Sudan University of Science and Technology
College of Post-Graduation studies
Mechanical Engineering Production

A Proposed Solution for the Erosive Wear Problem in Garri-4 Power Plant Sand Convoying System

حل مقترح لمشكلة التآكل بالتعرية في نظام نقل الرمل في محطة توليد كهرباء قري-4

Thesis submitted to Postgraduate College Sudan University of Science and Technology in Partial fulfillment of the Requirements for the Degree of M.Sc.

(Mechanical Engineering-Production Department)

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وَقُل رَّبِّ زِدْنِي عِلْمًا

صدق الله العظيم

Dedications

This work is dedicated to my family and many friends. A special feeling of gratitude to my loving parents, whose words of encouragement and push for tenacity ring in my ears. my brothers and sisters.
Also, this work dedicated to many friends, they have supported me throughout the process. I will always appreciate all they have done.
In addition, I dedicate this work to Garri-4 and Garri1,2 family, where this work is done, special dedications are owned to the Boiler Unit in Garri1,2.

Last, not least dedicate for my homeland Sudan.

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There are people like candles burn to light the way of the others, during this research I found many, give deep helping, the thanks is not give them their rights.

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Tanks any one helps in any field and all the teachers passed through my education levels.

Finally, I wish to thank all project readers who offered countless interesting, valuable, and stimulating suggestions.

In closing I am deeply grateful my parents for their endless love and patience.

Abstract:

Through centuries, the man try to optimize jobs, and reduce the costs. In transportations system, the compact one is more desirable. In this research the sand pneumatic conveying system, used in Garri-4 power plant CFB (Circulating Fluidized Bed) boiler, a problem of high rate erosion studied. And the research aiming to find optimum and reliable solution for it. Experimental test done by using sand-blasting machine to simulate and to test the proposed solution, which is the change of sand composition by mixing it with percentage of sponge coke powder, as well as the economic analysis done to evaluate and find the optimum solution. The study concludes that the mixture of 20% of sponge coke powder to sand has less erosion rate and more economical.

مستخلص

علي مر العصور سعي الانسان لتحسين الانظمة وتقليل التكاليف من خلال دراسة المشاكل ومعالجتها من خلال إيجاد الحلول المثلي منها. وتكمن اهمية انظمة ووسائل النقل في مناطق الانتاج في نقل المواد من مكان الي اخر كما تساعد في عملية تسهيل وتسريع الانتاج وتقليل الجهد. في هذا العمل تم التطرق لنظام نقل الرملة الهوائ المستخدم في محطة كهرباء قري4 التي تعمل بالفحم البترولي . ودراسة مشكلة التاكل الشديد في اجزاء الخط والناتج عن طبيعة الرمل القاسية. هدفت الدراسة الي وجود حلول اقتصادية واكثر فعالية بحيث يسهل تنفيذها علي ارض الواقع. وتم استخدام التجارب للتمثيل العملية داخل الخط باستخدام ماكينة Sand-Blasting لدراسة الحلول المقترحه وهو تغير طبيعة الرملة باضافة نسبة معايرة من بدرة الفحم البترولي. كما تم عمل دراسة اقتصادية لتقييم الحلول المقترحة. خلصت الدراسة الي ان نسبة 20% من بدرة الفحم البترولي بالنسبة لوزن الرمل هي الاقل تآكلاً مابين النسب الاخري والاكثر جدوى اقتصاديا.

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CAPTER 1

Introduction

1.1. Preface:

Through the centuries, man tried to reduce the costs and improve the performance of the system, and reduce the maintenance cost to be more economical.

The conveying system is considered the mussel of the industries, through which the different materials move from one point to another, either inside or outside the industries.

1.2. The problem Statement:

Garri 4 power plant is steam power plant, which use CFB (Circulating Fluidized Bed) boiler to generate steam. In CFB boiler the sand is required to maintains the continuous combustion of sponge coke and keep uniform heat distribution.

The sand delivered to the boiler by using the pneumatic convoying system as shown in figure (1.7). Where the piping system the medium through which the sand convoyed.

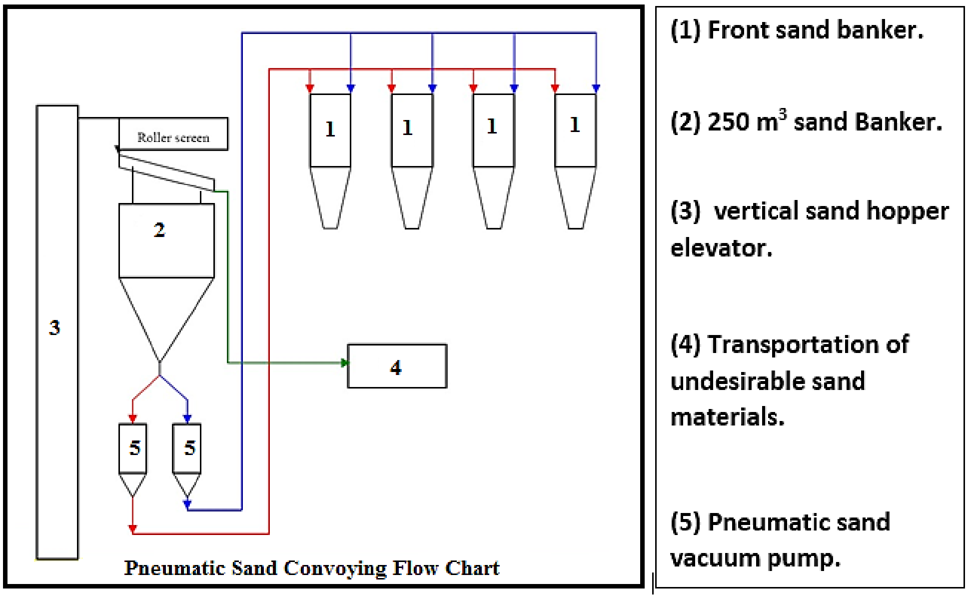

Figure 1.7: The layout of Sand pneumatic convoying system used in Garri-4 power plant

As the sand is considered abrasive particles, it caused a real wear problem, which appear in the piping fittings precisely in elbows and flange, the wear tear the piping fittings led to failure at the end. Where this problem is repeated almost weekly. (See Appendix).

1.3. Aim of this project:

The project aim to find optimum solution for the problems associated with Garri 4 case. That having less cost and more reliable.

1.4. The objectives of The Study:

- To Study the pneumatic sand convoying system.
- To find the source of the problem causing.
- To find optimum solution with respect to CFB boiler utilities.

1.5. Method:

The erosion rate of pneumatic sand system used in garri-4, studied through adapting sand-blasting machine to simulate the erosion rate inside the piping, where the powder of sponge coke added to the sand with different mixture percentage in purpose to decreased the erosion rate. As the economic analysis is done to evaluate each proposal.

CAPTER 2

Theocratical Background

2.1. Preface:

The Origin of world ‘pneumatic’ mid-17th century from French "pneumatique" or Latin "pneumaticus" from Greek word "pneumatikós", from "pneiu" means breath, "pneuma" means wind. which means containing or operated by air or gas under pressure [1].

A pneumatic conveying system is system through which bulk materials of almost any type can be transferred or injected using a gas flow as the conveying medium from one or more sources to one or more destinations. Air is the most commonly used gas, but may not be selected for use with reactive materials and/or where there is a threat of dust explosions.

Pneumatic conveying systems are basically quite simple and are eminently suitable for the transport of powdered and granular materials in factory, site and plant situations. [2].

2.2. History of Pneumatic Conveying System:

The pneumatic conveying system it's not modern system, it's found dates back to antiquity. The Romans, for instance, used lead pipes for water supply and sewerage disposal, whilst the Chinese conveyed natural gas through bamboo tubes. In 1847 the first documented pneumatic conveying system must be to the Peugeot plant at Valentigney, France where it served since for the exhaustion of dust from [3]. Since dry operation occurred only as a part of the grinding procedure, the system was designed to dedust a maximum of four grindstones simultaneously. The record of pipeline transportation of solids in air is more recent with the inception of fans to activate the first pneumatic conveying in 1866. [4].

In the late 19th century The first large scale application of pneumatic conveying و the vacuum conveying of grain. By the mid 1920s, negative and positive pressure conveying of grain was common. Since that time the practice of pneumatic wide variety of particulate solids. Between 1971 and 1977 A survey carried out by the British Hydrodynamics conveying has grown enormously and has extended to cover a Research Association, showed that the pneumatic conveying market in Britain grew by an order of magnitude and that during the one year period 1977 to 1978 a further 50% increase in the sales of equipment for pneumatic conveying systems was recorded [4].

During the First World War (1914 – 1918), was a difficult situation because of the high demand for foods, Labour scarceness and the risks of explosion were too high. All this factors influenced on the development of pneumatic conveying, which were the best solution for solving the problem. In the post-war period, pneumatic conveying systems were used for transportation coal and cement in the industry [4].

2.3. Type of Pneumatic Conveying System:

There are many versatile types of pneumatic conveying system as shown in the figure (2.1) [2]. Which can be utilized to transport different materials depends on process and material which need to be transport, the research focus in only one of this type which utilized in Garri 4 power plant, which is dense phase system, where its used to transport sand to the furnace.

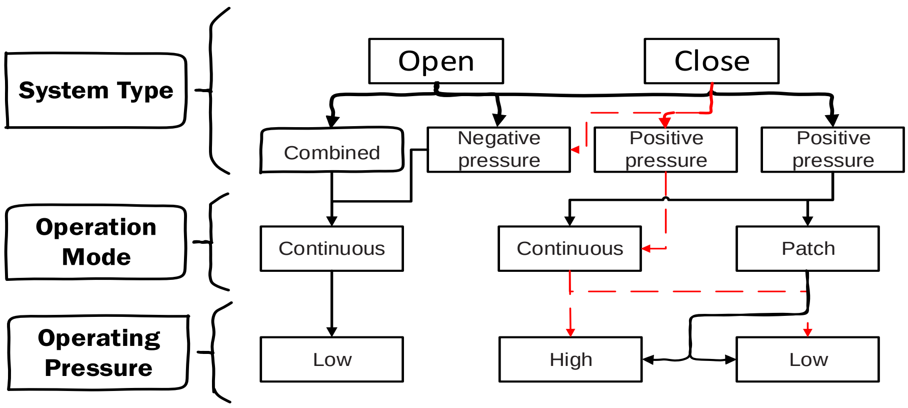

Figure 2.1: The Pneumatic Conveying System.

Here are most common pneumatic conveying systems used in industries:

2.3.1. Positive pressure system, which is shown in Figure (2.2) is probably the most common of all pneumatic conveying systems.

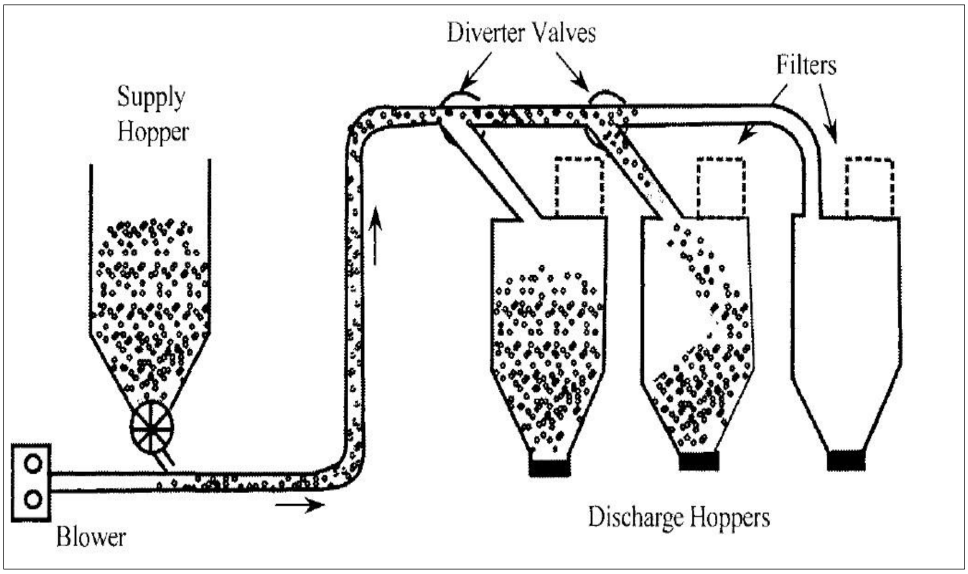

Figure 2.2: Positive pressure conveying system

In Positive pressure system, materials delivered with the help of the air from the fan or blower to the piping system. The systems are good to multiple discharge application; they are able to pick up material from the single point and delivered to several receiving points. The main characteristic of positive pressure systems is that the absolute pressure of conveying gas inside the pipeline is always greater than atmospheric pressure [4].

2.3.2. Negative pressure system, which is shown in the Fig (2.3), is commonly used to transport material from several feeding points to one receiving point. The principle of work of these systems is the same like in a domestic vacuum cleaner. The characteristic of the system is that the absolute gas pressure inside the system is lower than atmospheric pressure [4].

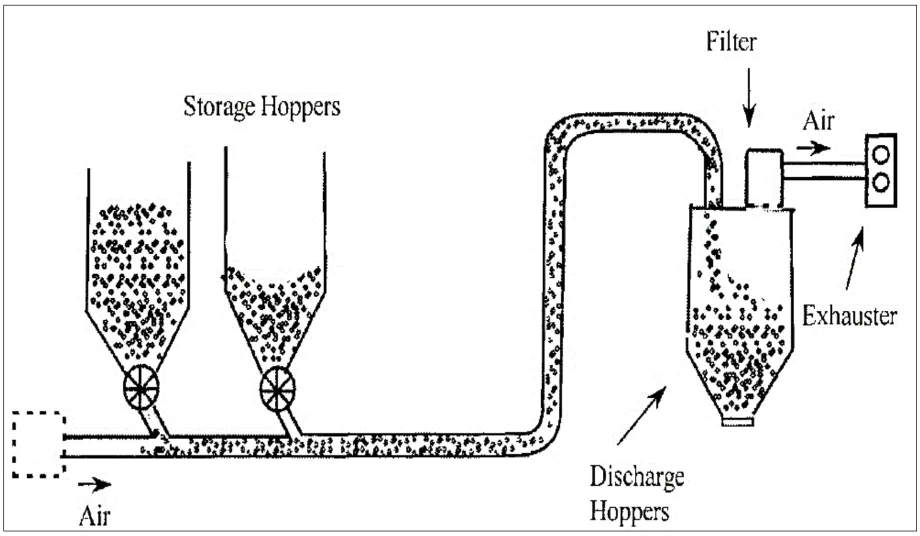

Figure 2.3: Negative pressure conveying system.

These systems are widely used to transport toxic and hazardous materials because the all gas leakage is inner [7].

2.3.3. Combined Negative – Positive pressure systems, are often referred to as "suckblow" systems. These systems are able to provide the multiple intakes and multiple discharge of a number of products. They are used in many industries [3]. The example of the system is shown in Figure (2.4).

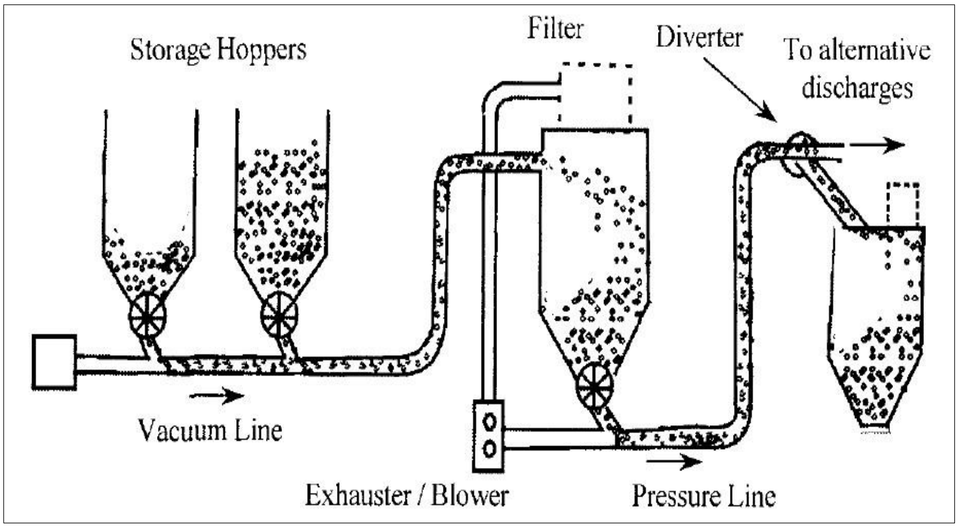

Figure2.4: Combined Negative-Positive pressure conveying system

As was mentioned above, the pneumatic conveying systems can be classified in terms of the conveying mode. All the systems described above can operate into two different categories:

i. **Closed loop system,** in the closed loop system, the conveying gas is recycled. This type of conveyor is particularly suitable for handling toxic and radioactive materials. The system also provides for the recirculation of the conveying gas and as such is well suited to such systems where gases other than air are employed.

ii. **Dilute phase systems are the most widely used systems,** and almost any material can be conveyed in dilute phase. These systems employ large volume of gas at high velocities. According to this mode the material is transported by a gas stream of sufficient velocity to entrain and re-entrain it for a distance, which is dependent on the available pressure. Typical dilute phase conveying system is shown in Figure (2.5).

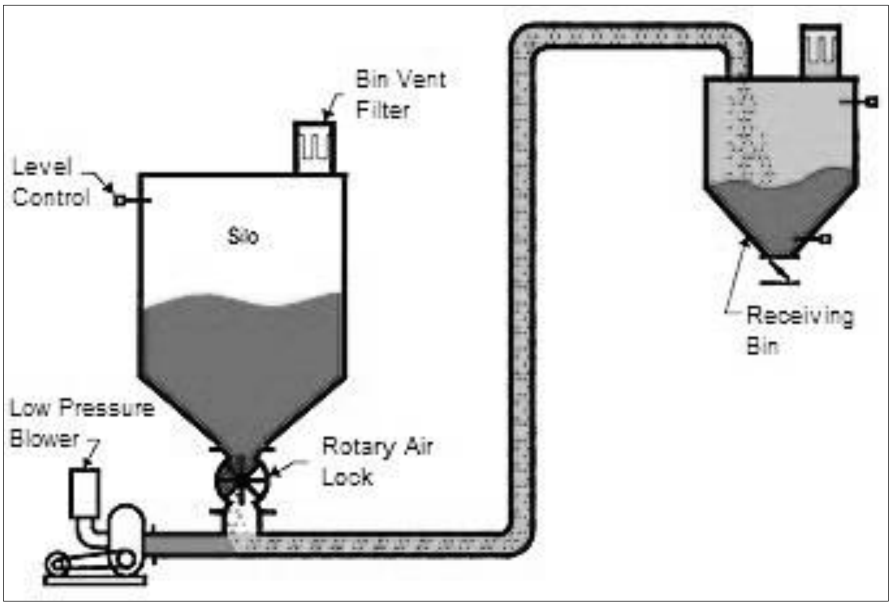

Figure 2.5: Schematic diagram of a dilute phase conveying system

iii. **Dense** phase **systems** are a system in which the material as plug or as a moving bed is pushed through a piping system for a distance dependent on the available pressure as shown in figure (2.6). In Garri 4 power plant cases to re-fluidize the material or re-separate the plug additional air added along the length of the pipeline. The system used transport the sand along long 130m piping system furnace silos.

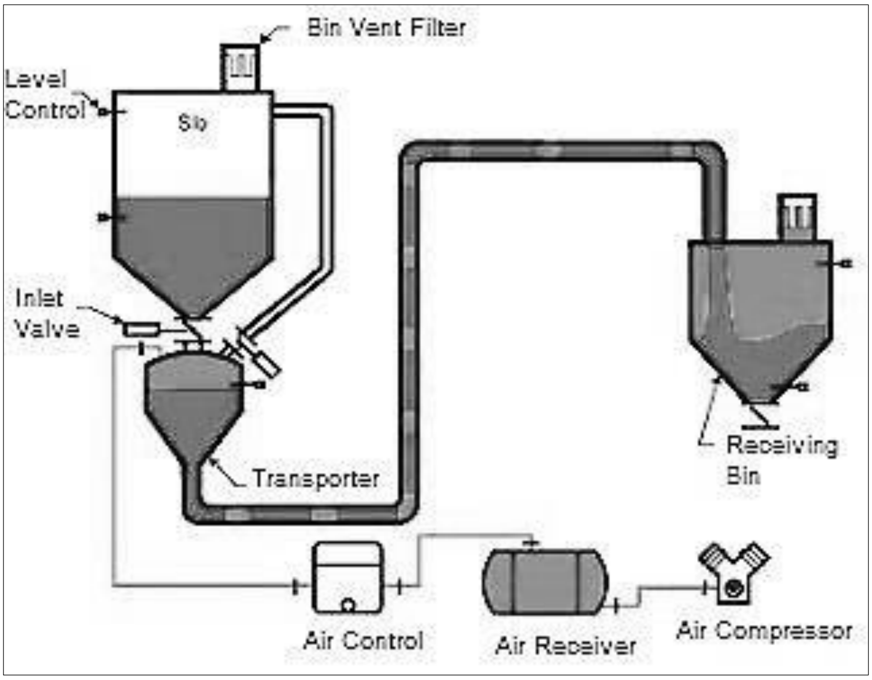

Figure 2.6: Schematic diagram of a dense conveying system

2.4. Advantages and disadvantages of a pneumatic conveying system:

There are many advantages and disadvantages of the pneumatic conveying system when its compared with other conveying systems [4].

2.4.1. Pneumatic conveying offers the user the following advantages:

- Dust free transportation of a variety of products.
- Flexibility in routing-can be transported vertically and horizontally by the addition of a bend in the pipeline.
- Distribution to many different areas in a plant and pick-up from several areas.
- Low maintenance and low manpower costs.
- Multiple use-one pipeline can be used for a variety of products.

- Security-pipelines can be used to convey high valued products.
- Ease of automation and control.

2.4.2.Disadvantages of a pneumatic conveying system:

Offset against the advantages, there are certain disadvantages which include:

- High power consumption.
- Wear and abrasion of equipment.
- Incorrect design can result in particle degradation.
- Limited distance.
- By virtue of the complex flow phenomena which take place, there is a requirement for high levels of skill to design, operate and maintain systems.

2.5. Garri 4 Power Plant Sand Pneumatic Conveying System:

The boiler applied in plant Garri 4 is CFB boiler, which uses sponge coke for burning. Analysis of its industrial composition: high calorific value; low volatile content; high fixed carbon content; very low ash content, etc. According to combustion characteristics of CFB boiler, some inert content should be available. Thus, the plant Garri 4 designs a demand addition of inert content 3t/h, including sand, limestone powder, and fine residue material.

The plant sand system is a combined mechanical-pneumatic conveying system which transports sand of appropriate quality to the plant and heap as standby. The first is mechanical conveying: use vertical sand hopper elevator to transport sand material to roller screen of 250 m3 sand bunker for screening; sand material of good quality will be fed in bunker while material of inappropriate quality will be discharged and transported. There are two units of pneumatic sand conveying systems installed under the sand bunker, and the two can be switched over or one is used while the other is standby. The sand material of appropriate quality will be fed to the 18 m3 fine residue and sand bunker of boiler front in pneumatic conveying mode; each set of CFB boiler is installed with two the boiler front fine residue bunkers and two sand bunkers, which are four in all. Under the condition that a single boiler is in full-load operation, two fine residue bunkers and two sand bunkers can be used for 12 hours. The following drawing illustrates the sand conveying system of power plant in Garri 4.

2.5.1 Parameters of the pneumatic conveying system:

Table (2.1): Parameters of the pneumatic conveying system

number	Item	Design parameter
1	Consumption capacity of sand	5 t/h
2	Design output power of the system	8 t/h
3	Ratio of conveying material and air	28 kg/kg
4	Distance of conveying	130 m
5	Specification of conveying pipe	Carbone Steel DN 100mm
6	Design initial speed	5-6 m/s
7	Design terminal speed	18 m/s
8	air flow of conveying	7.8 Nm3/min
9	air pressure of conveying	5-15 bar

The Garri 4 Power Plant Sand Pneumatic Conveying System associated with high erosive wear problem in fittings, its highly repeated in the elbows.

There is number of solution used to solve the problem such as Surface coatings, and wear back method, but still the problem exists.

2.6. Literature Review:

Here the most common industrial solutions for erosion inside the sand pneumatic conveying system is discussed. The wide range of research is conducted focusing in the most factors that effecting the erosion rate also discussed in this chapter.

One of the earliest printed page references can be considered a case of grain unloading from ships in Russia. In 1923 - 1924 the researcher and practitioner J. Gasterstadt have presented some basic studies in pneumatic conveying, investigated the linear relationship between pressure drop and mass flow rate for dilute phase flow and presented some experimental results of conveying in 100 m long horizontal pipe. In the same time the beginning of pneumatic conveying was in Japan and Germany [5].

In the late 1950’s through the 1960’s raised the activity in USA. An experimental work with a simple vacuum cleaner did by Fred Zens was the first development in pneumatic conveying in the United States. He presented plots of pressure drop versus gas flow rates which were named after him and are still in use. His book with Other on Fluidization and Fluid Particle Systems from 1960 is a big investigation and is a classic of pneumatic conveying [5].

Nowadays, pneumatic conveying is one of the most popular techniques of material transportation in industry.

Various design solutions have been developed in which high erosion rates are avoided by reconfiguring the system—such as the long radius bend, in which impact angle effect reduced which use in place of short radius bend. By this solutions number of problem could be reduced. But a number of factors relating to the material conveyed and the system itself have to be taken into account [2].

The following method are developed as industrial solution to treat the repeated problem.

2.6.1.Long radius bends:

A very low impact angle is an essential pre-requisite for minimizing erosion, particularly in the case of brittle surface materials. In the case of ductile materials, because of the remarkably steep increase in erosion with very small increase in impact angle. The long radius bend compounded with replaceable segments reduce and ease maintenance work as shown in Figure (2.8).

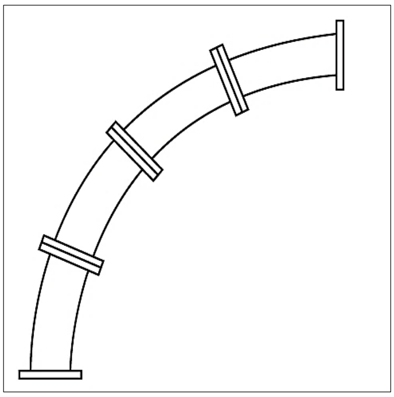

Figure 2.8: bend with replaceable and interchangeable 221⁄2° segments

2.6.2.The use of hard materials:

Hard, brittle materials are generally used in cases of severe wear. Materials used include Ni-hard, basalt and ceramics. These materials can generally be cast or formed into sections, and in the case of non-metals, are used for lining pipes and bends. Care must be taken with cast materials, for obtaining high surface finish, however if a porous surface if obtained, rapid erosion can result.

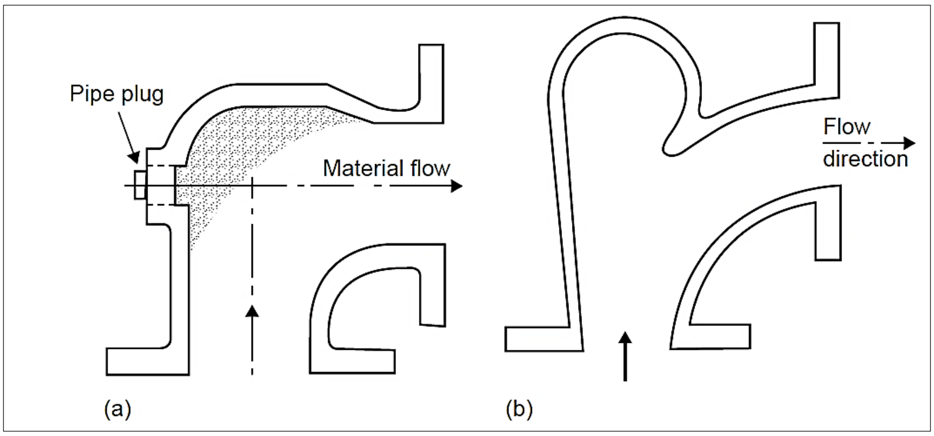

Figure 2.9: Sketch of specially developed bends for pneumatic conveying: (a) short radius bend with shallow depression (b) vortice *pocket bend.*

2.6.3. Surface coatings:

A wide range of materials can be applied to existing surfaces, and in many cases, they are applied to erosion resistant surfaces, such as Ni-hard, to give added protection. Polyurethane, which cures at ambient temperature, is often used. This can be sprayed, or applied in putty form by trowel, which is particularly useful for repairing eroded surfaces. Hard-facing metal alloys, tungsten carbide and a range of oxide ceramics can be applied to surfaces by means of flame spray coating. Some of these materials have very high hardness values, and combined with the fact that the surfaces can also be very smooth, they can provide good erosion resistance. The surface coatings, however, can generally be applied only in thin layers and so once this is penetrated the bend will rapidly fail.

2.6.4. Wear back methods:

A channel welded to the back of a bend and filled with concrete, as shown in Figure (2.10) is probably the most common method adopted. When the outer surface of the original steel bend erodes, the concrete will generally extend the life of the bend for a reasonably long.

This type of industrial solutions is used in Garri 4 case where the bend fail through erosion of the inside surface long before the material has penetrated the concrete. Also, when a primary wear point is established in the concrete at the initial impact point, deflection of particles can result, and these may cause erosion of the inside surface of the bend.

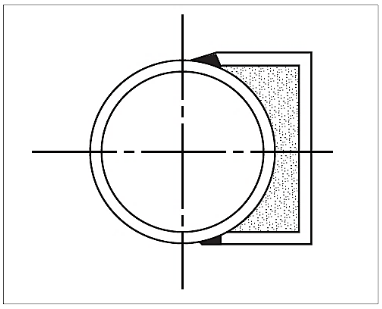

Figure 2.10: Wear back methods of bend reinforcement

2.6.5. Ease of maintenance:

Bends with the provision of replaceable wear backs as shown in figure (2.11) used. where it has very short radius, by the its can ease maintenance work, also can be made from hard materials to reduce the erosion effect.

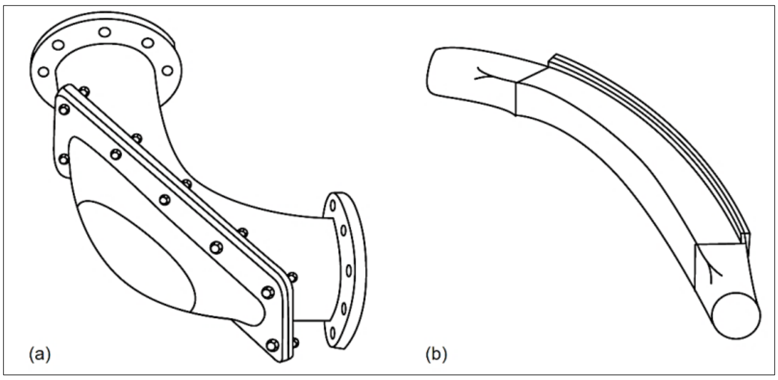

Figure 2.11: Bends with replaceable backs:

(a) regular bend and (b) square section bend.

2.7. The Parameters Effect the Erosion Rate in Pneumatic Conveying System:

The impact parameters that affect erosion rate in pneumatic conveying system are mainly size, shape, impact angle, velocity, and properties of the particles under consideration. The mechanical properties of a material are also a predominant parameter that affects erosion mechanisms.

2.7.1. The effect of size and shape of particles on erosion rate:

The size and shape of particles are of fundamental importance in many areas of engineering and scientific research, and in particular in tribology. The role of these particle characteristics is well recognized in the abrasive and erosive wear processes.

The size of particle is sometimes expressed in terms of the diameter of a circle of equal projected area or alternatively of equal projected perimeter, or may be expressed as the diameter of a sphere of equal surface area or of equal volume, in addition the statistical diameter may be used to represent the particle size.

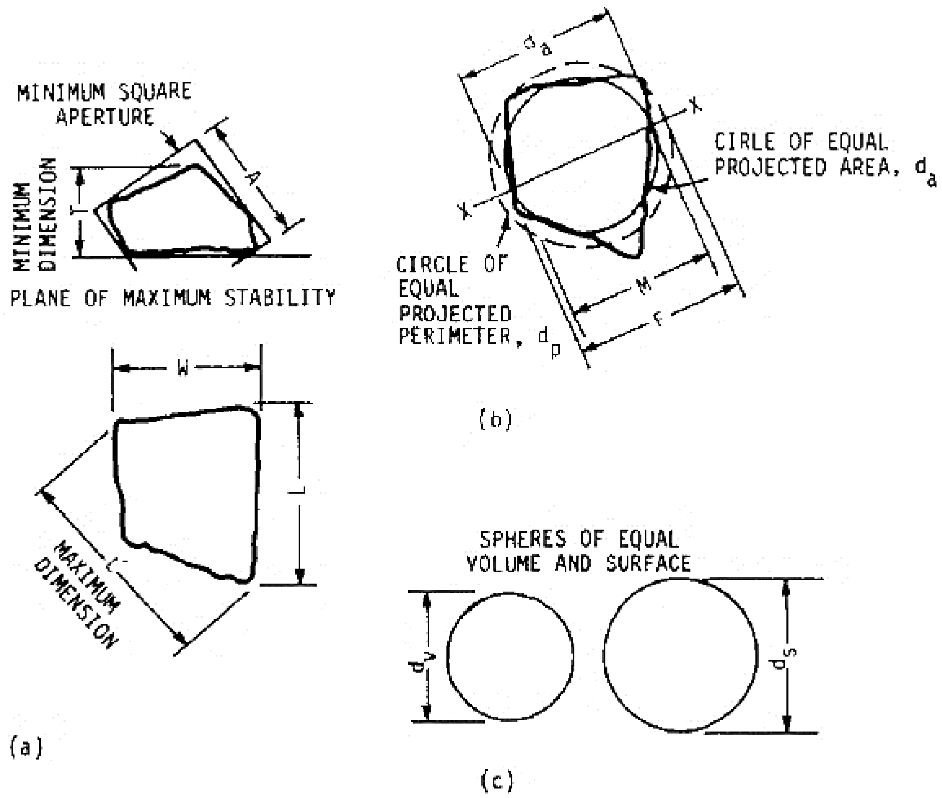

Fig 2.12: Illustration of parameters commonly used in particle characterizations:

(a) limiting dimensions; (b) two dimensions; (c) three dimensions. width W and length L, are the minimum distances.

The study of Sic, $A1_20_3$ and $Si0_2$ particles in various grit sizes are characterized by image analysis in terms of their area, area diameter, width, length, width-to-length ratio W/L and perimeter squared-to-area ratio P^2/A. Erosion rate increases with increasing particle size for Sic and A120s particles up to a certain value and decreases for $Si0_2$ particles. However, it increases with increasing P2/A and decreasing W/L for all three types of particles [6].

The study of the effect of rake angle on ploughing and micro-cutting on lead and steel targets using flat-faced single particles. Its concluded that micro-cutting was favored by positive or small values of negative rake angle. while ploughing occurred with large negative rake angle. Where The rake angle is defined as the angle between the perpendicular to target surface and the leading edge of impacting particle. Its depends upon the shape of the particle as a spherical particle will always impact the target surface with a large negative rake angle so that ploughing is the only plausible mode of deformation. However, an angular particle may impinge with either positive or negative rake angle. Considering random impact orientations, angular particles should be expected to produce both micro-cutting and ploughing as shown if figure (2.12-b).

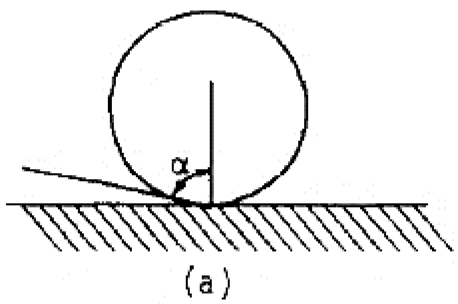

Figure 2.13: (a) Negative and, (b) positive rake angle for particle impacting on a target surface.

2.7.2. The effect of impact angle in erosion rate:

The dependence on the impact angle of erosion damage caused by solid particles is function of both impact angle and hardness of the materials its self.

So, that the normalized erosion damage vary from one material to another depends on its hardness, as shown in the following figure (2.13) [7] the higher erosion rate for iron at impact angle30^{o} where the higher erosion rate for Aluminum at impact angle 20^{o}.

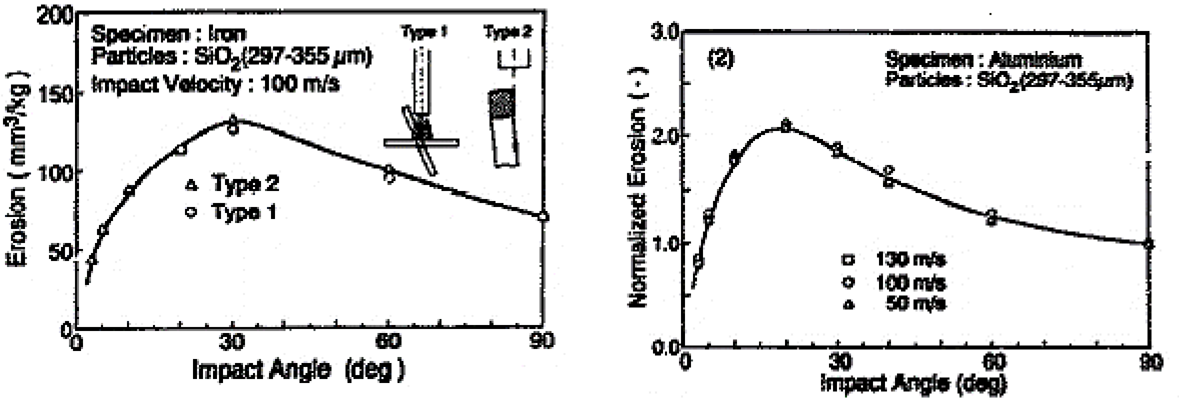

Figure 2.14: the impact angle versus the erosion rate for iron and aluminum.

2.7.3. The effect of particle velocity in erosion rate:

Velocity is a critical test variable in erosion, and can easily overshadow changes in other variables, such as target material, impact angle, etc.

The erosion rate of a material is dependent on several factors, including target material properties and erosion test conditions of angle, velocity, temperature, particle flux, and erodent. Erosion rate has been follow an empirical power law relationship with velocity:

$$Erosion\ Rates = kV^{n} \qquad \ldots\ldots\ldots\ldots.[8].$$

*where **V** is velocity, **k** is a constant, and **n** has values between 2 and 3.5 for metallic materials. Brittle materials tend to have a larger n range, from 2 to 6.5.*

The velocity exponent n is related to test conditions, and not target material properties, also depends on the erosion mechanism for the material tested [8].

2.7.4. The effect of material hardness against the erosion rate:

The effect of material properties on erosion rate is important area of consideration precisely the material hardness where its effect the value and the mechanism of the erosion rate.

The material has higher hardness value have more resistance force against erosion damage and vice versa for that having less hardness value.

The study conducted by *Y. I. Oka, M. Matsumura and T. Kawabata* 1993. Show that an increase in the hardness was seen on the fully eroded surfaces obtained in the cases of iron and aluminum, but a decrease was seen in the case of quenched carbon tool steel. No change in the hardness was seen in the cases of the acrylic resin and nylon [9]. This is indicating that the hardness ability against erosion effect not constant during the process and related to other factors, as other material properties.

2.7.5. The effect of particles hardness in erosion rate:

The hardness of the erodent particles relative to the material being eroded is an important, often overlooked, factor in erosion.

The erosion rate drops dramatically when particle hardness decreases below that of the material being eroded. It is quite possible that heat treatment of steels appears to have almost no effect on their erosion resistance may be partially due to the use of hard particles such as SiC and Al_2O_3 [5].

CAPTER 3

Theoretical Background

3.1. Preface:

This chapter discuss the procedure used to simulate the erosion inside the pneumatic sand conveying system used in gari4 power plant CFB boiler using new designed experiment device, through utilizing the sand-blasting machine to perform the test.

3.2. Materials:

There are different materials used to study the pneumatic conveying system, and they are the following.

3.2.1 Sand-Blasting:

Sandblasting as shown in figure (3.1) is actually an old term for "abrasive blasting". Sandblasting is a process of using compressed air to propel abrasive media at a very high velocity on a surface to clean (usually rust, old paint), to prepare the surface for a coating of some sort. It is also one of the easiest, quickest and convenient ways to remove impurities from surface prior to any type of coating.

i. Sand-Blasting Main Components:

- The abrasive vessel.
- The air compressor.
- The nozzle.

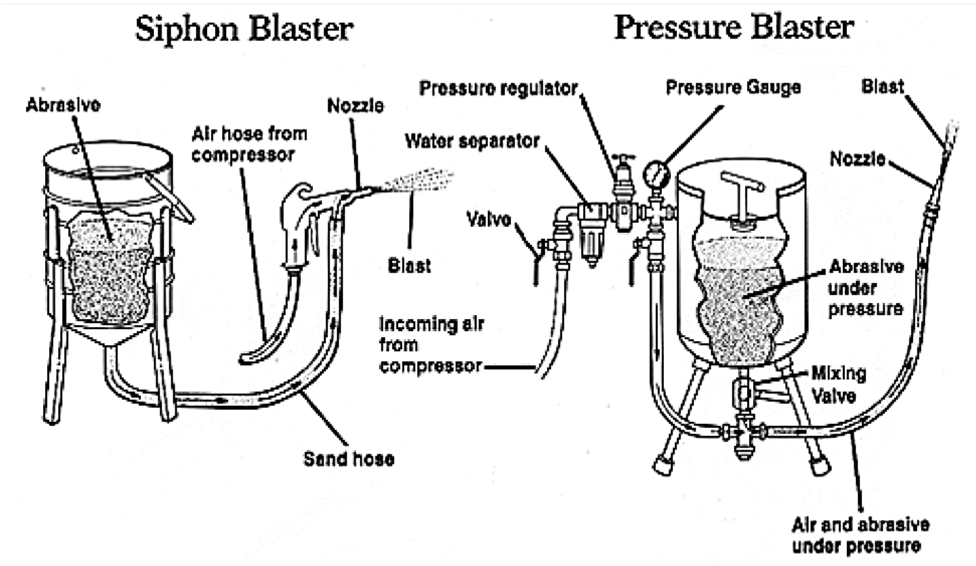

Figure 3.1: Siphon and Pressure blaster

The process of sand-blasting is which used the compressed air to blow the fine sand at a high pressure passed through the nozzle at a very high velocity. The process of sandblasting follow the this sequences:

- Loading of abrasives into the abrasive vessel.
- Second step is passing the pressurized air through the mixing device under the abrasive vessel.
- The pressurized air with entrained abrasive particles passed through the nozzle with high speed and under high pressure.
- In the test this nozzle is focused into the specimen which is help of the Sand-blasting fixture as shown in figure (3.2).
- The fixture used to mount the specimen with predefined angle and impact distance.

ii. The sand-blasting equipment used in the test:

The equipment used in the test is Pressure Blasting type with design pressure of 7 bar

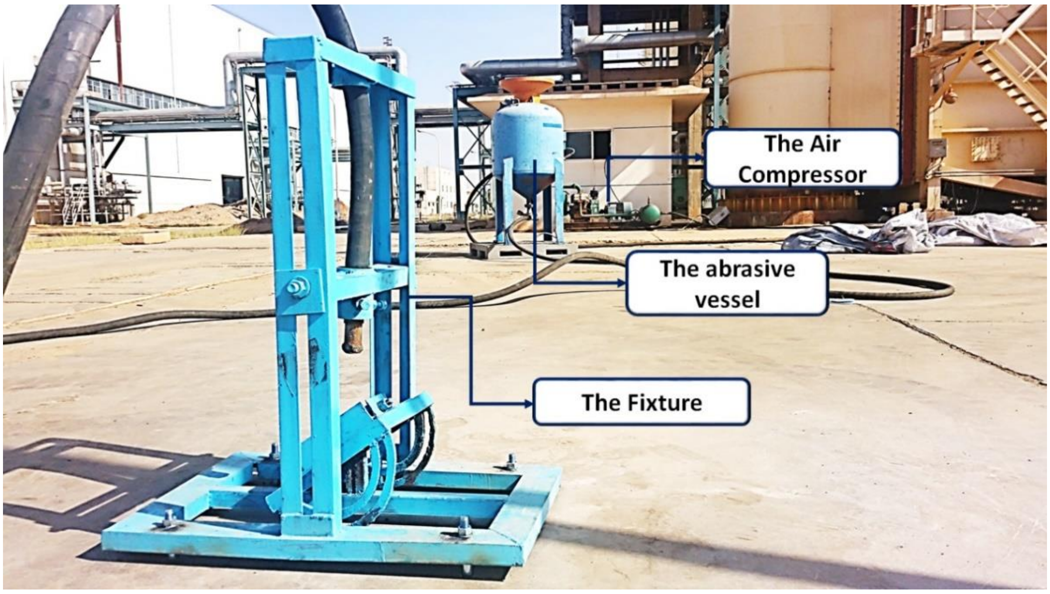

Figure 3.2: Sand-blasting Machine and fixture

3.2.2 The Sand-blasting Fixture:

The fixture as shown in figure (3.3) is rigid mechanical device used to fix the workpiece or specimen and allow easy, quick and consistently accurate locating, supporting and clamping the workpiece this result in faster and accurate operation in the workpiece.

The fixture used in the test is special design to fit the test piece and allow optimum workpiece locating to meet the angle and distance of the impact of the sandblasting nozzle.

The fixture properties:

The fixture designed to carry sand-blasting impact force. Also, the fixture designed to allow flexible angle adjustment 90 degree and impact distance range (0- 700 mm)

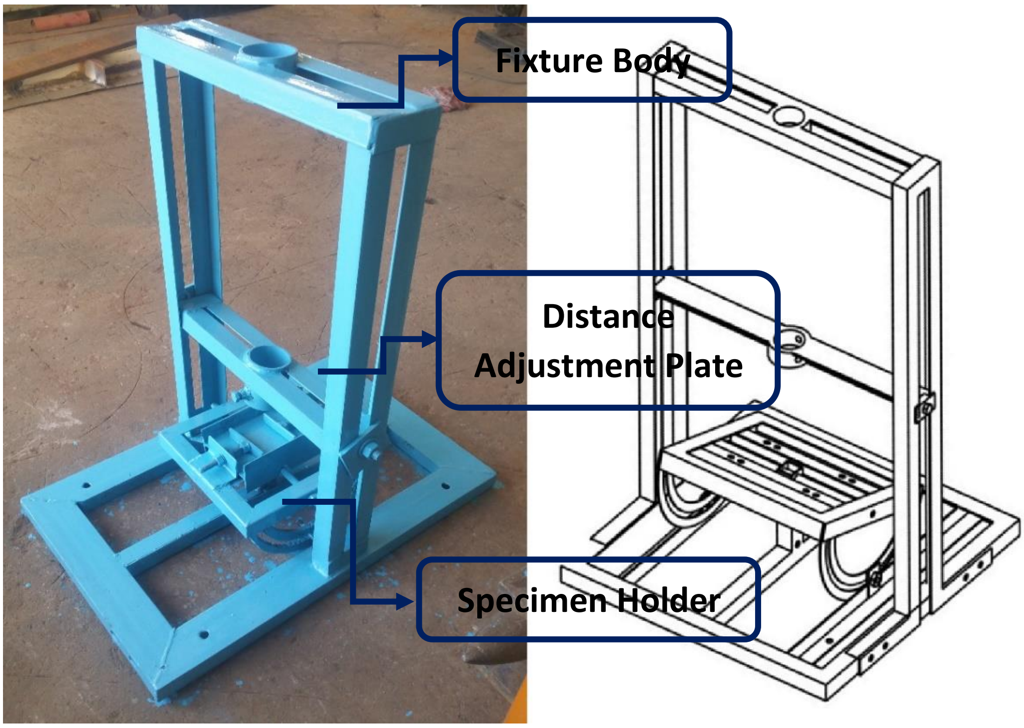

Figure 3.3: The sand-blasting fixture used in the test and its drafting.

3.2.3 Specimen:

The specimen as shown in figure (3.4) is apart or an individual taken as exemplifying a whole mass or number, and used to smoothing the test. The specimen either be the part or can be similar to the part that need to simulated in the study case.

Through this a test the system under study is erosion in pneumatic sand conveying system, particularly the elbow of high erosion wear problem. the elbow made of Carbone Steel Grade A36 with the following characteristics.

The specimen used to study this test is much approached to the above material characteristic with small different which is Carbone Steel grade A36 in plate form, having following hardness testing results.

Figure 3.4: The Specimen Used in the Test

Table (3.1): Specimen and piping material hardness properties

Type of Test	Specimen Materials	Piping Material
Rockwell Test B type	62.08	59.82
Brinell Test	89.84	85.2
Vicker Test	155.64	132.6

3.2.4 The Sand:

The sand used in CFB boiler to maintains the uniform heat distribution inside the furnace and also to keep the bed temperature at degree that permit the sponge coke to be burnt.

The sand is formed when the rock breakdown to the small size which is called the sand, the process of the rock breaking down of sand determines its shape.

The shape have high influences in the erosion causes by the sand, where the angular is highest, the rounder and semi rounder having less erosion rate and they almost form by water breakdown.

The sand used with the following properties:

Table (3.2): The properties of sand used in the test.

Sand Size(um)	**900**	**800**	**700**	**600**	**500**	**400**	**300**	**200**	**100**
Value	22.21	3.68	21.44	13.81	6.74	14.67	5.7	9.45	2.3
Sand Shape	**Rounder**			**Semi-Rounder**			**Angular**		
Value	27.11			44.71			28.18		

3.2.5 The Sponge Coke Powder:

Sponge coke is one type of petroleum coke, fuel type, which is derives from a final cracking process–a thermo-based chemical engineering process that splits long chain hydrocarbons of petroleum into shorter chains—that takes place in units termed coker units.

The mechanisms that cause sponge coke or shot coke to form are not well understood and cannot be accurately predicted. In general, lower temperatures and higher pressures promote sponge coke formation. Additionally, the amount of heptane insoluble present and the fraction of light components in the coker feed contribute. While its high heat and low ash content make it a decent fuel for power generation in coal-fired boilers, petroleum coke is high in sulfur and low in volatile content, and this poses environmental (and technical) problems with its combustion. Its gross calorific value (HHV) is nearly 33500 KJ/kg which is twice the value of average coal used in electricity generation.

The sponge coke used in the test is produced by KRC Khartoum Refinery Company with calorific value 3600 kj/kg. in powder form.

3.2.6 Measurement tools:

To gain result from a test or an experiment measurement tools need to meter the weight, size, time, or any type of scalar or vector, which is a parameter of the test.

There are different measurement tools used in this research and they are in the following lines.

i. Balance:

There are two type of balance used in study:

The sensitive laboratory balance as shown in figure (3.5) used to measure the weight of the specimen before and after the test to measure the erosion which the specimen are subjected during the test.

The sensitive balance used in the test is (ADAM AFP-4100L) balance, which is digital balance have maximum weight (4100 g), with readability (0.01g), repeatability (Std. dev) (0.02g), and linearity of (±0.03g).

Figure 3.5: Sensitive laboratory balance, type (ADAM AFP-4100L)

Ordinary laboratory balance as shown in figure (3.6) used to measure sand and sponge coke weight before the test to prepare the mixture percentage and the weight before the test, and also to measure the sand after the test to measure sand passed during the test which is cased the workpiece erosion.

The balance used in the test is (ADAM ACB-3000P) balance, which is digital balance have maximum weight (3000 g), with repeatability (Std. dev) (0.1g), and linearity of (±0.2g).

Figure 3.6: Ordinary laboratory balance, type (ADAM ACB-3000P)

ii. Size Measuring tools:

There are different size measuring tools used to measure the specimen size, the impact angle, and impact distance, and they are:

- Vernier used to measure the specimen thickness, width, and the length.
- Proctor used to measure the impact angle.
- Meter used to measure the impact distance.

iii. Hardness tester:

The hardness is most important material characteristic can be considered in the erosion case studies. Where its have great influence on solid particle erosion. The solid particles erosion decrease dramatically when the hardness increased and vice versa.

The hardness of the workpiece and the piping system material is measured using the portable hardness tester type (TH160) made by TIME Group Inc, the device has calibration date is 22 November 2017.

3.2.7 Test Environment:

The test environment is setup of the test to simulate the case study, at most at possible. All the parameters in the actual case study set in the test environment.

The Test Specifications and parameters:

All models tested in the same conditions in term to study the erosion rate through changing the sand composition by adding predetermined sponge coke powder weight in percentage proportional to the sand weight. So, that the test parameters set during the all test found in the following table plus the above materials characteristics.

Table (3.3): The test environment characteristics

Test Environment	
Characteristics	Value
Pressure	7bar
Impact Angle	40 °
Impact Distance	150mm
Air Density	1.127 kg/m^3
Air flow rate	2 m^3/min
Particle speed	87.73 m/s

3.3. Methodology:

The pneumatic sand conveying system used in Garri4 is dense phase type, in which the sand flow inside the pipe in pulse followed by pressurized air.

The eddies occur when the flow change from laminar to turbulent flow and this frequently occurs in the piping fitting particularly in the elbow, which observed as high and repeated erosion wear.

The test aim to study the erosion rate in term of kilogram of material eroded per kilogram of sand passing through workpiece, this performed by pre-metering the specimen Wight before and after the test as well as the sand passing through the specimen during the test.

3.3.1. The Test Procedure:

The test follow the following procedure to simulate the case study:

To simulate the case, study the test parameter set to be similar to case study and are as the following:

The air pressure is 7 bar, type of flow is pulse type, angle of impact is 40^o, the impact distance is 150mm, the material is as the piping material Table (3.1).

- Firstly, the test equipment's including the fixture Figure (3.3) installed, and tested before doing the test.
- The angle, and impact distance adjusted, where the specimen its already installed into the fixture.
- The main valve at the air inlet to the abrasive vessel used to control the pulse action.
- The pressure adjusting valve set to pass the same pressure of the compressor, which is 7 bar.

- When all the above step done the test start by starting the air compressor, until the pressure reach 7 bar, at this moment the inlet valve opened allow pressurized air to inter the abrasive vessel and entrained the sand particles to hit the workpiece, and the flow continue to 30 seconds.
- The above point is repeated for same workpiece five times, and the test repeated for five workpieces.
- After that the sand mixed by sponge coke powder 100% and 05% sponge coke powder mixture, and also the above procedure repeated.
- The 10%, 15%, 20%, and 25% Sponge coke and 100% sand mixture all test by same procedure.
- The sand weight measured before and after the test to measure the sand weight passed through the workpiece as well as the sand passed during the pulse also measured to ensure that.
- When the test finished the workpieces, weight measured to calculate the mass eroded in each one.

The data collected and test parameter are presented in table (3.4).

Table (3.4): present the sample table in which the data collected

<table>
<tr><th rowspan="2">Group</th><th colspan="2">Test Environment</th><th>Sample no</th><th colspan="3">Sample size (mm)</th><th colspan="2">Sample Weight(g)</th></tr>
<tr><th>Characteristics</th><th>Value</th><th></th><th>Width</th><th>Length</th><th>Thickness</th><th>Before Test</th><th>After test</th></tr>
<tr><td rowspan="5">X</td><td>Pressure (bar)</td><td>x</td><td>1</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>Impact Distance(mm)</td><td>x</td><td>2</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>Impact Angle</td><td>x</td><td>3</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>Sand Weight (g)</td><td>x</td><td>4</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>S.C %</td><td>x</td><td>5</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
</table>

***Table (3.5):** Present the sample table of calculation*

Sample no	**Eroded Material Wight (g)**	**Erosion Rate (kg/kg sand)**
1	x	x
2	x	x
3	x	x
4	x	x
5	x	x
Average	x	x

CAPTER 4

Result & Discussion

4.1. Preface:

The Pneumatic sand conveying system has been studied and the proposed solution tested, by simulating the case study. During the test the workpiece with pre-determined weight is subjected to sand particles erosion representing the existence system, where the mixture of sand and sponge coke powder is representing the proposed solutions.

The 05%, 10%, 15%, 20%, and 25% percentage of sponge coke to the sand fixed amount of sand is solution models used in study.

4.2. Result:

There are Six models used in the test, each model having five specimens and they named aphetically A, B, C, D, E, and F, each model subjected to predetermined percentage of sand and sponge coke mixture. And they are set to be 00%, 05%, 10%, 15%, 20%, and 25% sponge coke percent from the sand weight.

The erosion rate for each model is average of the five specimens' erosion rate, where its calculated as shown in the previous chapter, the erosion rate data corresponding to the mixture of sand and sponge powder percentage were collected from six experiments.

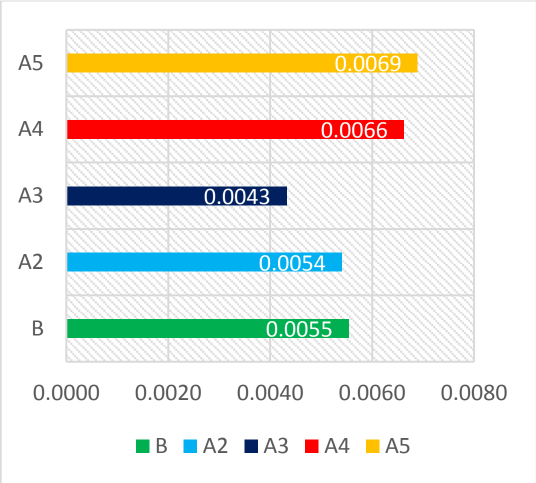

Figure 4.1: The Erosion rate in the five specimens of Group A

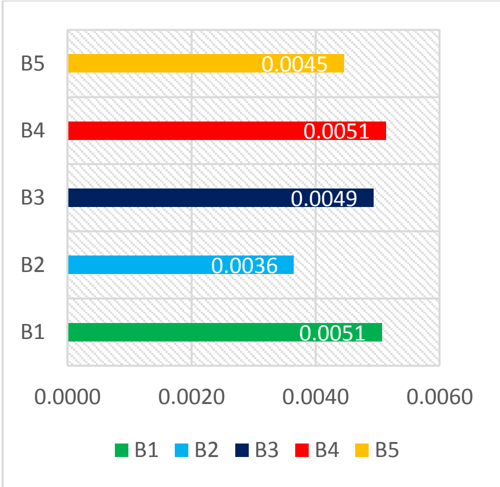

Figure 4.2: The Erosion rate in the five specimens of Group B

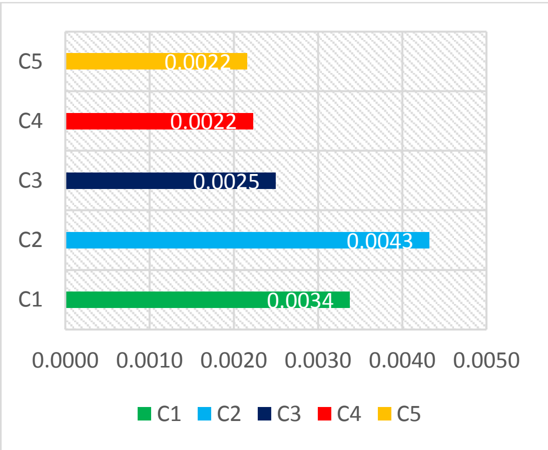

Figure 4.3: The Erosion rate in the five specimens of Group C

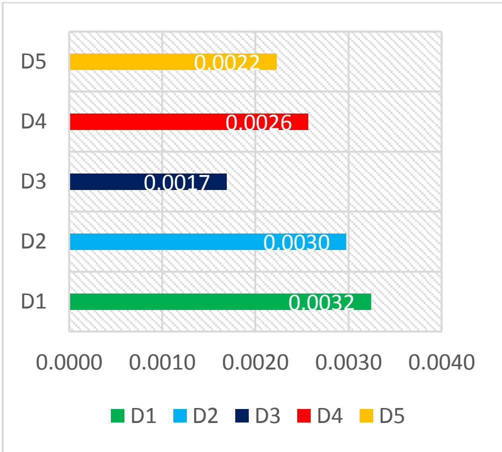

Figure 4.4: The Erosion rate in the five specimens of Group D

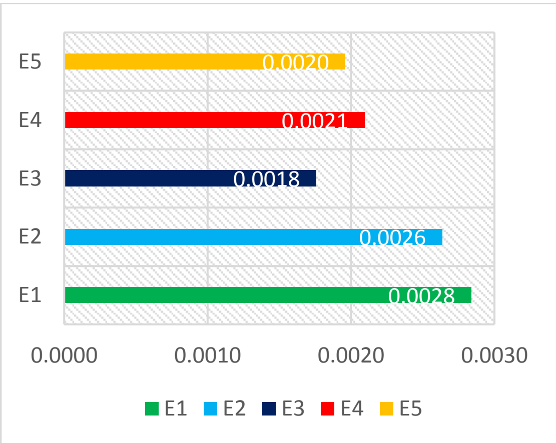

Figure 4.5: The Erosion rate in the five specimens of Group E

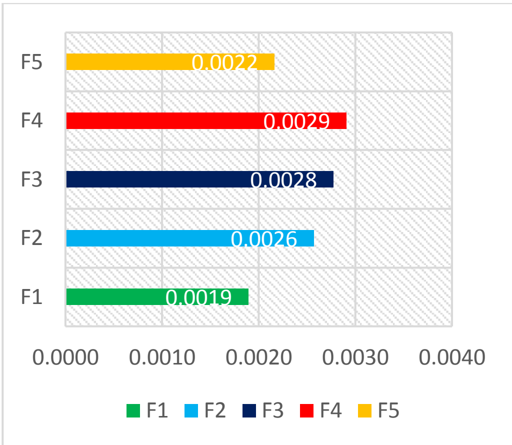

Figure 4.6: The Erosion rate in the five specimens of Group F

The erosion rate in all specimens as grouped presented in the next figures above.

Table (4.1): Present the erosion rate and decreased in erosion when compared with model A

The Group	Percentage of powder	Erosion Rate	Decreased in Erosion
A	0%	0.00576	0%
B	5%	0.00465	19%
C	10%	0.00292	49%
D	15%	0.00254	56%
E	20%	0.00226	61%
F	25%	0.00246	57%

The erosion rate is measured by (Kg of material eroded)/(Kg of Sand Passed)

4.3. Result Discussion:

As mentioned early, one of the main objectives of the current investigation was to determine the erosion rate for the above six model and conclude the must optimum one.

As can be seen in the figure (4.7) below the model E with 20% sponge coke to the sand mixture is highest erosion decreased with 61% proportional to the model A where its represent the present case.

Where there is little decreased when 5% of sponge coke to sand with 19% proportional to the model A.

Model F, model E, model D, and model C are the not far different when they compare together, where they are in range of 0 to 22% of decreased in erosion rate to the model A.

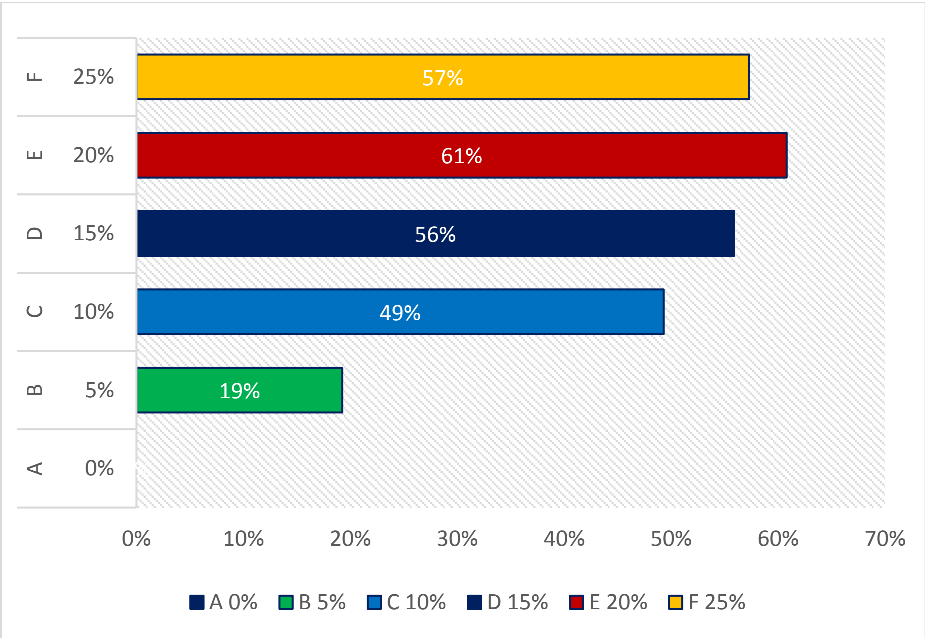

Figure 4.7: The decreased in erosion when compared with model A

4.3.1. The system modification to adapt the sponge coke powder mixture:

The sand and sponge coke powder mixing machine, and other installation material added to the system to adapt the solution when it approved.

The mixer that can be used is available as 6 cubic meters per hour, that can deliver at least 8 ton per hour.

4.3.2. Economic Analysis:

The economic analysis assesses the most project by focusing on the real financial activity. The economic analysis takes account of the fact that price developments over predetermined horizon.

The economic analysis in this chapter developed for the six model to assess them in term of maintenance, operational, and other cost.

The annual worth method, with 15% interest and five years', and 10 years' horizons used to evaluate all model.

Also, the tangible factor considered in this particular, where invisible factors not financial required and ease in other boiler utilities.

Table (4.2): Maintenance cost per job

Maintenance cost per job	**Cost(SDG)**
Labor	250
Filer	20
Materials	150
Power	20
Total	**440**
Cost Per Year	**91520**

The failure in the piping for the old model occur at rate 208 times/year. The operation cost and other equipment's maintenance that kept in all model not consider in this analysis.

Table (4.3): Six models net cash flow, for the five years'

	Net Cash Flow					
End of Year	**Old Model [A]**	**Model [B]**	**Model [C]**	**Model [D]**	**Model [E]**	**Model [F]**
0	0	125000	125000	125000	125000	125000
1	91520	75979	48481	42465	37954	41176
2	91520	73903	48481	42465	37954	41176
3	91520	73903	48481	42465	37954	41176
4	91520	73903	48481	42465	37954	41176
5	91520	75103	48481	42465	37954	41176
Salvage Value	0	-75000	-75000	-75000	-75000	-75000
Annual Worth 15%	91520	102144	74646	68630	64119	67341
Present Worth 15%	352297	430485	324630	301474	284108	296512

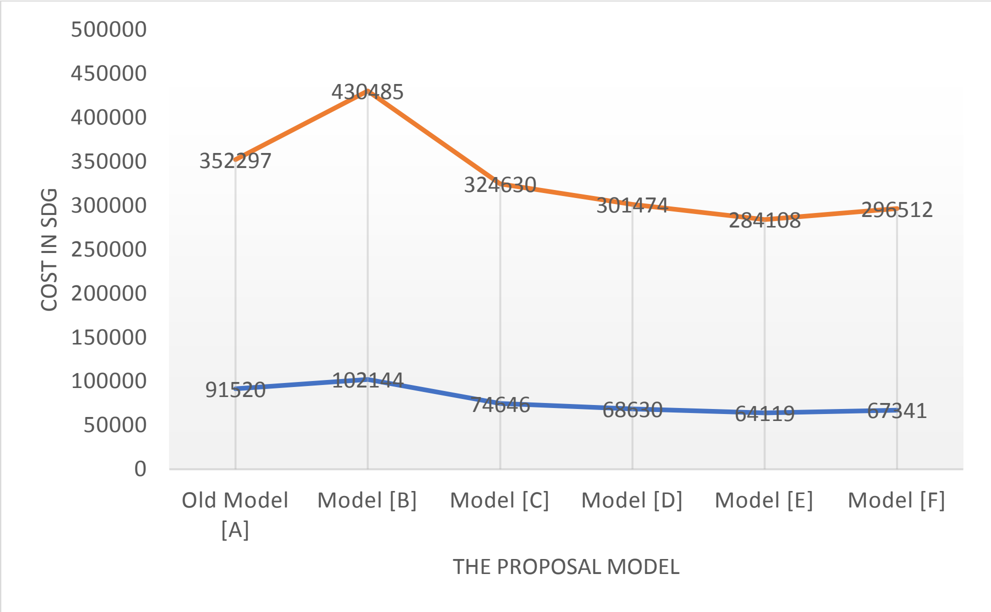

Figure 4.8: Five years' horizon annual cost and present value of money

As shown in figure (4.8), where the financial analysis is done for five years' horizon and 15% interest rate, the model (B) show the highest Annual cost with (102144 SDG) and also is the highest present value of many (430485 SDG), although it has less erosion than the old model (A), due to the initial cost of installing and modification of the new system. where the model(E) show lower annual cost with (64119 SDG) and also lower present value with (284108 SDG).

Table (4.4): Six models net cash flow, for the 10 years'

	Net Cash Flow					
End of Year	**Old Model [A]**	**Model [B]**	**Model [C]**	**Model [D]**	**Model [E]**	**Model [F]**
		12500	12500	12500	12500	12500
0	0	0	0	0	0	0
1	91520	73903	48481	42465	37954	41176
2	91520	73903	48481	42465	37954	41176
3	91520	73903	48481	42465	37954	41176
4	91520	73903	48481	42465	37954	41176
5	91520	73903	48481	42465	37954	41176
6	91520	73903	48481	42465	37954	41176
7	91520	73903	48481	42465	37954	41176
8	91520	73903	48481	42465	37954	41176
9	91520	73903	48481	42465	37954	41176
10	91520	73903	48481	42465	91520	41176
		-	-	-	-	-
Salvage Value	0	25000	25000	25000	25000	25000
Annual Worth 15%	**91520**	**97583**	**72161**	**66145**	**61634**	**64856**
Present Worth 15%	**481944**	**520029**	**386152**	**354475**	**330717**	**347687**

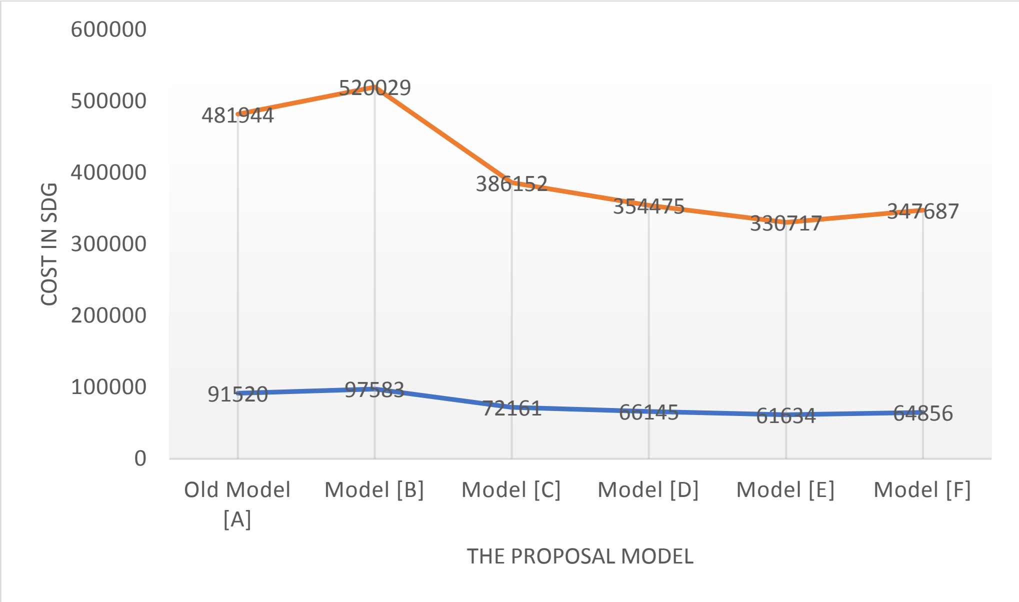

Figure 4.9: 10 years' horizon annual cost and present value of money

As shown in figure (4.9), where the financial analysis is done for 10 years' horizon and 15% interest rate, the model (B) also show the highest Annual cost with (97583 SDG) and also is the highest present value of many (520029 SDG), although it has less erosion than the old model (A), due to the initial cost of installing and modification of the new system. where the model(E) show lower annual cost with (61634 SDG) and also lower present value with (330717 SDG).

For model B the operation and maintenance cost is higher than the model A, where the model B having less erosion rate in each 5 and 10 year horizon, this because the initial cost of suppling and installing the sand sponge coke mixer.

4.3.3. The Intangible factor can be put into consideration:

There are many intangible factors can be considered during the result implementations, and may be limitation for the on successful solution, and they are:

i. The availability of sponge coke powder:

The sponge coke powder is found when the sponge coke conveying system under operation and collected by the dust collector and the poor of conveyers selling also form the sponge coke powder, this powder is collected, but the amount that can be collected may be not enough to mix more than 2.5 ton per day that cannot allow to more than 11$ but some time more than this amount can be collected may reach to 5 ton per day.

This factor put the decision in the hand of the operation engineer but at all any percentage of sponge coke to the sand more than 10% is consider economical.

ii. Some operational aspects:

The sand availability in the furnace is most necessary without it there is no uniform combustion inside the furnace as the bed temperature may fall down led to stop in sponge coke burning and so on to the shutdown of the unit, so that the damage of the line that led to loss the sand in the furnace led to sequence of losses:

- The shutdown of the unit directly decrease its life time.
- Also, to restart the unit consumed more time, and this consider the loss of opportunity cost that can be gained if the unit normal operation.
- As the startup of the unit, from cold state require liquefied Diesel Oil (LDO), which consider highly fuel cost.

CAPTER 5

Conclusion & Recommendations

5.1. Conclusion:

As discussed in details under Chapter 1, the main aim of the project is to find optimum solution for the problems of high erosion rate in Garri-4 power plant sand pneumatic conveying system. That having less cost and more reliable. The experimental method used to evaluate the erosion rate in the old system, and also used to test the proposed solutions, as well as the economic analysis used to evaluate each model.

The model (E) with mixture of 20% of sponge coke powder having minimum erosion rate and also lower maintenance and operational cost during 5 and 10 Years horizon, and also its save from intangible factor such in loss of sand into the furnace, that led to decrease of bed temperature and obstacle the fuel combustion, furtherly shutdown of the unit, and loss of power generation.

5.2. Recommendations:

- Due to the limitation of resources the testing equipment's' can be modified to be more accurate and give more accurate result by adding more measurement devices and flow control equipment's, such as pressure control regulator, speed controller, etc.
- Also, the high-speed camera can be added to the testing equipment's to studding the erosion mechanism and tracking the particles inside the piping.
- The new modification for the system to adapt the mixing of sponge coke powder with the sand.
- In terms of the solutions can be proposed for further study, the ash which already produced as due to the burning of the sponge coke can be utilize instead of sponge coke powder.

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Appendix:

Garri-4 Sand Pneumatic conveying system:

1- Pneumatic Convoying Pumps

2- Gasifying Device

3- Failure in elbows
 

The Data collected from the test:

Sample no		Sample size	Sample Weight g		Eroded Material Wight	Erosion Rate
		Length	Before Test	After test		
A	1	9.91	264.75	263.93	0.82	0.00554
	2	9.85	262.94	262.14	0.8	0.00541
	3	9.82	262.05	261.41	0.64	0.00432
	4	9.56	254.15	253.17	0.98	0.00662
	5	9.97	264.22	263.2	1.02	0.00689
B 05%	1	9.51	252.65	251.9	0.75	0.00507
	2	10.24	272.71	272.17	0.54	0.00365
	3	9.6	255.13	254.4	0.73	0.00493
	4	9.81	261.46	260.7	0.76	0.00514
	5	9.27	247.69	247.03	0.66	0.00446
C 10%	1	9.65	256.93	256.43	0.5	0.00338
	2	9.93	262.73	262.09	0.64	0.00432
	3	9.62	256.54	256.17	0.37	0.00250
	4	10.5	279.9	279.57	0.33	0.00223
	5	9.91	263.63	263.31	0.32	0.00216
D 15%	1	10.41	277.34	276.86	0.48	0.00324
	2	10.15	271.68	271.24	0.44	0.00297
	3	10.2	274.59	274.34	0.25	0.00169
	4	9.71	259.4	259.02	0.38	0.00257
	5	9.68	256.36	256.03	0.33	0.00223
E 20%	1	9.61	255.96	255.54	0.42	0.00284
	2	10.17	271.12	270.73	0.39	0.00264
	3	9.41	250.15	249.89	0.26	0.00176
	4	9.78	261	260.69	0.31	0.00209
	5	9.55	255.46	255.17	0.29	0.00196
F 20%	1	9.85	261.68	261.4	0.28	0.00189
	2	9.41	250.15	249.77	0.38	0.00257
	3	10.4	277.94	277.53	0.41	0.00277

	4	9.63	265.19	264.76	0.43	0.00291
	5	9.55	262.5	262.18	0.32	0.00216

The sand sponge coke powder mixer: