firing shrinkage (Sf), which is determined as follows:

\[ Sf = \frac{\text{length after drying} - \text{length after firing}}{\text{length after drying}} \times 100 \]

8. Total linear shrinkage (St), which is determined as follows:

\[ St = \frac{(\text{Original length} - \text{Fired length}) \times 100}{\text{Original length}} \]

3.1.4.2 Production of full size bricks:

According to the results obtained from brick models, the mix (2:10 kaolin: Nile silt) was found to be the appropriate mix
Soil represented by composite sample II (A1, B1, C1 & D1 to a depth of two meters) was excavated by the plant chain buckets excavator and loaded on a dumper truck to the working yard near the production line. Soils of all layers were first properly blended using a loading shovel and then mixed with kaolinite clay.

The mix was then watered and left for ageing for (2-4) days to give ample time for the water to breakdown the clay lumps and then enhance even distribution of water between clay particles. The mix was then processed by the plant production line and full size (250*120*67) mm bricks were produced using the plant Extruder.

Drying was carried out in the plant drying chambers, ten bricks were selected randomly from the dried bricks and fired in the electric furnace at a temperature of 900°C with soaking period of two hours.

The following properties were determined:

1. For wet bricks (directly from shaping line):
   i) Dimensions
   ii) Wet weight
   iii) Moisture content of shaping.

2. For green dried bricks
   i. **Dimension**
   ii. Dry weight (After oven drying for 24 hours at 105°C)
   iii. Dry compressive strength
   iv. Linear dry shrinkage %
   v. Volumetric shrinkage (to determine L.H)

3. For fired bricks:
   i. Dimensions
   ii. Final fired weight
   iii. Loss in weight after firing
   iv. Linear firing shrinkage (Sf)
   v. Water absorption
   vi. Compressive strength
Chapter four

4. Test Results and Discussion

4.1 Introduction:

In this section the physical, chemical and mineralogical analysis were presented and discussed, together with geological profile of test pits and behavior of bricks model and full size bricks during drying and after firing.

4.2 Physical, chemical and mineralogical analysis

4.2.1 Individual samples

4.2.1.1 Geological profile and physical test results

Table (4.1) shows the Geological profile of the test pits while Tables (4.2) to (4.6) and Figures (4.1) to (4.13) show the particle size distribution, Atterberg limits and linear shrinkage of soils of test pits at different depths.

In this respect the first layer (0.0-1.0 m depth) of test pits A1-G1 of row (1) is well-graded clayey silt with varying amount of clay ranging from 16-26 % and high content of silt 65-79 %.

The second layer (1.0-2.0 m) of these pits is sandy clayey silt with varying amount of clays (10-23 %) and sand (6-30%) while its, lower layer (2.0-4.0 m) is clayey silt with ranging amount of sand (0-25%) and high content of silt (53-81%).

The plasticity index of these three layers is 11-27, 0-18 and 11-19 % respectively which confirm the above classification.

In case of soil of row (2) as shown in Table (4.3) the top first layer for pits A2, B2, C2, is non-plastic with high silt content ranging between 78- 85% and sand ranging between 15- 22%, while its second layer (2-4 m) soil is sandy clayey silt with varying amount of clay 19-30% and sand 2-9% with the plasticity index varying between non plastic to 17 %.

The soil of pits D2, E2, F2 and G2 ( of row 2) is clayey silt with, clay content 15-25% and silt 60-78%.

Regarding soil of row (3), The first layer (0.0-1.0 m depth) of all test pits is non-plastic soil with high content of silt. These test pits were only excavated to a depth of 2.0 m.
The second layer of these test pits (of row 3) which is below 1.0m has varying content of silt and clay ranging between 52 and 100% and plasticity index ranging between 9 and 17%.

The first layer (0.0–1.0 m) of test pits of row 4(A4-G4) is well-graded sandy silt with silt and clay ranging between 53% and 83% and sand between 17 and 45%.

The linear shrinkage of this layer is low, which means that the clay content is low.

The first layer (0.0-2.0 m) of row 5 is sandy clayey silt with the plasticity index ranging from non-plastic to 47%. The higher values being of pits F5 and G5 while the lower values were for pits A5-B5. This is confirmed by the high contents of silt and clay of test pits F5 and G5.

Table (4.1) Geological profile of test pits of row(1) soil

<table>
<thead>
<tr>
<th>Test Pit No</th>
<th>Depth</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(0.0-1.0m)</td>
<td>(1.0-2.0 m)</td>
<td>(2.0-3.0 m)</td>
<td>(3.0-4.0m)</td>
</tr>
<tr>
<td>A1</td>
<td>Clayey silt</td>
<td>Sandy clayeysilt</td>
<td>Sandy clayey silt</td>
<td>Sandy clayey silt</td>
</tr>
<tr>
<td>B1</td>
<td>Clayey silt</td>
<td>Sandy clayeysilt</td>
<td>Clayey silt</td>
<td>Clayey sandy silt</td>
</tr>
<tr>
<td>C1</td>
<td>Clayey silt</td>
<td>Sandy clayeysilt</td>
<td>Clayey silt</td>
<td>Sandy clayey silt</td>
</tr>
<tr>
<td>D1</td>
<td>Sandy clayeysilt</td>
<td>Sandy clayeysilt</td>
<td>Sandy clayeysilt</td>
<td>Sandy clayeysilt</td>
</tr>
<tr>
<td>E1</td>
<td>Sandy clayeysilt</td>
<td>Sandy clayeysilt</td>
<td>Sandy clayeysilt</td>
<td>Sandy clayeysilt</td>
</tr>
<tr>
<td>F1</td>
<td>Clayey silt</td>
<td>Sandy clayeysilt</td>
<td>Sandy clayeysilt</td>
<td>Sandy clayeysilt</td>
</tr>
<tr>
<td>G1</td>
<td>Sandy clayeysilt</td>
<td>Clayey sandysilt</td>
<td>Sandy clayeysilt</td>
<td>Clayey sandysilt</td>
</tr>
</tbody>
</table>
Table (4.2) Physical Properties of Soil of row (1) between River Bank and excavator

<table>
<thead>
<tr>
<th>Designation</th>
<th>Depth (m)</th>
<th>L.L</th>
<th>P.L</th>
<th>P.I</th>
<th>Clay</th>
<th>Silt</th>
<th>Sand</th>
<th>Linear shrinkage %</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.0-1.0</td>
<td>45</td>
<td>25</td>
<td>20</td>
<td>26</td>
<td>72</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1.0-2.0</td>
<td>33</td>
<td>-</td>
<td>N.P</td>
<td>10</td>
<td>60</td>
<td>30</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>2.0-3.0</td>
<td>42</td>
<td>24</td>
<td>18</td>
<td>18</td>
<td>75</td>
<td>7</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td>3.0-4.0</td>
<td>42</td>
<td>26</td>
<td>16</td>
<td>24</td>
<td>62</td>
<td>14</td>
<td>9.3</td>
</tr>
<tr>
<td>B1</td>
<td>0.0-1.0</td>
<td>56</td>
<td>31</td>
<td>25</td>
<td>25</td>
<td>75</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1.0-2.0</td>
<td>33</td>
<td>-</td>
<td>N.P</td>
<td>23</td>
<td>62</td>
<td>15</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>2.0-3.0</td>
<td>41</td>
<td>28</td>
<td>13</td>
<td>20</td>
<td>80</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>3.0-4.0</td>
<td>41</td>
<td>30</td>
<td>11</td>
<td>19</td>
<td>56</td>
<td>25</td>
<td>6.4</td>
</tr>
<tr>
<td>C1</td>
<td>0.0-1.0</td>
<td>44</td>
<td>33</td>
<td>11</td>
<td>25</td>
<td>73</td>
<td>2</td>
<td>2.7</td>
</tr>
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- Means it is not determined
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4.2. 1.2 Chemical Analysis

Chemical analysis of Soba silt was carried out previously, as revealed by Table (4.7). But in this work only Sulphate and chloride contents were determined for test pits A1-F1 and for composite samples 11 and 21, as shown in Table (4.8).
From chemical analysis mineralogical composition of soba silt was determined by using method of rational analysis. Table (4.9) shows the mineralogical composition of Soba silt.

It is clearly seen that it contains a considerable amount of free silica (quartz). But this amount is within the acceptable limits of 35-50% for brick clays (1).

It worth mentioning that silica is usually present into two forms free silica as quartz or combined silica as in combination with alumina e.g. clays or in combination with fluxes and alumina to form feldspar, mica etc (1). Presence of silica in clays reduces plasticity, refractoriness, drying and firing shrinkage and tensile and crushing strength.

Alumina in Soba silt occurs in the form of clay mineral and feldspar and it is within the acceptable limit for brick clays (10-25%) (1). Aluminous compounds, other than clay minerals reduce plasticity since they are not plastic and increase refractoriness, provided that the total percentage of alumina is greater than 5% (1).

Iron content of Soba silt (9.44-11.6%) is slightly higher than that generally present in brick clays (3-9%). But this high content seams to have no negative effect on the end product as the fired bricks have clear red colour and have no efflorescence.

Iron and its compounds may occur in many forms such as ferric oxide (Fe₂O₃), iron sulphides (FeS and FeS₂), iron carbonate (FeCO₃), ferrous and ferric oxides, ferrosilicate, ferro-alumino-silicates, ferrous aluminate, soluble iron salts and chlorites (1). Presence of iron compound may reduce refractoriness, and if soluble may form scum and spots on bricks, and they may affect the colour (1).

Chief calcium compounds in clays are calcite (CaCO₃), various calcium silicate and alumino-silicates, which include feldspar and mica. They may act as fluxes and hence reduce vitrification temperature and refractoriness of clay. They also reduce shrinkage and facilitate drying. If they present in form of CaCO₃, when heated to about 900 °C, they are converted to CaO (calcium oxide) which is known as quick lime and if it remains uncombined, on cooling it may absorb moisture from atmosphere. In doing so it will expand causing bricks to crack or burst (lime blowing or bursting). Moreover, although calcium sulphate are not commonly present in natural clays it may be formed on firing in clays containing calcium carbonates and pyrites (1). It is the main cause of efflorescence and scum.
Magnesium compounds approximately have the same effects like that of calcium compounds. They occur in clays in the form of magnesite MgCO₃, dolomite MgCa (CO₃), chlorites, spinel, corierite and as various magnesium silicate and alumino silicate. Iron and magnesium contents of Soba silt is (9.51-7.3%) which is less than that found in brick clays (15%). To avoid the harmful effect of calcium and magnesium compounds (lime bloating, efflorescence and scum) they should be in a fine form where their particles do not exceed 1.0 mm in size (1). It is evident from soil classification test that these compounds are present in fine form and thus confirmed by the fact that the produced bricks show no lime blowing or efflorescence.

As indicated in Table (4.7) sodium oxide (Na₂O) content varies from 1.21 to 1.54% and potassium oxide (K₂O) content varies from 1.12 to 1.35%. The total alkalies content is reasonable when compared with similar brick-making clays (Na₂O 0.2%-1.2% and K₂O 1.7-3.5%).

Alkali compounds in clays reduce refractoriness, vitrification temperature, green and dry strength of bodies containing them and reduce drying shrinkage since they preserve open texture.

Loss on ignition of Soba silt (10.55-12.37%) is within limits generally found in clays (6-14%) (1). It is a measure of volatile contents such as sulphur dioxide SO₂, sulphur trioxide SO₃, Carbon dioxide CO₂ and water vapour, which are released during firing after decomposition of the various constituents of the soil.

**Table (4.7) Chemical Composition of Soba Plant soils**

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<th>As tested By Geology Department Ministry of mining</th>
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</tr>
<tr>
<td>MgO</td>
<td>3.09 2.68</td>
<td>2.72 2.55</td>
</tr>
<tr>
<td>CaO</td>
<td>6.42 5.85</td>
<td>5.00 4.76</td>
</tr>
<tr>
<td>Component</td>
<td>Test 1</td>
<td>Test 2</td>
</tr>
<tr>
<td>-------------------------</td>
<td>---------------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>As tested By Institute for Materials Testing Belgrade 1982</td>
<td>As tested By Geology Department /Ministry Of Mining</td>
<td></td>
</tr>
<tr>
<td>Test 1</td>
<td>Test 2</td>
<td>Test 1</td>
</tr>
</tbody>
</table>
| Table (4.9) Mineralogical composition of Soba silt

Table (4.8) Sulphates and Chloride Contents of Soba soil

<table>
<thead>
<tr>
<th>Test Pit No</th>
<th>Depth (m)</th>
<th>Sulphate Content %</th>
<th>Chloride Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.0-1.0</td>
<td>0.05</td>
<td>Nil</td>
</tr>
<tr>
<td>B1</td>
<td>1.0-2.0</td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td>C1</td>
<td>1.0-2.0</td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td>D1</td>
<td>1.0-2.0</td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td>E1</td>
<td>1.0-2.0</td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td>F1</td>
<td>1.0-2.0</td>
<td>0.02</td>
<td>Nil</td>
</tr>
<tr>
<td>Composite 11</td>
<td>0.0-2.0</td>
<td>0.05</td>
<td>Nil</td>
</tr>
<tr>
<td>Composite 21</td>
<td>0.0-2.0</td>
<td>Nil</td>
<td>Nil</td>
</tr>
</tbody>
</table>

Test 1 and test 2 indicate different boreholes but on the same site
4.2.2 Composite Samples

a. Physical analysis:

From the obtained results it was clear that Soba soil is very heterogeneous, a thing which necessitates mixing of some soil strata. Four composites were formed.

Table (4.10) and Figure (4.14) exhibit the particle size distribution, Atterberg limits and linear shrinkage of composite samples.

It is clear that all these samples are almost identical and variation between test pit soils is reduced to the minimum and composites become clayey silt with clay content of 19-21 % and silt content of 67-78 % and with P.I ranging between 14-17 %.

<table>
<thead>
<tr>
<th>Composite Soil</th>
<th>Atterberg limits</th>
<th>Grain Size distribution</th>
<th>S.G</th>
<th>Linear Shrinkage %</th>
<th>S.L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L.L</td>
<td>P.L</td>
<td>P.I</td>
<td>Clay%</td>
<td>Silt%</td>
</tr>
<tr>
<td>11</td>
<td>41</td>
<td>27</td>
<td>14</td>
<td>21</td>
<td>70</td>
</tr>
<tr>
<td>21</td>
<td>41</td>
<td>27</td>
<td>14</td>
<td>20</td>
<td>67</td>
</tr>
<tr>
<td>12</td>
<td>39</td>
<td>25</td>
<td>14</td>
<td>20</td>
<td>78</td>
</tr>
<tr>
<td>22</td>
<td>43</td>
<td>26</td>
<td>17</td>
<td>19</td>
<td>73</td>
</tr>
</tbody>
</table>

**Table No (4.10) Physical Properties of Composite samples**
**b. Mineralogical analysis:**

The results of mineralogical analysis showed that the soil samples contained a considerable amount of quartz which was noticeable from the physical analysis and feldspar with calcite while the main clay mineral was montmorillonite. Some illites and kaolinite were also present (see appendix A-1 and A-2.)

c. **Leather hard**

Leather hard m.c for all composite samples was determined as outlined previously and the results are shown in Figure (4.15) to (4.18). The leather
hard m.c for all the four composites was found to range between 14.6 % - 15.6%.

4.2.3 Kaolinitic Clay

a. Physical analysis

The physical characteristics of three samples of kaolinitic clay from three different locations are presented in Table (4.11) and Figure (4.19). Its clay content is slightly higher than that of the Nile silt and its linear shrinkage is much lower than that of the Nile silt. This is why kaolinite clay is added to Nile silt in order to increase clay content and to reduce shrinkage.

Table (4.11) Physical characteristics of Kaolinite Clays

<table>
<thead>
<tr>
<th>Kaolinite clay location</th>
<th>Atterberg limits</th>
<th>Grain Size distribution</th>
<th>S.G</th>
<th>Linear Shrinkage %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L.L</td>
<td>P.L</td>
<td>P.I</td>
<td>Clay%</td>
</tr>
<tr>
<td>I</td>
<td>33</td>
<td>22</td>
<td>11</td>
<td>27</td>
</tr>
<tr>
<td>II</td>
<td>31</td>
<td>21</td>
<td>10</td>
<td>22</td>
</tr>
<tr>
<td>III</td>
<td>31</td>
<td>21</td>
<td>10</td>
<td>22</td>
</tr>
</tbody>
</table>

b. Chemical analysis

Chemical analysis of kaolin from Omdurman location was carried out at Geological Research Authority of the Ministry of Energy and Mining. Table (4.12) shows results of chemical analysis. From chemical composition rational analysis was carried out to determine minerals present in the kaolin. Table (4.13) shows the computed mineral
composition of kaolin. It was clearly seen that there was a large amount of quartz in this kaolin.
Table (4.12) Chemical composition of kaolin from Omdurman

<table>
<thead>
<tr>
<th></th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>68.2</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>21.6</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>1.44</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.32</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.26</td>
</tr>
<tr>
<td>LOI</td>
<td>7.79</td>
</tr>
</tbody>
</table>

Table (4.13) Mineralogical composition of Kaolin from Omdurman

<table>
<thead>
<tr>
<th>Location</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soda mica</td>
<td>3.21 %</td>
</tr>
<tr>
<td>Potash mica</td>
<td>2.72 %</td>
</tr>
<tr>
<td>Kaolin</td>
<td>48.72 %</td>
</tr>
<tr>
<td>Free silica</td>
<td>42.8 %</td>
</tr>
<tr>
<td>Others</td>
<td>2.55 %</td>
</tr>
</tbody>
</table>

C. Mineralogical Analysis of kaolin

Mineralogical analysis showed that the dominating mineral was quartz with some quantities of kaolinite and small amount of illite. This result confirmed the fact that the
kaolinite under investigation contained high percentage of quartz as clearly indicated by both physical and chemical analysis.

4.3 Effect of kaolin addition:

Generally addition of kaolin increases plasticity and decreases shrinkage of composite samples, Table (4.14).

But addition of more kaolin (more than 10%) gives less plastic mix as indicated by lower PI.
In this context addition of 10% kaolin to Soba silt seems to give an appropriate mix. But this has to be further tested and confirmed by technological tests.

4.4 Technological Tests

4.4.1 Production of bricks models

4.4.1.1 Drying of the prepared brick models

As stated previously in section 3.1.4.1 brick models were made from different soil composites with different kaolinite clay additions using BRRI laboratory de-aired Extrusion machine. The produced green bricks models were directly put in a closed chamber to simulate the drying conditions at the Factory. Three bricks from each batch were taken every day outside the closed chamber and dried under room conditions. These different conditions of drying influenced the behavior of drying of the produced brick models as shown in Table (4.15). Brick models from pure composite and that of 10% kaolin mix were difficult to extrude and shape and were completely disintegrated when dried directly at room condition while those from 20 and 30% kaolin extruded well and showed minor cracks when dried directly in room condition. Furthermore composites with 20 and 30% kaolin unlike pure composite and 10% kaolin mix showed no cracks after first 24 hours drying in closed chamber and then in open room conditions.
The forming m.c for all mixes ranged between 24.5-28.5% indicating that as the percentages of kaolin increased in the mix m.c decreased. This had positive effect in decreasing linear shrinkage and thus decreasing the possibility of cracking. This was further confirmed by the fact that the dimensions of model bricks from pure composite were less than of mixes incorporating kaolin. Table (4.16) shows these facts clearly.

The dry compressive strength of bricks models range between 21.7-24.5MPa and it increases with the increase of kaolin proportion.
This strengthened the idea of adding kaolin to Nile Silt so as to help in reducing or getting rid of drying problems

4.4.1.2 Firing behavior of model bricks

After complete drying, brick models that remained undamaged were heated and fired in an electric oven to 900°C with a soaking period of one hour and then allowed to cool down inside the oven. Table 3.17 shows the results of tests conducted on fired models, from which the following facts can be drawn:

- There were no great changes in the dimensions of brick models after firing as the firing shrinkage was relatively low (about 0.5-1.67%). The total shrinkage was found to be about 5.6-9.4% and the loss in weight was about 7.8-8.7%.
- The fired compressive strength was greatly increased. The highest fired compressive strength was achieved by the blend of 20% kaolin and 80% Nile silt. This may be due to the good gradation obtained by the mix which, permits good compaction as evidenced by the bulk density and due to the good drying behavior of the mix where no cracks occurred as cracks generally reduce compressive strength., the 30 % Kaolin mix gave the lowest compressive strength. This might due to extra quartz added as kaolin contains high percentage of quartz.
- The produced fired clay bricks models were characterized by no efflorescence.
Accordingly and from these results the mix containing 20% kaolin seems to be the most appropriate mix for Nile silt at Soba factory.

4.4.2 Production of full size bricks:
From the fore-mentioned discussions full size bricks (250x120x67) mm were manufactured at Soba brick plant as outlined in section 3.1.4.2 from the 20% kaolin mix since it was the most appropriate mix for Nile silt at Soba.
4.4. 2.1 Drying behavior of full size bricks

Drying is carried out in a closed chamber dryer for four days, and then the chamber was opened partially for other two days and finally opened completely for further drying.

Leather hard m.c was determined as stated previously in section 3.1.3.1.

- The forming m.c of full size bricks was slightly higher than that of model bricks. It was 30% on average. On mass production high m.c is sometimes required to prevent the cutting wire, for example, from damage and to ease the extrudability of the extruder.

- The leather hard m.c of the mix from which full size bricks was found to be 13.7% while that of pure Nile silt (composite 11) was 15.4%. This confirms the already stated fact that addition of kaolin decreases the forming m.c. This means that bricks after L.H m.c can be drawn out of chambers and dried directly under sun rays without fear of cracking and this has been confirmed practically.

- The linear shrinkage was rather high it was about 9%.

- Although this mix selected as appropriate but still there was a relatively high percentage of cracking during drying, and it was realized that the pattern of cracking was approximately identical for all bricks and this was largely thought to be due to the method of brick forming. This lead to make some changes in the die so as to equalize the pressure all over the die in order to have even distribution of clay substance all over the die. This gave better results, but still there were some cracks. Further an opening materials (10% grogs and animal
dung) were added to decrease the linear shrinkage and to free the bricks from cracks. This decreased the drying breakage from 27% to 5%.

4.4.2.2 Firing Behavior of full size bricks

Some bricks after drying were fired at laboratory furnace, similar to model bricks and some bricks were at the factory kiln.

- Bricks fired at laboratory furnace showed no cracks.
- Cracks and percentage of breakage were tremendously decreased when bricks of kaolin, grogs and Nile silt mix were fired at the factory kiln.
- The compressive strength of fired bricks was greatly increased as compared with that of green bricks and it was found to be 23.1MPa on average.
- Bricks showed no efflorescence
- Water absorption was relatively low if compared with that of local traditional bricks.
Chapter Five

5. Conclusions and Recommendations

5.1 Conclusions

The following conclusions could be drawn:

1. Blue Nile sediments at Soba were found to be very heterogeneous e.g., the plasticity index varied widely between non-plastic to 47%, a thing, which, necessitates homogenization by blending the different layers of sediment before being used in brick production.

2. Soba soil was of high silt content which rendered it difficult for shaping.

3. Soba silt showed high linear shrinkage at drying although it contained high percentage of silt and appreciable amount of sand. This was due mainly to the nature of clay which contained montmorillonite minerals. This lead to serious drying problems as manifested by cracking and high percentage of breakage during drying. To overcome this, drying must be controlled. In case of Soba plant this was achieved by decreasing rate of drying and drying was
carried out in humid atmosphere (drying in closed chambers for several days)

4. Kaolin of Omdurman was contains kaolinitic clay 48% kaolin but contained appreciable amount of silica. This was why it was less plastic and had low shrinkage.

5. Generally additions of kaolin to Nile silt of Soba increased its plasticity and decreased its shrinkage but beyond certain limits decreased the plasticity (10% addition gave higher P.I than that of both 20 and 30% additions).

6. Addition of kaolin decreased both forming and leather hard m.c, which was reflected positively on drying behavior of bricks.

7. Addition of kaolin increased the green strength of Nile silt at Soba.

8. Blend of 20% kaolin and 80% Nile silt although it gave lower green strength than that of 30% kaolin and 70% Nile silt blend but gave the highest firing strength.

9. Blend 20% kaolin and 80% Nile silt was the appropriate mix for the Nile silt at Soba (medium plasticity, good extrudability, good drying behavior, medium green strength and higher fired strength)

5.2 Recommendations

1. Good blending of the Nile sediments is highly recommended to minimize its variations.

2. To enhance good sedimentation (quantitatively and qualitatively) at Soba factory, the excavator rail should be moved to give way for flood water to enter and deposit its sediment. The sediment can further be increased if an appropriate dyke is built.

3. Due to low plasticity of the Nile silt at Soba (high silt and low clay content) and due to its high sensitivity to drying (presence of montmorillonite), dry press process or stiff mud process (where low m.c is used for forming) can be
tried in any future expansion of the factory or in any new brick factory using Nile sediments.

4. It is high time to look for alternative clays away from Nile banks to avoid the problems of the Nile silts and to avoid the environmental hazards caused by such industry.