“AN ATTEMPT TO INCREASE THE EFFICIENCY OF A TUNNEL KILN WITH THE HELP OF ENERGY BALANCE”

An industrial defined project report
Submitted by

PATEL JAY TUSHARBHAI	(Enroll. No.130320119112)
BHATT PRANJAL SANJAY	(Enroll. No. 130320119009)
PATEL YASH DIPAKBHAI	(Enroll. No.130320119128)
RAVAL KRUNAL SHAILESHBHAI	(Enroll. No.130320119139)

Internal Guided by

PROF. HITESH G. PATEL
Mechanical Engineering Department
LJIET, Ahmedabad.

External Guided by

MR. NARENDRA VADHER
Vacunair Engineering Co. Pvt. Ltd.
MR. VIPUL SHAH
Vipul Shah & Associates

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In
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L. J. INSTITUTE OF ENGINEERING & TECHNOLOGY
Sarkhej, Ahmedabad
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Chandkheda, Ahmedabad

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CERTIFICATE

This is certify that work embodied in this report entitled **"An attempt to increase the efficiency of Tunnel kiln with the help of energy balance"** was carried out by **Team No. 74826 (Mechanical Engineering)** at L.J. Institute of Engineering and Technology, Ahmedabad (GTU code 032) for partial fulfilment of B.E degree to be awarded by Gujarat Technological University. This research work has been carried out under my supervision.

Team members:

Patel Jay Tusharbhai (130320119112)

Bhatt Pranjal Sanjay (130320119009)

Patel Yash Dipakbhai (130320119128)

Raval Krunal Shaileshbhai (130320119139)

Date:
Place: Ahmedabad

Internal Guide:

Prof. Hitesh G. Patel **External Examiner Sign.**
Assistant professor
Mechanical Engineering Department,
L.J. Institute of Engineering & Technology,
Ahmedabad, Gujarat.

Mr. Tushar M. Thakar
Head of Mechanical Engineering Department
L.J. institute of Engineering & Technology
Ahmedabad, Gujarat.

Gmail

Yash Patel <yashp2296@gmail.com>

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Unique	This is undertaken after glazing of the clay	-
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ACKNOWLEDGEMENT

It will always be a pleasure to remind the fine people in the Shiv Shakti Ceramics for their sincere guidance we received to uphold our practical as well as theoretical skills in engineering.

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Most importantly, none of this could have happened without our family. We are thankful to our parents, for the fact this study could not be undertaken without their blessings.

Patel Jay Tusharbhai

Bhatt Pranjal Sanjay

Patel Yash Dipakbhai

Raval Krunal Shaileshbhai

“An attempt to increase the efficiency of a Tunnel kiln with the help of energy balance”

Submitted by
Patel Jay Tusharbhai
Bhatt Pranjal Sanjay
Patel Yash Dipakbhai
Raval Krunal Shaileshbhai

Supervised by
Prof. Hitesh G. Patel
Assistant Professor, Mech. Engineering Dept.,
L.J. Institute of Engineering and Technology,
Ahmedabad.

ABSTRACT

To perform energy balance and find out the major cause of heat loss. From the results obtained, we can reduce various losses and thereby increase the efficiency of the kiln. All major ceramic manufacturing industries use tunnel kiln for firing of the clay. With the help of tunnel kiln clay is converted into ceramic. But the main disadvantage of a traditional tunnel kiln is its low efficiency. All small industries work with the traditional kilns. These industries cannot afford to install a new design high efficiency kiln (roller kiln). Hence to increase the efficiency of the tunnel kiln an attempt has been made. Energy balance is used to find out the net output per unit input and also to find out the major losses that contribute in kiln having its low efficiency. With these results change could be made in the existing kiln to increase its efficiency.

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CHAPTER 1: INTRODUCTION

1.1 Introduction about project

Most of ceramics industries use a Tunnel kiln in order to fire clay into ceramics. This is undertaken after glazing of the clay. In this project, we have to perform the energy balance of the tunnel kiln, and look for the region where maximum heat loss takes place, by minimizing the same.

1.1.1 What is a Tunnel Kiln?

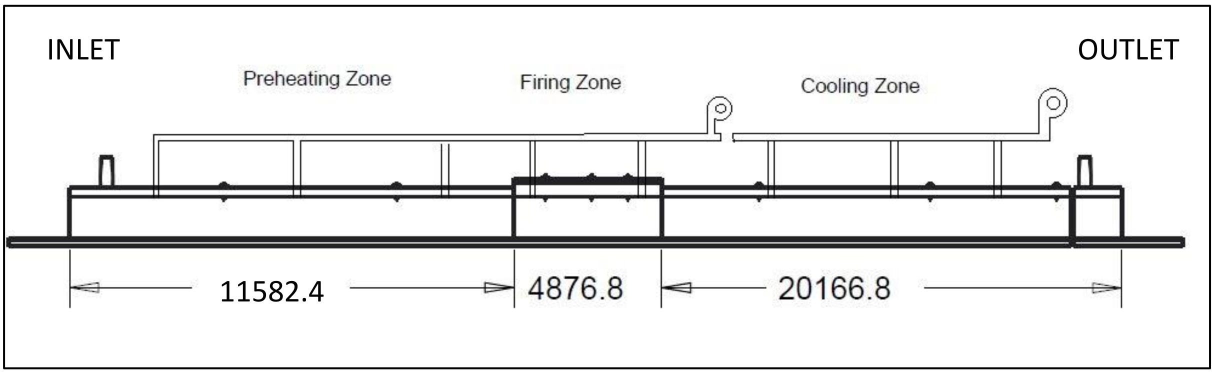


Figure 1.1: Wireframe of kiln *All dimensions are in mm

- A kiln is a thermally insulated chamber, a type of oven which produces sufficient temperatures to complete the processes like hardening, sintering, drying and baking.
- A Tunnel kiln is a long and continuous area in which step by step heating of the product takes place.
    - It is divided into 3 parts:
        1. Pre-heating Zone.
        2. Firing Zone.
        3. Cooling Zone.

- Here, temperature in each zone is according to the process taking place.
- A kiln is generally electrical fired, But this is a traditional kiln and gas fired.
- The kiln we are observing under our project is totally different.

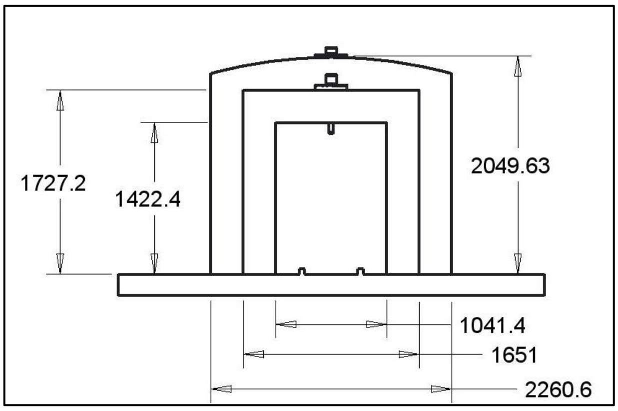


Figure 1.2: Front view of kiln

This wireframe model is prepared in geometric modelling software Creo Parametric; it resembles the kiln which is studied in our work.

1.1.2 About Industry

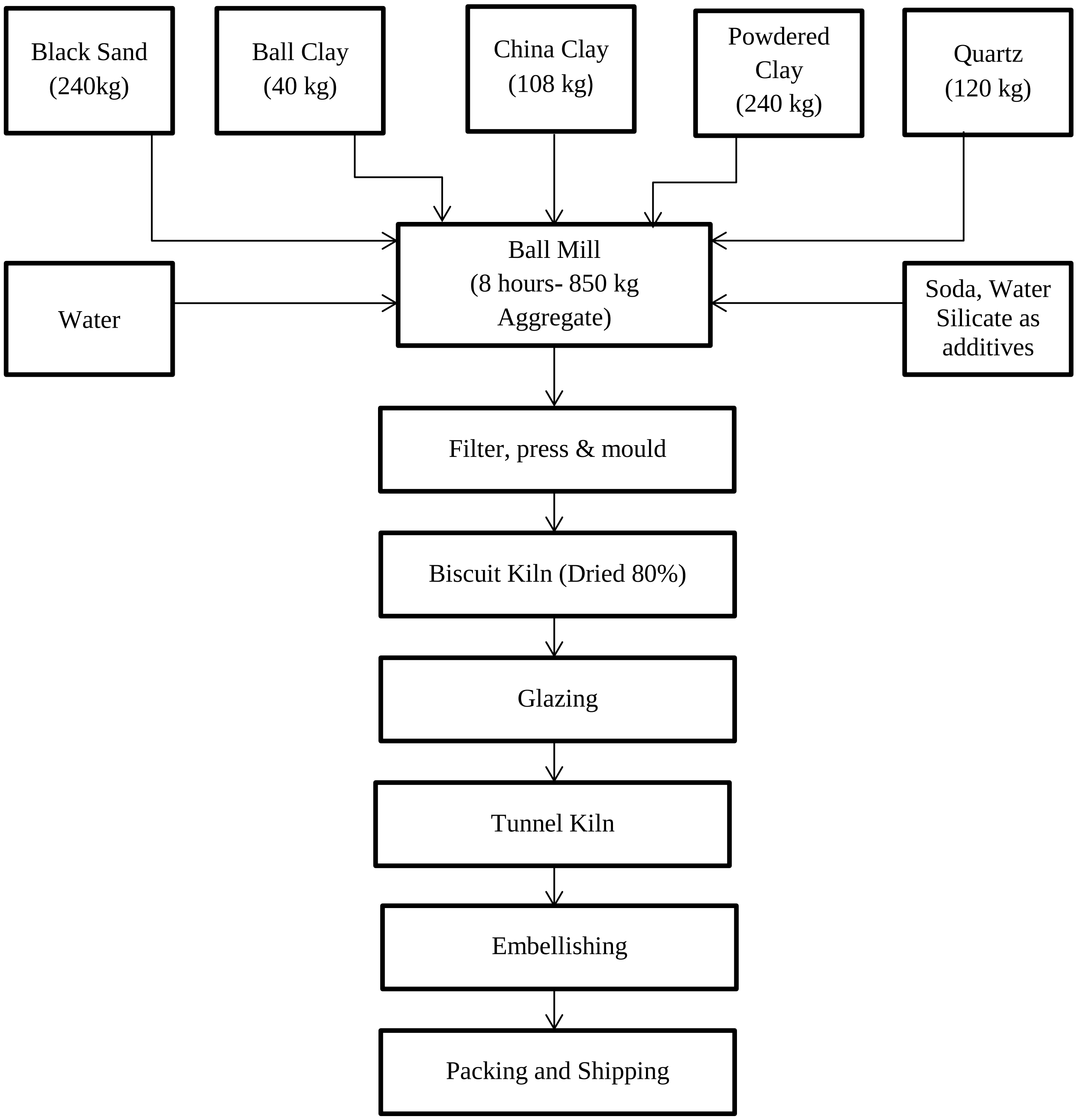


Figure 1.3: Flowchart of industrial process

- The above is flowchart for processes taking place within the industry.
- Major product of Shiv Shakti Ceramics is cups and saucers. Different sizes and grades of cup are manufactured from raw material up to finishing and packing.
- Raw material consisting of Black Sand (340 kg), Ball Clay (40 kg), China Clay (108 kg), Powdered Clay (240 kg) and Quartz (120kg). All this along with this soda, water silicate as additives are used.
- This mixture is then placed in ball mill for 8 hours to prepare a thick clay aggregate. 850 kg of aggregate is prepared in this.

- This thick clay aggregate is cut and placed in mold, dried, and fired in the kiln up to form a ceramic product. Industry consists of basically 3 tunnel kilns.
- Firstly, a biscuit kiln present is here to absorb 80% of water from the shaped clay aggregate. Afterwards, this unbaked product is dipped into a layer of glaze.
- Secondly this glazed product is fired into the Firing kiln so that in forms a shiny ceramic texture as we observed in our household cups and saucer.
- Thirdly, after cooling artwork is done on this ceramic and is place in the last smallest kiln which heats this artwork of design at its place.
- Our Energy Balance is based on the major firing kiln. It is 120' long.

1.1.3 Information about our observed kiln

- Large sized entry and exit doors are present.
- It consists of Ceramics fiber insulation material of 3" are present on inner as well as outer surfaces. Following figure will illustrate the same easily.

Figure 1.4: Entry of Tunnel kiln

Figure 1.5: Exit of Tunnel kiln

Figure 1.6: Cooling zone of Tunnel kiln**(**Side view**)**

1.1.3(A) Brick and cart

- The center brick skeleton of tunnel kiln is 6” in width. Fire resistant brick made up from HFK material.
- The maximum service temperature of the brick is 1340°C and 1.003 kJ/kg of specific heat. This bricks also called as fire bricks or kiln bricks consist of Aluminum oxide up to 50-80% and minimum amount of Silica.
- These provided values also apply for brick that are used in preparation of cart/trolley. This HFK insulation material prepared used bricks of 6” x 3” x 3”.
- Each of these carts consists of approximate amount of 300 bricks.
- The center portion of this cart is made up of Ultra-light weight material in order for drop in the weight of the cart.

Figure 1.7: Cart with Sagger

1.1.3 (B) Sagger

- Sagger is generally present in order to hold the ceramics products into the position so that they do not move.
- These saggers have specific heat of 1.001 kJ/kg, but their weight is high.
- Each of this sagger has approximated about 200 grams to 4 kg of weight.
- The shapes and sizes of this sagger vary from work to work
- Such sagger are correspondingly shown in the following figure

Figure 1.8: Sagger for cup

Figure 1.9: Sagger for saucer

1.1.3(C) Motion of entry and exit

- These carts are pushed into the Tunnel kiln with the help of motor and a feed screw.
- Feed screw and motor are connected to the screw with the help of a timer setting system. This timer can be set manually which in turns set the movement of the screw.
- The existing setting is so bitterly that it takes each slide about 1 hour to enter into the preheating zone from loading zone.
- The entire length of the tunnel kiln is 120 feet i.e. 1440 inches, and corresponding length of the cart is 66 inches. Therefore in all totals of 24 carts can be accommodated in the kiln.
- Feed screw is present only to pushed one cart. The rest of them are moved forward by the one behind.
- A rail is present at the bottom of each of this cart and by rolling motion it moves forward.
- So, the major observation is that each cart is pushed forward by the one behind.

- Each cart enters the kiln at 1 hour, and subsequently each cart leaves the kiln every 1 hour.
- Therefore we have considered our working cycles to be 1 hour.
- The energy based calculations are carried out by the basis of each hour.

Figure 1.10: Firing Zone (Side view)

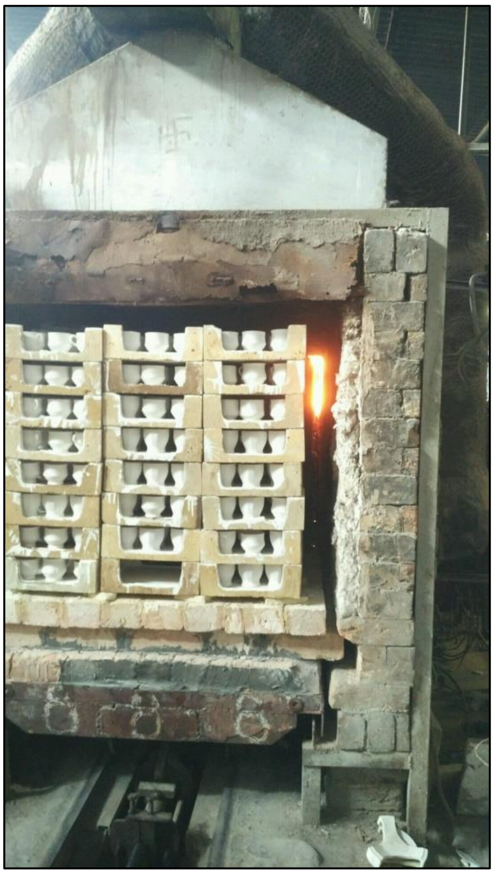


Figure 1.11: Tunnel Kiln

1.1.4(C) Temperature measurement on kiln surface

- To measure the total heat loss from the outside surface of the tunnel kiln its temperature has to be measured. For this purpose first the Infrared thermometer was used.
- However, the Infrared thermometers are not thought to be as highly accurate as surface probe measurement of the same surface.
- The accuracy of infrared thermometer is affected by moisture, dust, fog, or other particles in the air and also by change in ambient temperature.
- Therefore the temperature readings taken by the Infrared thermometer are also verified by simple thermocouple thermometer.

Figure 1.12: Infrared Thermometer

Figure 1.13: Thermocouple Thermometer

1.2 Problem Definition

- Our project mainly focuses on the increase in the efficiency of the kiln by energy balance.

NET INPUT = NET OUTPUT + LOSSES

- From the research paper we have studied the energy distribution in the kiln takes place as following way:

TOTAL ENERGY SUPPLIED = P + M + C + HM + HF + SL + LC + X + Y + Z

- Where,

P = Heat consumed in pre-heating

M = Heat consumed in Main heating

C = Heat released during cooling

HM = Heat absorbed by the material which is to be baked

HF = Heat absorbed by kiln furniture

IL = Surface losses

LC = Chimney losses

Here, X = Losses into the environment by opened entries and exit

Here Y = Losses due to Evaporation of water (loss in weight of cart), Ground losses, Opening losses, Unburnt fuel losses (residue).

- Generally a tunnel kiln is an open system (there is no closed boundaries of the system. There is continuous movement of the baking material in and out.
- Here the X amount of heat released cannot be constrained or put a stop.
- The total energy supplied includes the amount of heat generated due to combustion of fuel.
- In this traditionally fired kiln, Gas fuel (PNG) is used. The major advantage of gaseous fuel is that there is minimum or near about zero residue. And hence, it can be neglected.
- There will be other losses such that heat absorbed by insulation i.e. increase in mass of the insulation due absorption of energy which is very negligible.
- Such losses further cannot be calculated and hence we define them under variable 'Z'.

1.3 Objective of Problem

- The main objective of our given problem is that to increase the efficiency of the Tunnel kiln.
- It includes calculating the losses of the kiln, and formation of suitable solution.
- The average efficiency of Tunnel kilns lies from 22% to 25%. Hence in order to increase it more, problem may occur with the stability of the system.
- Breakdown of cart by reducing its weight in a working kiln will not be done.

CHAPTER 2:
LITERATURE REVIEW & PATENT SEARCH

2.1 Review of Research papers

Review of research papers are the most important in our case study. This is because energy balance based calculations are generally undertaken in these papers. Research is our greater priority. Such of these research papers include the energy balance which is undertaken by us and shows heat transfer processes that are undertaken within this. However, research papers also include the various way of reducing heat input with greater output.

Paper 1: Vicente de Paulo Nicolau; Alessandro Pedro Dadam (Oct./Dec. 2009)

"Numerical and experimental thermal analysis of a tunnel kiln used in ceramic production"

The author has shown the different types of heat transfer process occurring inside the tunnel kiln. Also it discusses that which type of insulation for the prevention of heat loss is going to be effective.

Paper 2: Preeti Kumari, Radha Krishan, L.K. Sharma (July 2015)

"Energy Efficient Tunnel Kilns with Superlative Firing Atmosphere for Ceramic Industries"

This research paper discusses how important is the length of the kiln and also the individual length of each zone in kiln. It shows how can efficiency change with increase or decrease in its length.

Paper 3: Sameer Maithel, R Uma, Anil Kumar and N Vasudevan

"Energy Conservation and Pollution Control in Brick Kilns"

Here we also get the acute knowledge about how the design and different type of chimney affect the performance of the tunnel kiln. It discusses number of different chimneys and its specification.

Paper 4: M.R. Ravi, P.L. Dhar and Sangeeta Kohli

"Energy Audit and Improvement of an Up draught Pottery Kiln"

Here it is discussed about the low efficiency old pottery kilns. How that kiln can be converted into high efficiency kilns and reduces pollution.

Paper 5: Monica F. Naccache, Marcos S. P. Gomes. (November 6-11, 2005)

"Numerical simulation of flow and heat transfer through a tunnel kiln"

This research paper show how the old kilns are polluting since they used sawdust as fuel. It also shows the advantages of using natural gas as the fuel.

Paper 6: Friedherz H. Becker, Lars Lorenz, Dr. H. C. Gerd Walter (August 2006)

"Heat exchange in a fast firing kiln for gloss firing of porcelain"

This research paper includes the analysis of longitudinal and cross flow in the tunnel kiln of the ceramic load and heat flow.

Paper 7: Goran Stojanovski, Mile Stankovski (August 28 - September 2, 2011)

"Advanced Industrial Control Using Fuzzy-Model Predictive Control on a Tunnel Kiln Brick Production"

This explains fuzzy control system's working when applied to a tunnel kiln controller. Fuzzy control system is widely used for machine control. It is a type of logical control which is used when results cannot be just described in the terms of analogy 0 or 1.

Paper 8: Yu Zhang, Junfeng Wang, Tino Redemann, Eckehard Specht (April 2015)

"Thermal behavior of kiln cars while traveling through a tunnel kiln"

This research paper solely focuses on the behavior of cart inside the tunnel kiln. It focuses on reducing the specific heat consumption for the cart heating and increasing efficiency with use of material having better thermal properties.

Paper 9: Linsheng Wei, Liangyin Guo, Zhang Yafang, Hu Zhaoji,Tan Zhihong (2014)

"Numerical Study of Waste Heat Recovery from Tunnel Kiln Utilized to Produce Rare Earth Phosphor"

This research paper includes recovery of the waste energy for the production of phosphorous element.

Paper 10: Dipen V.Chauhan, S. N. Misra, R. N. Shukla (2012)

"Study of high emissivity coating of ceramic material for energy conservation"

Here it is told that Gujarat has a high production of product produced in tunnel kiln. It shows that over 30-40% of the product cost is due to low efficiency of the tunnel kiln.

2.2 Study of patents

The study of patents includes for the search of the possible solutions which are undertaken by us. This corresponding study of patents has also been uploaded to PMMS, however top 10 patents we have observed are included in list. Some of these patents make use of roller kiln instead of tradition al Tunnel kiln which has greater efficiency. Patents also include decreasing the weight of kiln furniture in order to decrease the heat absorbed by them. I.e. fire more with less.

Patent 1: Liu Jiuming (May 2015)

"Integrated refractory brick firing equipment"

The heated refractory material carried on the cart throughout the exit of the kiln is force cooled by the water jackets around it through which cold water is passed and the cart is cooled faster than conventional free cooling.

Patent 2: Liu mengdong (Feb 2011)

"Integrated two-layer reverse energy-saving tunnel kiln"

The upper is the firing zone where high temperatures are produced and the lower level is the preheating zone where the requirement is low. This can help in energy saving and making the kiln efficient.

Patent 3: Hu junming (April 2014)

"Energy-saving double-layer ceramic tunnel kiln"

The roller kiln uses no. of rollers on which material is placed and the material is entered from one end and pushed throughout the kiln and got outside by the roller. And the rate of the speed of the rollers is higher than the previous used carts. Also the rollers are kept inside of the kiln therefore the heat is also kept inside therefore the heat lost, because of the cart material is also eliminated.

Patent 4: Gunning, Xu Yue, Yan Yunfei, Hou Guihua, Jiang Ruixin rain,Zhang Feng (June 2016)

"Tunnel kiln capable of reducing dust emission and method for reducing dust emission of tunnel kiln"

To make kiln more environment friendly dust emission can be reduced with the use of a suction fan. Suction fan helps in collecting the waste dust particle which also affect the kiln performance.

Patent 5: Li Shiwu, Leng Guo Wei, Xiao Lixin (Oct 2013)

"Tunnel kiln"

This patent shows a Tunnel kiln with modifications.

Patent 6: Wang Hongwei (April 2013)

"High-yield efficient tunnel kiln"

This high yield efficiency tunnel kiln is prepared by changing the burner position at entry and exit of firing zone. So in order to have faster heating of the cart and reducing the amount of gases required for the same process

Patent 7: Nanbu masamitsu (Jan 2003)

"Method for producing artificial lightweight aggregate"

Make light weight bricks of fly ash direct firing is not possible as it still contains some flammable particles. So the raw material is first fired inside a kiln where that heat is used for some work and then the raw material used for manufacturing.

Patent 8: Yuan peisheng (16.01.2013)

"Integrated energy-saving tunnel kiln sintered by closed combustion"

If the combustion chamber can be closed by heat resistant door then heat loss can be reduced and energy can be saved.

Patent 9: Guo junping,cai zhencheng,cai zhenfeng,wu wu (05.12.2012)

"Large-section high-efficiency energy-saving type gas tunnel kiln"

Dimension ratio such as length to height, width to height is also an important factor. Keeping this ratio in its optimum limit can increase its efficiency.

Patent 10: Wang daocheng, si hongkang, liu chuantao, shao changhong. (29.04.2015)

"Natural gas tunnel kiln exhaust heat recovery circulation pipeline thermoelectric hot water supply system"

The waste heat can also be recovered to make hot water useful in day to day life.

CHAPTER 3:
ANALYSIS, DESIGN METHODOLOGY & IMPLEMENTATION STRATEGY

3.1 AEIOU summary canvas

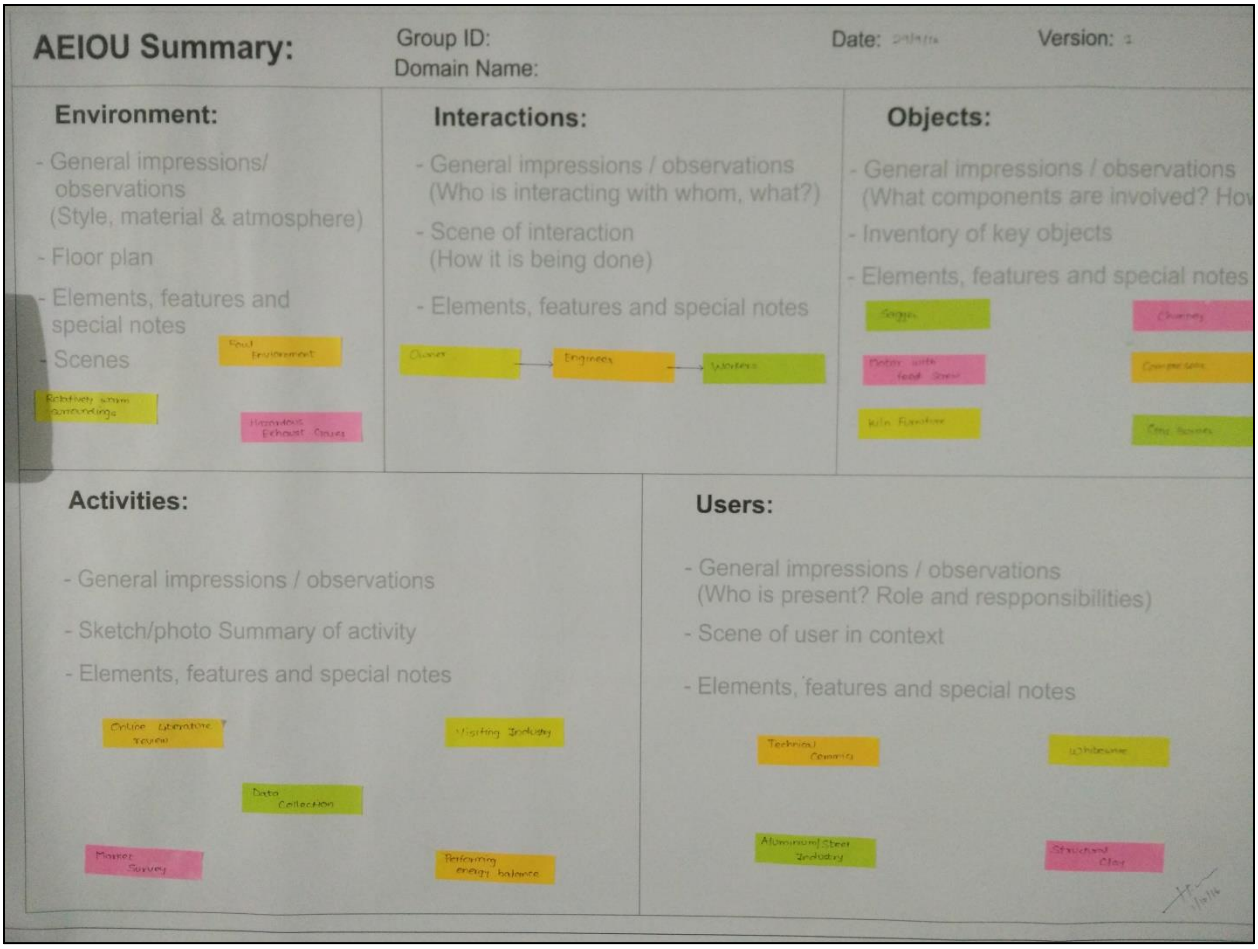


Figure 2.1 AEIOU canvas

3.1.1 AEIOU summary canvas methodology

- First of we all observed problems such as of the amount of heat liberated during the process of the firing in the kiln, health hazard, losses taking place, the amount of ceramics being wasted.

3.2 Ideation canvas

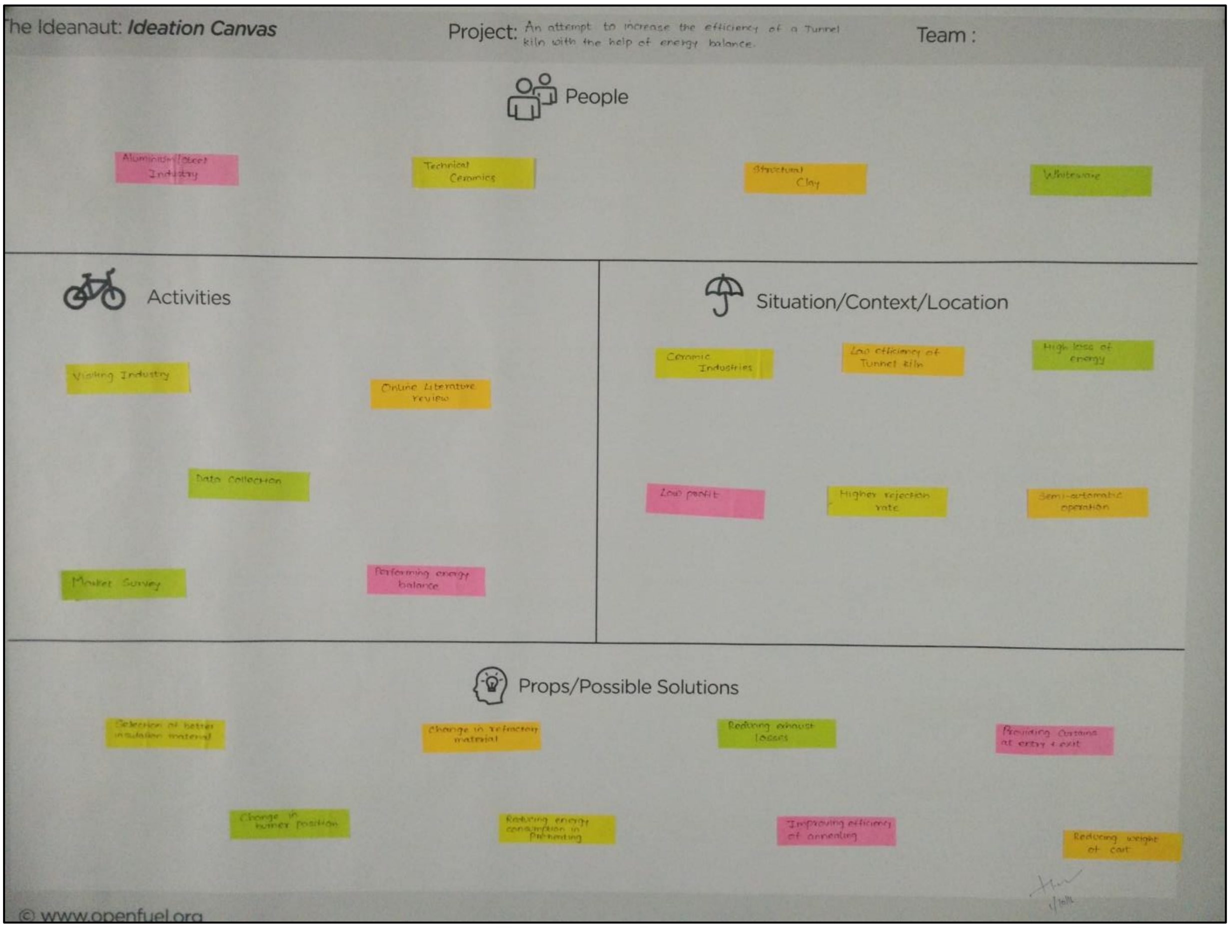


Figure 2.2 Ideation canvas

3.2.1 Ideation summary canvas methodology

- The target people within this organization are generally, the various industrialists which produce ceramic hardware.
- Also the companies which provide better housing crockery and the buyers of this crockery i.e. people like us.
- Possible and proposed solutions decided by us include as automation of kiln and total removal/change of the insulation. However, these solution could prove too much of costly for the company.

3.3 Product development canvas

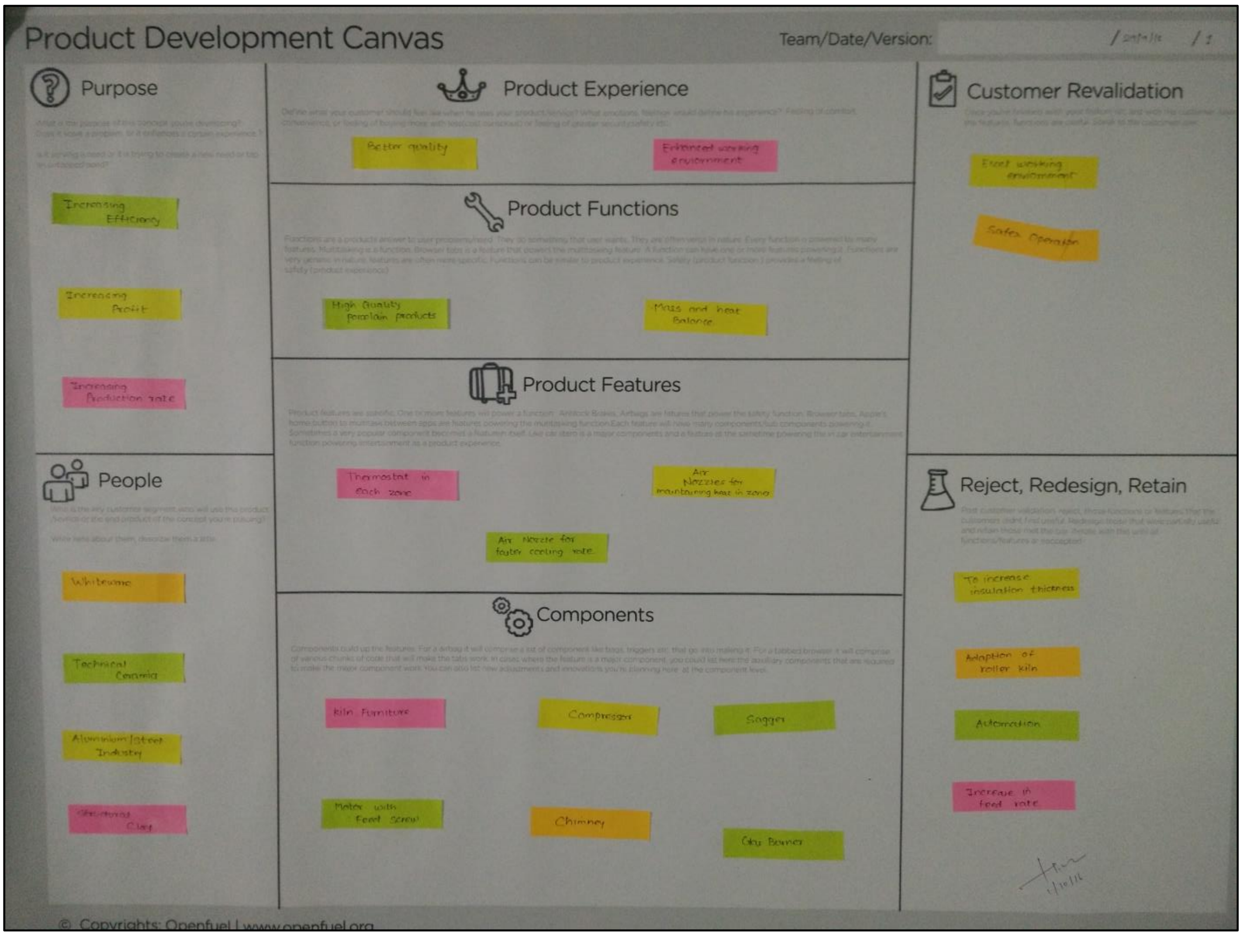


Figure 2.3 Product development canvas

3.3.1 Product development canvas methodology

- The purpose of our project is to increase the output with minimum input. Product functions include this high quality ceramics (which are properly baked and have very good shine.
- The project redesign could be possible. However it will have greater cost.

3.4 Empathy mapping canvas

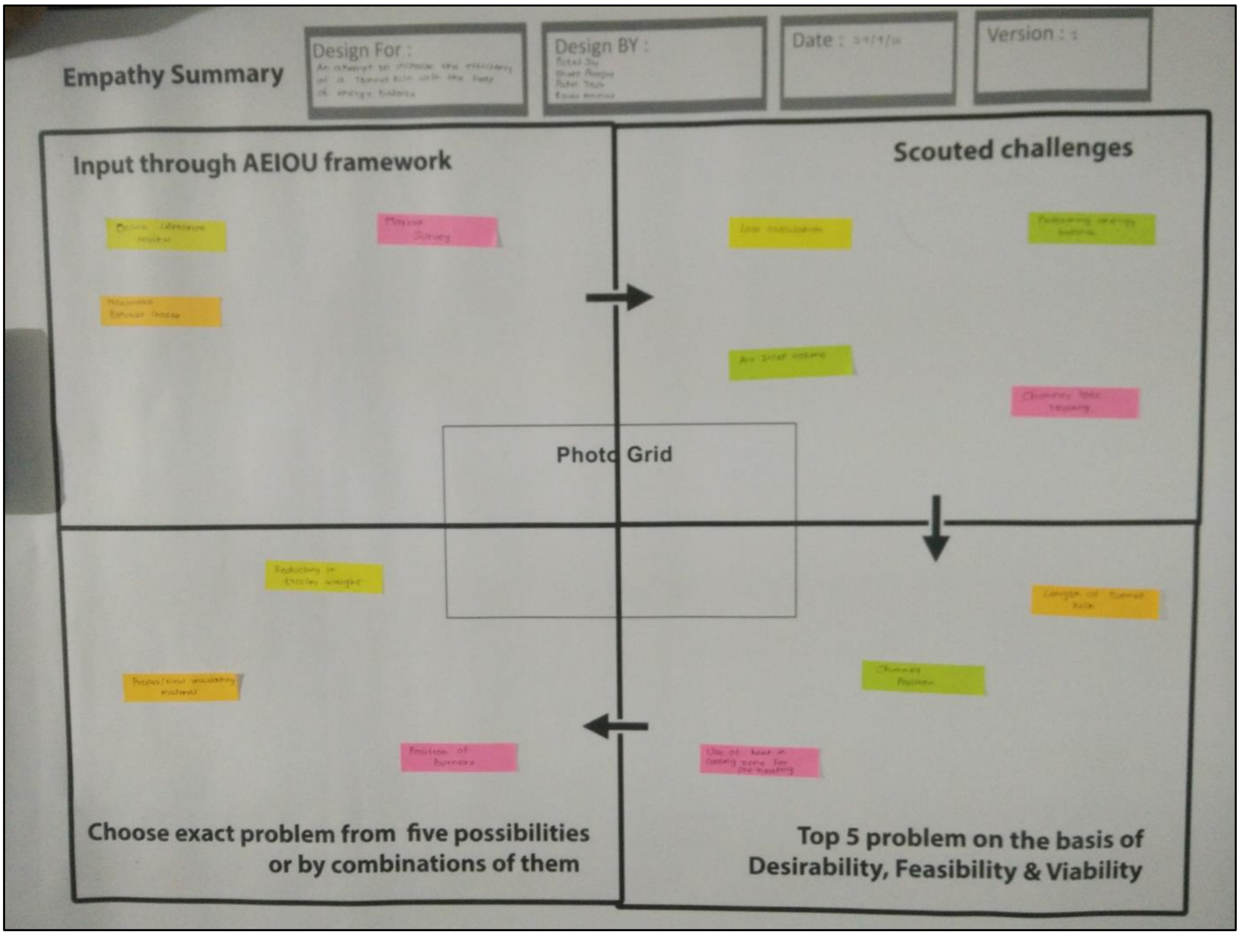


Figure 2.4 Empathy canvas

3.4.1 Empathy summary canvas methodology

- It includes the top 5 problems we have undertaken within our project. The possible combinations in order to overcome those problems are included in this canvas.

3.5 Business Model Canvas

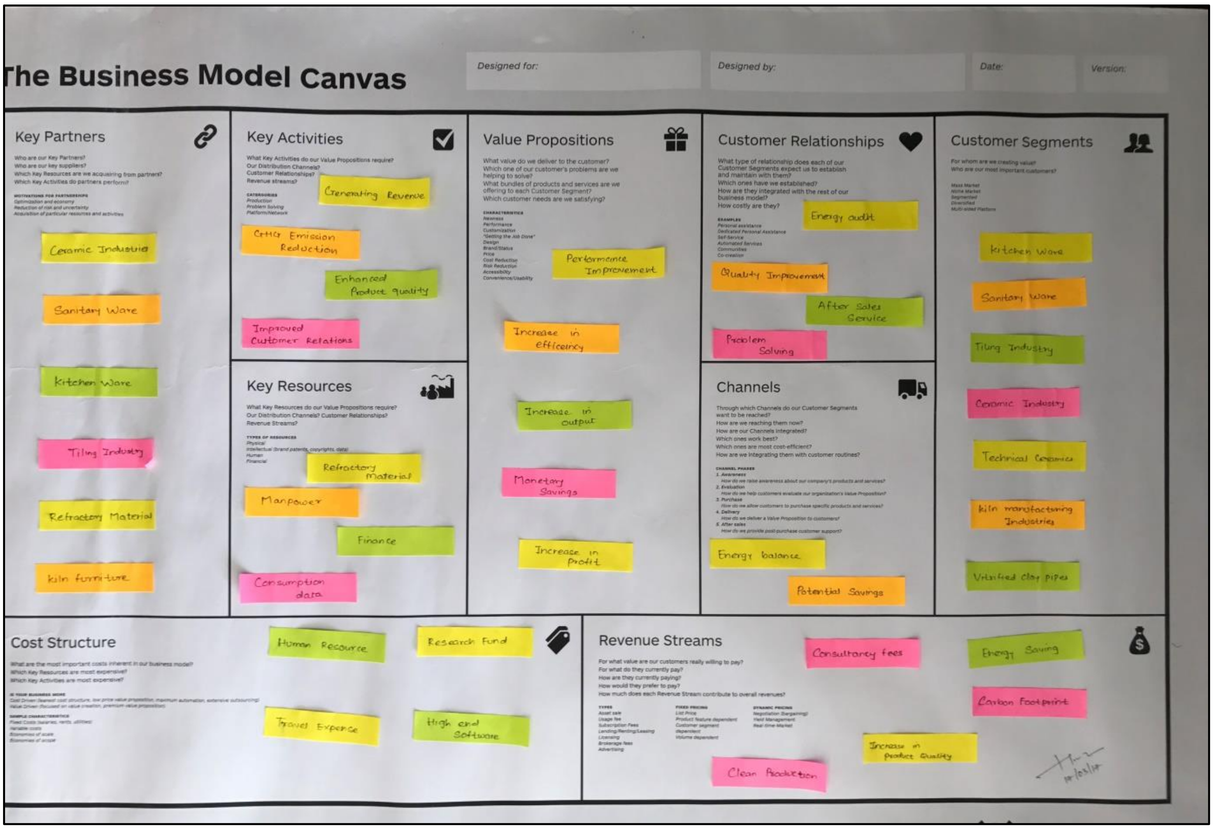


Figure 2.5: Business model canvas

3.5.1 Business model canvas report

- **<u>KEY PARTNERS</u>**

o **Finance Partners & Decision committee**

Team Members

1) Jay Patel 2) Krunal Raval
3) Pranjal Bhatt 4) Yash Patel

o **Raw material partners**

1) Interkiln Industries Ltd.

o **Human Resources committee**

1) Jay Patel
2) Krunal Raval

o **Marketing Partners**

1) Pranjal Bhatt
2) Yash Patel

- ## **KEY ACTIVITIES**

o Manufacturing Unit
1) Kiln Furniture Manufacturer
2) Kiln manufacturer

o Testing Unit
1) Prof. Hitesh Patel
2) Shiv Shakti Ceramics
3) Anil Impex

o Customer Service
1) Pranjal Bhatt
2) Jay Patel

o R&D Department
1) Yash Patel
2) Krunal Raval

- ## **KEY RESOURCES**

o Finance
1) Jay Patel
2) Yash Patel

o Safety Equipment
1) Fire extinguisher
2) Limit switches for cart
3) Safety Gloves

o Material
1) Refractory material
2) Cart furniture
3) Insulation material

o Machines and Tools
1) Infrared Thermometer
2) Pressure Gauge
3) Thermostat

- ## **CUSTOMER RELATIONSHIPS**

The aim is to provide better kiln performance by increasing its efficiency or production rate and try to meet all the customer requirements and maintain a good relationship with customers.

o Feedback Service & Maintenance
1) Krunal Raval
2) Yash Patel

o Discount & Advertisements
1) Jay Patel
2) Pranjal Bhatt

- ## **CHANNELS**

o Marketing Schemes
By implementing effective marketing techniques or by giving some discounts or schemes the product sales can be increased.

- **Advertising**

Advertising lets the prospective customers know about the products and it channels the customers with the vendor.

- **Internet**

Internet is an unavoidable medium for marketing and advertising. The company may use it to attract the potential customers in the field and can gain profit from it.

- **Promotion Activities**

Company can do promotional activities like organizing seminars and take part into exhibition and make the consumers aware about company and its vision.

- **<u>CUSTOMER SEGMENTS</u>**

The customer segment consists of all the ceramic manufacturing industries which uses the tunnel kiln for production of ceramic. It involves

1) Wall and floor tiles
2) Bricks and roof tiles
3) Household ceramic
4) Refractory products
5) Sanitary ware
6) Technical ceramic
7) Vitrified clay pipes
8) Inorganic bounded abrasives

- **<u>COST STRUCTURE</u>**

- **Human Resource**

Manpower required undertaking the whole process starting from marketing, sales, data collection, data analysis, providing viable solution and implementing it and also providing after sales service.

- **Travel Expense**

It involves the expense which the person has to spend in travelling when one has to go to the company for data collection for the analysis.

- **Research funds**

These funds have to be declared by the company for further development of the company as the company has to constantly develop new methods to remain in the competitive market.

- **High end software**

The company has to invest in the different software to undertake the analysis process.

CHAPTER 4:
ENERGY BALANCE CALCULATIONS

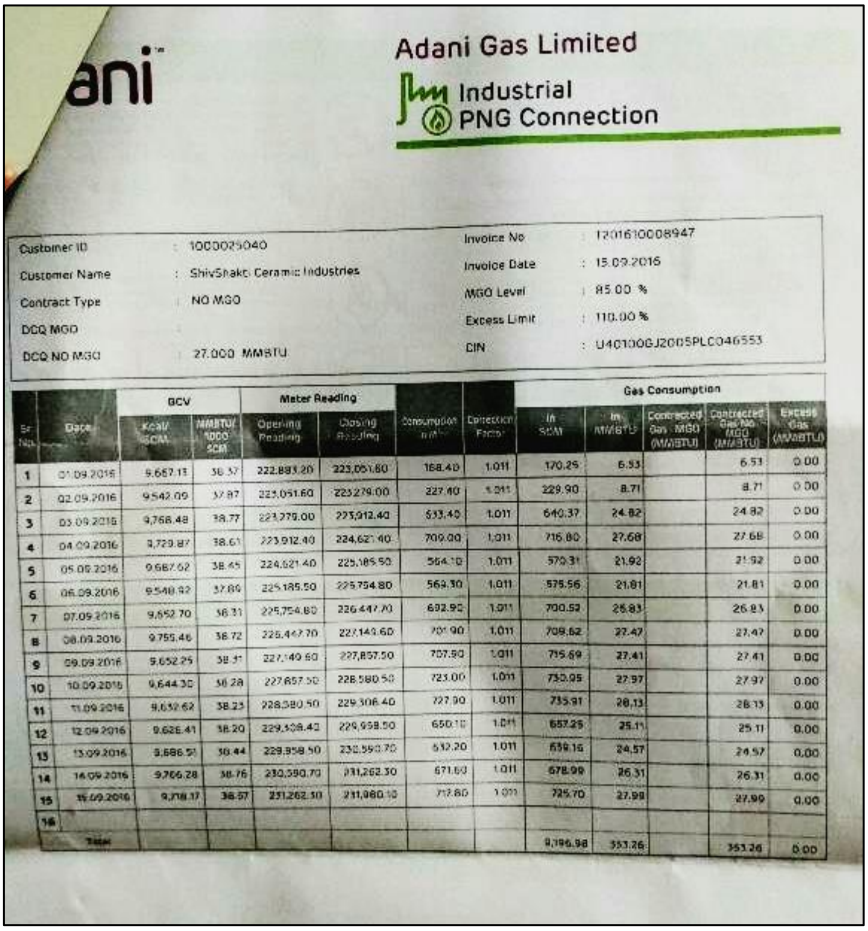
4.1 Practical Data:

- Tunnel Kiln Dimensions:
  - Length of Preheating zone, L_p = 11.58 meter (38 feet) (456 inch)
  - Length of Firing zone, L_f = 4.87 meter (16 feet) (192 inch)
  - Length of Cooling zone, L_c = 20.12 meter (66 feet) (792 inch)
  - Total length, L = 36.57 meter (120 feet)
  - Height with insulation in Preheating and cooling zone, h = 1.73 meter (68 inch)
  - Height with insulation in Firing zone, H = 2.03 meter (80 inch)
  - Width in preheating and Cooling zone, w = 1.65 meter (65 inch)
  - Width in firing zone, W_f = 2.26 meter (89 inch)
  - Insulation Dimensions:
    - At sides:
      - Thickness = 12 inch
    - At top:
      - Thickness = 6 inch
- Weights:
  - Cup (raw) = 111 gram
  - Saucer (raw) = 179 gram
  - Cup (baked) = 96 gram
  - Saucer (baked) = 170 gram
  - Sagger:
    - Cup = 3.934 kilogram
    - Saucer = 226.5 gram
- 1 cup sagger contains 9 cups.
- 1 saucer row contains 28 saucers. (First and last saggers are kept empty)
- Hence,
  - Total cups = No. of sagger*No. of cups in each sagger
    = 42 * 9
    = 378 cups.
  - Total saucers = No. of row*No. of saucers in each row
    = 20 * 28
    = 560 saucers.

- Total Weight:
  - Cups = Total cups * Weight of each cup
    = 378 * 111
    = 41958 gram
    = 41.958 kilogram
  - Saucers = Total saucers * Weight of each saucer
    = 560 * 179
    = 100240 gram
    = 100.24 kilogram
  - Cup sagger = Total sagger * Weight of each sagger
    = 42 * 3.934
    = 165.228 kilogram
  - Saucer sagger = Total sagger * Weight of each sagger
    = 600 * 226.5
    = 135900 gram
    = 135.9 kilogram
- Total sagger weight (cup+saucer) = 301.128 kilogram
- Total raw product, M_{clay} = 100.24 + 41.958
  = 142.198 kilogram
- Total weight on cart, M_{load} = Total sagger weight + Total raw product
  = 301.128 + 142.198
  = 443.34 kilogram
- Mass of brick on cart:
  - Volume of brick = l * b * h
    = 67 * 40 * 10
    = 26800 $inch^3$
    = 439173.31 cm^3
  - Now,
    Density of brick material = 1.1 $gram/cm^3$
  - Mass of brick, M_{brick} = Density * Volume
    = 1.1 * 439173.31
    = 483090.64 gram
    = 483.09 kilogram
- Total weight of trolley, $M_{trolley}$ = $M_{brick} + M_{wheel}$
  = 483.09 + 66.91
  = 550 kilogram
- Mass of water lost, M_w = 8% of total raw product
  = 11.37 kilogram

- The total volume of fuel consumed is calculated by referring to the company's monthly bill of gas consumption.

- Following is the bill of monthly gas consumption from company's gas provider (Adani Gas Ltd.).



ani

Adani Gas Limited

Industrial PNG Connection

Customer ID	: 1000025040		Invoice No	: 1201610008947
Customer Name	: ShivShakti Ceramic Industries		Invoice Date	: 15.09.2016
Contract Type	: NO MGO		MGO Level	: 85.00 %
DCQ MGO	:		Excess Limit	: 110.00 %
DCQ NO MGO	: 27.000 MMBTU		CIN	: U40100GJ2005PLC046553

Sr. No.	Date	GCV		Meter Reading		Consumption m³	Correction Factor	Gas Consumption				
		Kcal/ SCM	MMBTU/ 1000 SCM	Opening Reading	Closing Reading			In SCM	In MMBTU	Contracted Gas MGO (MMBTU)	Contracted Gas NO MGO (MMBTU)	Excess Gas (MMBTU)
1	01.09.2016	9,667.13	38.37	222,883.20	223,051.80	168.40	1.011	170.25	6.53		6.53	0.00
2	02.09.2016	9,542.09	37.87	223,051.60	223,279.00	227.40	1.011	229.90	8.71		8.71	0.00
3	03.09.2016	9,768.48	38.77	223,279.00	223,912.40	633.40	1.011	640.37	24.82		24.82	0.00
4	04.09.2016	9,729.87	38.61	223,912.40	224,621.40	709.00	1.011	716.80	27.68		27.68	0.00
5	05.09.2016	9,687.62	38.45	224,621.40	225,185.50	564.10	1.011	570.31	21.92		21.92	0.00
6	06.09.2016	9,548.92	37.89	225,185.50	225,754.80	569.30	1.011	575.56	21.81		21.81	0.00
7	07.09.2016	9,652.70	38.31	225,754.80	226,447.70	692.90	1.011	700.52	26.83		26.83	0.00
8	08.09.2016	9,755.46	38.72	226,447.70	227,149.60	701.90	1.011	709.62	27.47		27.47	0.00
9	09.09.2016	9,652.25	38.31	227,149.60	227,857.50	707.90	1.011	715.69	27.41		27.41	0.00
10	10.09.2016	9,644.30	38.28	227,857.50	228,580.50	723.00	1.011	730.95	27.97		27.97	0.00
11	11.09.2016	9,632.62	38.23	228,580.50	229,306.40	727.90	1.011	735.91	28.13		28.13	0.00
12	12.09.2016	9,626.41	38.20	229,308.40	229,958.50	650.10	1.011	657.25	25.11		25.11	0.00
13	13.09.2016	9,686.57	38.44	229,958.50	230,590.70	632.20	1.011	639.16	24.57		24.57	0.00
14	14.09.2016	9,766.28	38.76	230,590.70	231,262.30	671.60	1.011	678.99	26.31		26.31	0.00
15	15.09.2016	9,718.17	38.57	231,262.30	231,980.10	717.80	1.011	725.70	27.99		27.99	0.00
16												
Total								9,196.98	353.26		353.26	0.00

Figure 4.1: Monthly consumption of fuel

- Volume of fuel consumed, V_f	=	22 m^3
- Density of PNG	=	0.718 kg/m^3
- Mass of fuel consumed, M_f	=	22*0.718
	=	15.87 kilogram
- Average Production capacity/day	=	Total weight of raw product * No. of carts/day
	=	142.198 * 22
	=	3128.36 kilogram
- Capacity of kiln	=	Average production/day + 15%
	=	3128.36 + (0.15 * 3128.36)
	=	3128.36 + 469.25
	=	3597.61 kilogram/day

- Average temperature readings inside the tunnel kiln

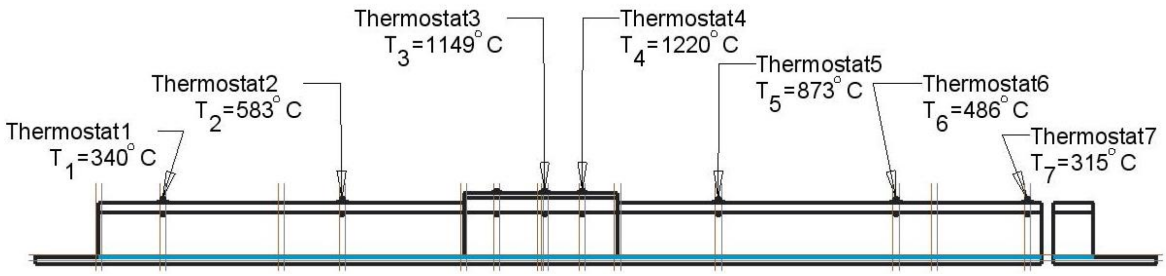


Figure 4.2: Temperature at Thermostat

Table 4.1: Thermostat readings

Thermostat Number (Zone)	Average Temperature
0	35°C
1	340°C
2	583°C
3	1149°C
4	1220°C
5	873°C
6	486°C
7	315°C

4.2 Constants:

Table 4.2: Values of various co-efficient

Specific heat of clay, $C_{p(clay)}$	0.87 kJ/kg K
Specific heat of sagger, $C_{p(sagger)}$	1 kJ/kg K
Specific heat of trolley, $C_{p(trolley)}$	1 kJ/kg K
Equivalent thermal Conductivity of preheating zone, K_p	0.1525 kJ/m K
Equivalent thermal Conductivity of firing zone, K_f	0.139 kJ/m K
Equivalent thermal Conductivity of cooling zone, K_c	0.1525 kJ/m K
Stefan Boltzmann constant, σ	$5.67 * 10^{-11}$ kJ/m^2 s K^4
Latent heat of water, L_w	2264.76 kJ/kg

4.3 Energy Balance of Tunnel kiln

- Average temperature readings of outside wall of tunnel kiln.

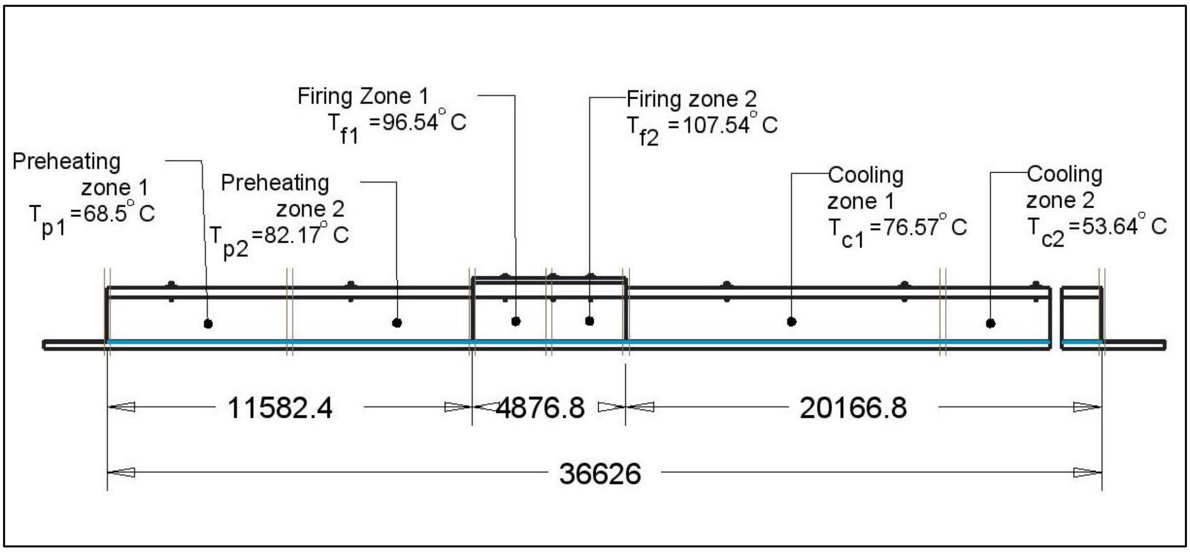


Figure 4.3: Avg. Surface temperature in each zone *All dimensions are in mm

Table 4.3: Temperature readings

Ambient Temperature, T_a	35 °C
Preheating zone-1 Temperature, T_{p1}	68.5 °C
Preheating zone-2 Temperature, T_{p2}	82.17°C
Firing zone-1 Temperature, T_{f1}	96.54 °C
Firing zone-2 Temperature, T_{f2}	107.54 °C
Cooling zone-1 Temperature, T_{c1}	76.57 °C
Cooling zone-2 Temperature,T_{c2}	53.64 °C
Exit Temperature of cart, T_{co}	105 °C
Exhaust gas Temperature, T_{ex}	350 °C

4.3.1 Total energy at inlet:

- Calorific value of gas (PNG),(C.V.) = 13,272 kcal/Kg
- Mass of fuel supplied per hour,(m_f) = 15.664 Kg/Hr
- Q_{inlet} = m_f * C.V.

  = **2,07,892 kcal/hr**

4.3.2 Heat loss due to cart at outlet:

- $Q_{clay} = M_{clay}C_{pclay}\Delta T$

  $= 1998.6$ kcal

  Here, Q_{clay} is the heat loss due to clay elements kcal /hr,
  M_{clay} is the mass of clay elements,
  C_{pclay} is the specific heat of clay(kcal /kg K),
  ΔT is the temperature difference between the cart exit temperature and ambient temperature.

- $Q_{sagger} = m_{sagger}C_{sagger}\Delta T$

  $= 301.12*1*(105-35)$

  $= 5037.85$ kcal

  Here, Q_{sagger} is the heat lost due to saggers kcal /hr,
  m_{sagger} is the total mass of saggers,
  C_{sagger} is the specific heat of sagger kcal /kg K.

- $Q_{trolley} = m_{trolley}C_{trolley}\Delta T$

  $= 550*1*(105-35)$

  $= 9201.72$ kcal

  Here, $Q_{trolley}$ is the heat lost due to trolley kcal /hr,
  $m_{trolley}$ is the mass of trolley,
  $C_{trolley}$ is the specific heat of trolley kcal /kg K.

- $Q_{cart} = Q_{clay} + Q_{sagger} + Q_{trolley}$

  $=$ **16238.18 kcal/hr**

Here, Q_{cart} is the total heat loss due to cart.

4.3.3 Heat loss due to surface heat rejection:

The total surface area of different zones of kiln is as follows:

- $A_p = 2(L_p*h) + (L_p*w)$

  $= 59.59\ m^2$

  Here, A_p is the total surface area of preheating zone,
  L_p is the length of the preheating zone,

h is the height of kiln at preheating zone,
w is the width of the preheating zone.

- A_f = $2(L_f*H) + (L_f*W_f)$

  = $30.844\ m^2$

  Here, A_f is the total surface area of firing zone,
  L_f is the length of the firing zone,
  H is the height of kiln at firing zone,
  W_f is the width of the firing zone.

- A_c = $2(L_c*h) + (L_c*w)$

  = $102.69\ m^2$

  Here, A_c is the total surface area of cooling zone,
  L_c is the length of the cooling zone,
  h is the height of kiln at cooling zone,
  w is the width of the cooling zone.

- **<u>Heat loss calculation</u>:**
  - R_{p1} = $\sigma A_p(T_{p1}^4 - T_a^4)*3600/2$

    = 6688.49 kcal/hr

    Here, R_{p1} is the heat loss from the first half of preheating zone surface kJ/hr,
    T_{p1} is the kiln outside temperature in the first half of preheating zone,
    T_a is the ambient temperature.

  - R_{p2} = $\sigma A_p(T_{p2}^4 - T_a^4)*3600/2$

    = 10,049.38 kcal/hr

    Here, R_{p2} is the heat loss from the second half of preheating zone surface kJ/hr,

T_{p2} is the kiln outside temperature in the second half of preheating zone.

  - R_{f1} = $\sigma A_f(T_{f1}^4 - T_a^4)*3600/2$

    = 7259.98 kcal/hr

    Here, R_{f1} is the heat loss from the first half of firing zone surface kJ/hr,
    T_{f1} is the kiln outside temperature in the first half of firing zone K.

- R_{f2} = $\sigma A_f(T_{f2}^4 - T_a^4)*3600/2$
  = 9006.66 kcal/hr

Here, R_{f2} is the heat loss from the second half of firing zone surface kJ/hr,
T_{f2} is the kiln outside temperature in the second half of firing zone K.

- R_{c1} = $\sigma A_c(T_{c1}^4 - T_a^4)*3600/2$
  = 15,049.23 kcal/hr

Here, R_{c1} is the heat loss from the first half of cooling zone surface kJ/hr,
T_{c1} is the kiln outside temperature in the first half of cooling zone K.

- R_{c2} = $\sigma A_c(T_{c2}^4 - T_a^4)*3600/2$
  = 11,750.85 kcal/hr

Here, R_{c2} is the heat loss from the second half of cooling zone surface kJ/hr,
T_{c2} is the kiln outside temperature in the second half of cooling zone K.

- $Q_{surface}$ = $R_{p1} + R_{p2} + R_{f1} + R_{f2} + R_{c1} + R_{c2}$
  = **53,804.23 kcal/hr**

Here, $Q_{surface}$ is the total heat loss from the kiln surface kJ/hr.

4.3.4 Heat loss due to evaporation of water

As the raw clay product bakes some percent of its weight is reduced due to loss of water content in it.
The loss of water weight is about 8%. So the total weight loss m_w is (8%* Total raw product (M_{clay}).

- Therefore m_w = 11.37 kilogram
- Q_{water} = $m_w L_w$
  = **6100.34 kcal/hr**

Here, Q_{water} is the heat loss due water loss kJ/hr,
m_w is the mass of water lost,
L_w is the latent heat of evaporation of water kJ/kg

4.3.5 Chimney losses

- V_f = 22 m^3/hr
- Volume of air per 1 m^3 of fuel 9.523 m^3/hr.
- V_a = 9.523*22

  = 209.53 m^3/hr

- Amount of excess air needed for proper combustion is 20%.
- V'_a = 209.53*1.2

  = 251.424 m^3/hr
- V_{gas} = $V_f + V'_a$

  = 273.424 m^3/hr at 35°C

- With help of Charles' Law volume of gas at 350°C (V'_{gas})is 553.06 m^3/hr.
- Enthalpy difference of air at 350°C and 35°C(H_{air}) is 93.162 kcal/m^3.
- $Q_{chimney}$ = V'_{gas}*H_{air}

  = **51,639.58 kcal/hr**

Here, V_f is the volume of fuel m^3/hr,
V_a is the total volume of air m^3/hr,
$Q_{chimney}$ is the heat loss due to exit of flue gases at high temperature.

4.3.6 Losses due to open surface at inlet and outlet

- A_o = 2.8516 m^2
- Q_{o1} = $\sigma A_o(T_{ex}^4 - T_a^4)$*3600

  = 19,705.32 kcal/hr
- Q_{o2} = $\sigma A_o(T_{co}^4 - T_a^4)$*3600

  = 1588.19 kcal/hr
- $Q_{opening}$ = $Q_{o1} + Q_{o2}$

  = **21,293.51 kcal/hr**

Here, A_o is the opening area,
Q_{o1} is the opening loss at inlet of the kiln,
Q_{o2} is the opening loss at the exit end of kiln,
$Q_{opening}$ is the total opening loss from both ends of the kiln.

4.3.7 Heat loss due to ground surface below the kiln

As the ground surface area is 1/3 that of total surface area of kiln hence the heat loss is 1/3 that of $Q_{surface}$

- Q_{ground} = 1/3 * $Q_{surface}$
  = **17,934.74 kcal/hr**

  Here, Q_{ground} is loss of heat into the ground.

4.3.8 Total heat loss

- Q_{loss} = $Q_{cart} + Q_{surface} + Q_{water} + Q_{chimney} + Q_{opening} + Q_{ground}$
  = 166,864.45 kcal/hr

4.3.9 Total useful heat

- Q_{useful} = Total inlet-Total loss
  = $Q_{inlet} - Q_{loss}$ (Q_{inlet} =**2,07,892 kcal/hr**)
  = **41,027.98 kcal/hr**

Here, Q_{useful} is the total useful energy of the kiln.

4.3.10 Energy consumed by clay

- Zone 0-1
  $Qs_{(0-1)}$ = $M_{raw}\, C_{p(clay)} \Delta T$
  = **9025.31 kcal**

- Zone 1-2
  $Qs_{(1-2)}$ = **7181.45 kcal**

- Zone 2-3
  $Qs_{(2-3)}$ = **16,727.21 kcal**

- Zone 3-4
  $Qs_{(3-4)}$ = **2098.23 kcal**

Total amount of heat consumed = $Qs_{(0-1)} + Qs_{(1-2)} + Qs_{(2-3)} + Qs_{(3-4)}$
= 9025.31 + 7181.45 + 16,727.21 + 2098.23 kcal
= **35,032.2 kcal**

Also, for total sintering taking place in this process can be written as 10% of total amount of heat absorbed by clay

- Q_{sclay} = Q_{sc} * 1.1
  = **38,528.33 kcal/hr**

  Here, Q_{sclay} is the total heat used by clay in heating and sintering.

4.3.11 Unaccounted heat

- $Q_{unacc} = Q_{useful} - Q_{sclay}$

  $= \mathbf{2495.35\ kcal/hr}$

  Here, Q_{unacc} is the unaccounted heat energy.

4.4 Energy balance

- Each cart enters the kiln at 1 hour, and subsequently each cart leaves the kiln every 1 hour.
- Therefore we have considered our working cycles to be 1 hour.
- The energy based calculations are carried out by the basis of each hour.

NET INPUT = USEFUL HEAT + NON USEFUL HEAT

- **NON- USEFUL HEAT (LOSSES)**

  $= Q_{cart} + Q_{surface} + Q_{water} + Q_{chimney} + Q_{opening} + Q_{ground}$

  = 166,864.45 kcal/hr

- **USEFUL HEAT & UNACCOUNTED HEAT**

  $= Q_{sclay} + Q_{unacc}$

  = 38,528.33 + 2495.35

  = **41,027.978 kcal/hr**

Hence,

NET INPUT = USEFUL HEAT + NON USEFUL HEAT

2,07,892 kcal/hr = 166,864.45 kcal/hr + 41,027.978 kcal/hr

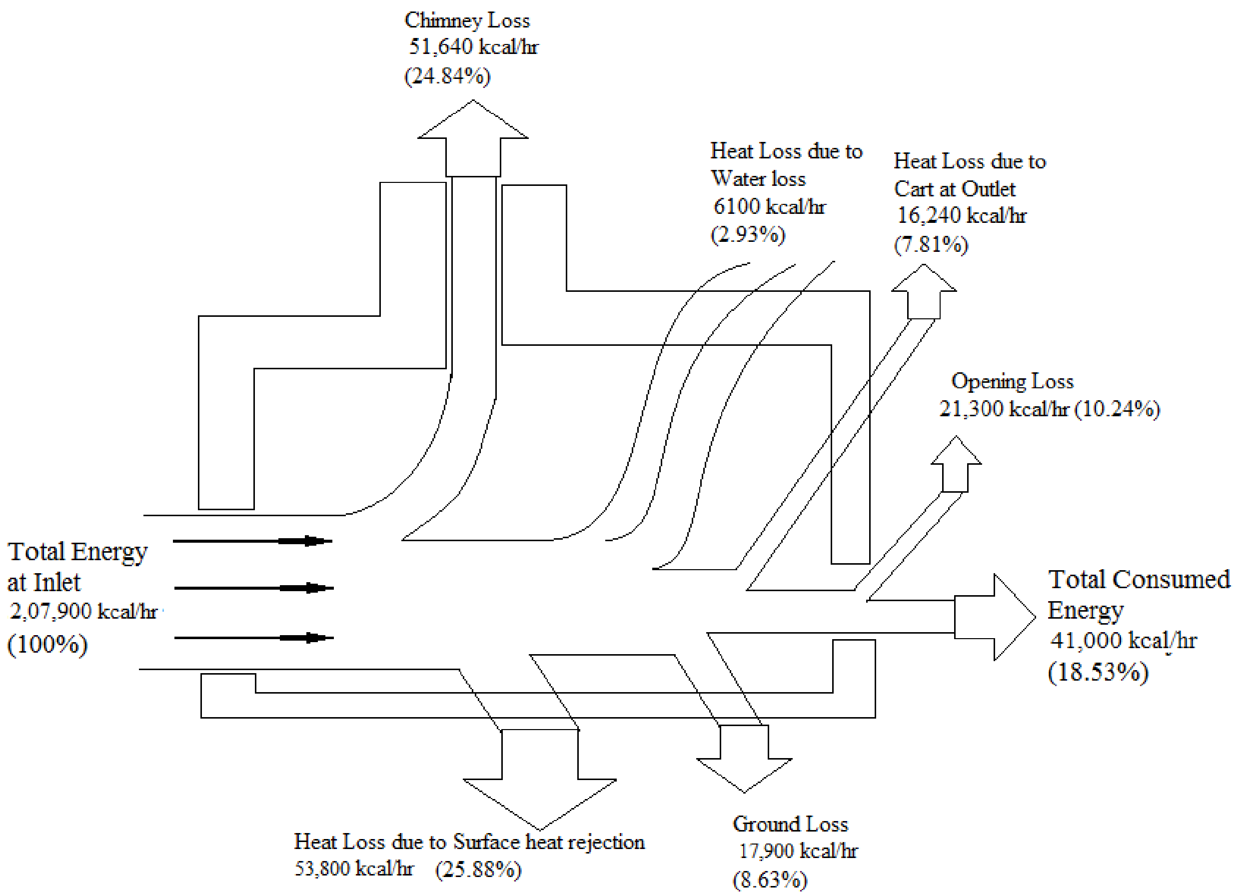


Figure 4.4: Sankey diagram

Table 4.4: Final Calculation

Regions	Values in kcal/hr	Net percentage (%)
Loss due to cart, Q_{cart}	16240	7.81
Loss due to surface, $Q_{surface}$	53,800	25.88
Loss due to reduce in weight, Q_{water}	6100	2.93
Chimney losses, $Q_{chimney}$	51,640	24.84
Opening losses , $Q_{opening}$	21,300	10.24
Ground losses, Q_{ground}	17,900	8.63
Heat absorbed by clay, Q_{sclay}	38,528	18.53
Unaccounted heat, Q_{unacc}	2450	1.2

5.1 Energy audit comparison

- In the above a chapter energy division in various fields can be understood.
- It can be represented as follows :

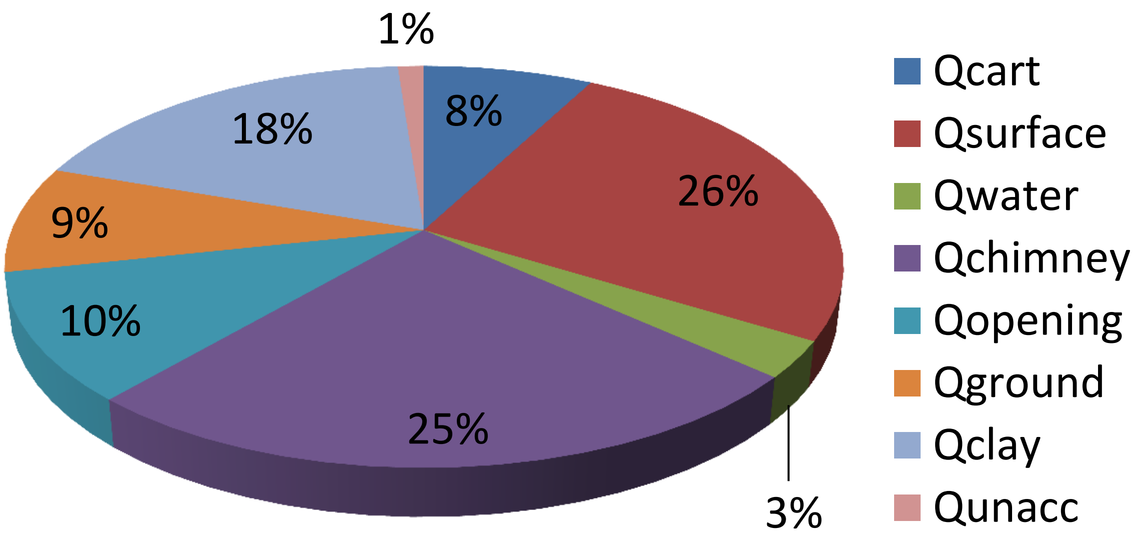


Figure 5.1: Distribution of energy

- Here, it can be noticed that maximum amount of energy is lost in chimney and in surface losses or insulation losses.
- In order to deduce the efficiency of a kiln it needs to be compared with another efficient kiln i.e. Ideal kiln.
- The kiln observed by us was at Anil Impex, Naroda.
- It is 136 feet long (16 feet longer than Shiv Shakti kiln). The dimension of the zone are
    - Pre Heating Zone : 52 feet
    - Firing Zone : 20 feet
    - Cooling Zone : 64 feet

- The dimensions of cart are slightly greater than the existing kiln.
- The respective cart load and cart dimensional comparison of the cart is as shown as follows :

Table 5.1: Structural comparison

Feature	ShivShakti Kiln	Ideal Kiln
No. of articles loaded on cart		
Cups Saucers	378 560	1536 0
Total raw Product	142 kg	169 kg
Total refractory weight	301 kg	510 kg
Weight of Trolley	550 kg	510 kg
Total cart load	993 kg	1189 kg
Ratio of kiln furniture to the ceramic ware weight per cart	2.118	3.02

- The Ideal kiln refers to the kiln at Anil Impex.
- The capacity is greater than the one compared to ShivShakti kiln.
- Following is the comparison of heat losses between two corresponding kilns.

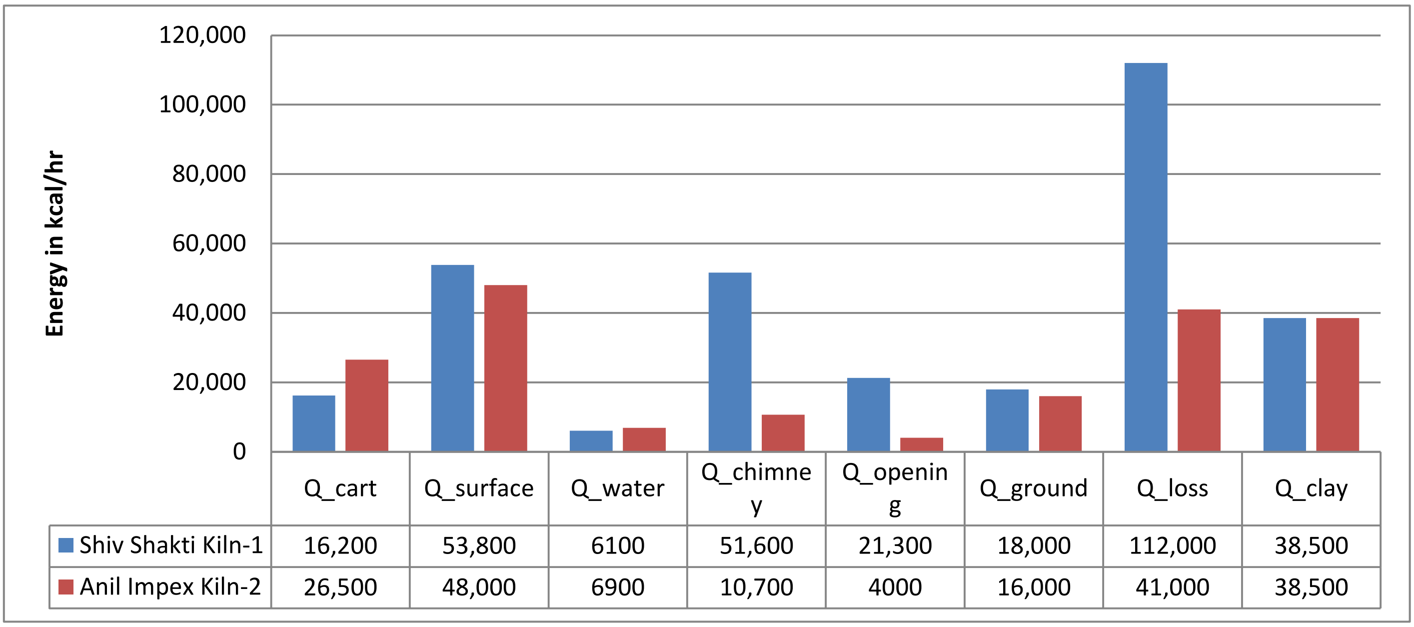


Figure 5.2: Comparison of Tunnel kiln

- In this kiln the inlet is 2,76,349 kcal/hr, which is more compared to that of Shiv Shakti kiln.
- From the above represented graph, it is observed that the heat supplied in kiln at Anil Impex is more compared to the one at ShivShakti.
- However, the losses observed are less.
- As the result of the energy balance for the tunnel kiln it can be concluded that the major reasons for the lower efficiency of the tunnel kiln are the heat losses through chimney and Insulation losses.

5.2 Effect on Performance of kiln by increasing length

- By increasing **its length by 10 feet** the flue gases which previously use to exit at 330°C will now have to travel additional 10 feet of distance before exit. In this extra 10 feet distance two new kiln carts can be accommodated. Since these additional carts enter at ambient temperature and now they are surrounded by flue gases with high temperature, the carts will absorb the heat from the flue gases. This will help in reducing the flue gas or chimney loss in the kiln and also heat the carts before it can reach the previous entry point of the kiln. Now the cart entering the kiln will have higher temperature at entry and hence less time will be required for the cart to reach the necessary temperature.
- So now the cycle time of cart in the kiln can be reduced and in turns its production capacity can be increased without increasing its consumption rate.
- From practical observation and taking the reference of 'CER- European commission' for the above new length of the kiln the flue gas temperature is around 200 °C to 250 °C.

<u>Calculating the amount of energy saved:</u>

(i) For temperature 200 °C:

- Volume of gas at 200 ºC,

$$
\begin{aligned}
V_{gas200} &= V_{gas}*(200+273/35+273) \\
&= 273.424*(473/308) \\
&= 419.9\ m^3 \\
&\sim 420 m^3
\end{aligned}
$$

- Enthalpy of air at 200 °C $= 472.5$ kJ/kg
  $= 578.8\ kJ/m^3$

- Energy lost in Chimney, Q' $= V_{gas200}$ * (Enthalpy difference)
  $= 83{,}496$ kJ/hr

- New opening loss, $Q_{open200} = \sigma A_o(T_{200}^4 - T_a^4)*3600$
  $= 23897$kJ/hr

- Energy saved, E_{saved} = Previous loss - New loss
  = (216060+82477.07) - (83496+23897)
  = 191,144 kJ/hr

- Total energy saved in 2 hours $= E_{saved}*2$

  = 382288 KJ

Similarly, calculating for exhaust gas temperature of 250 °C we find the total energy saved to be around 270850 KJ.

By considering the above temperatures the energy saved is from 45.3% to 64%.

- From the above saved energy 25% is lost due to insulation, ground and other miscellaneous losses. From the remaining energy on 14.45% energy is absorbed by the clay while the rest is used up by the kiln furniture and refractory material. So by calculating the rise in temperature in ceramic by absorbing the above amount of energy we get a temperature to be in between of 157 °C to 208°C.
- In manufacturing of ceramic ware the product needs to remain at the temperature of 1050 °C to 1100 °C for a fixed period of time. It is called residence time.
- Total time spent by a cart in firing zone is 3 hours 12 minutes. Out of this time 1 hour is required by cart to reach the temperature and it stay at temperature for about 2 hours 12 minutes.
- Before the extending the kiln the cart was entering the firing zone at a temperature of 780 °C. Now since cart that enters the kiln is already at high temperature hence the cart that is now entering the firing zone has its temperature raised also. So now the cart will take less time in heating up to the temperature of 1050 °C to 1100 °C.
- By trial and error for number of different temperatures we can say that the cart that is now entering the firing zone will have the temperature of 876 °C.
- For that temperature the time that it need to reach the temperature of 1100 °C is 42 minutes. (Experimental result)
- Previously the pushing of the cart was done in such a way that the residue time is maintained and cart remains sufficient time in the firing zone. But now the total time need is; residence time + new heating time.
  2 hours 12 minutes + 42 minutes
  = 2 hours 54 minutes.

<u>Existing cycle timing and production rate:</u>

- Current cycle time (T_c) is 24 hours. Hence each hour one cart exits the kiln.
- So the kiln has to capacity to process 24 carts every day.

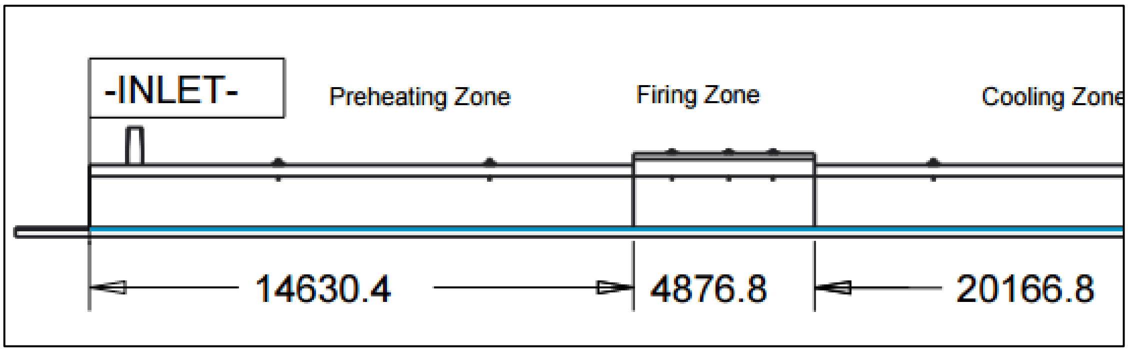


Figure 5.3: Extended Pre-heating zone *All dimensions are in mm

5.2.1 New cycle time

- Previously in travelled 5 feet in one hour. Now its speed can be calculated as follow.
- Time required for cart to travel 5 feet,

$$T' = (2\tfrac{54}{60})*5/16$$

$$= 0.9 \text{ hours (54 minutes)}$$

- New cycle time $T_c' = 0.9*120/5$

$$= 21.6 \text{ hours}$$

- New production rate is $= 24/0.9$

$$= 26.67 \text{ carts}$$

5.3 Change in insulating material

- The surface insulation at Shiv Shakti Ceramics is more than 10 years old.
- Most of the industries use cerawool fiber as the insulating material.
- Cerawool, being amorphous in state undergoes change of state into crystalline due to heating at high temperature.
- Hence with passage of time the texture of the cerawool changes and it results into major formation of cracks and pores. There is continuous change on state of insulating material.
- Heat radiated out from these pores in turn result into losses at the surface.
- Following are the calculations of the surface temperature taken by an infrared thermometer.

Table 5.2: Surface Temperature readings

Temperature reading	Shiv Shakti Kiln-1	Anil Impex Kiln-2
Ambient Temperature, T_a	35 °C	27 °C
Preheating zone-1 Temperature, T_{p1}	68.5 °C	40.6 °C
Preheating zone-2 Temperature, T_{p2}	82.17°C	59.64°C
Firing zone-1 Temperature, T_{f1}	96.54 °C	76.47 °C
Firing zone-2 Temperature, T_{f2}	107.54 °C	81.78 °C
Cooling zone-1 Temperature, T_{c1}	76.57 °C	71.32 °C
Cooling zone-2 Temperature, T_{c2}	53.64 °C	45.01°C
Exit Temperature of cart, T_{co}	105 °C	105 °C
Exhaust gas Temperature, T_{ex}	350 °C	130 °C

- From the above measured values the temperatures in the Ideal kiln is 20°C less than the Shiv Shakti kiln.
- This is because the presence of fresh insulating material and its ability to conserve heat.

- Also Ideal kiln possesses asbestos plates in the outer surface of the kiln. This asbestos plates present decreases the contact of insulation with outside material and resulting into longer life of insulation.
- An additional Zirconia coating present in the inner brick lining prevents the direct contact of flue gases on the insulating material.
- However Zirconia is a preventative measure.
- Various Cerawool insulating materials are available.
- Following are classification of various materials available in the market.

Table 5.3: Insulation material properties

Properties	**Cera Blanket**	**Cerachem blanket**
Temperature	1260	1425
Chemical composition (%)		
Al_2O_3	42-46	33-37
SiO_2	54-58	48-52
ZrO_2	-	13-17
Fe_2O_3	0.1	0.1
Tensile Strength (kgf/m^2)		
64 kg/m^3	2500	2500
96 kg/m^3	**4500**	**4500**
128 kg/m^3	6000	6000

- From the above provided data cerawool blanket with density 96 kg/m^3 is perfect for pre-heating and cooling zone.
- From available data of ideal kiln taking 20 ºC drop in surface temperatures.

A. <u>For Pre-heating Zone</u>

Take surface temperatures to be 48.5 °C instead of 68.5 °C for R_{p1} and 62.17 °C instead of 82.17°C for R_{p2}.

- R_{p1}' = $\sigma A_p(T_{p1}^4 - T_a^4)*3600/2$

  = 2448.65 kcal/hr

- R_{p2}' = $\sigma A_p(T_{p2}^4 - T_a^4)*3600/2$

  = 5263.18 kcal/hr

B. For Firing Zone

Take surface temperatures to be 76.54 °C instead of 96.54 °C for R_{f1} and 82.54 °C instead of 107.54°C for R_{f2}.

- R_{f1}' = $\sigma A_f(T_{f1}^4 - T_a^4)*3600/2$

  = 4460.33 kcal/hr

- R_{f2}' = $\sigma A_f(T_{f2}^4 - T_a^4)*3600/2$

  = 5942.24 kcal/hr

C. For Cooling Zone

Take surface temperatures to be 66.57 °C instead of 76.57 °C for R_{c1} and 43.64 °C instead of 53.64°C for R_{c2}.

- R_{c1}' = $\sigma A_c(T_{c1}^4 - T_a^4)*3600/2$

  = 10,762 kcal/hr

- R_{c2}' = $\sigma A_c(T_{c2}^4 - T_a^4)*3600/2$

  = 4343 kcal/hr

Hence total amount of radiation loss = 332194 kcal/hr

The energy supplied is 20,600 kcal/hr less than the initial value.

Q_{inlet} will decrease upto 1,87,292 kcal/hr.

- $M_f' * C.V. = Q_{inlet}$

  M_f' = 14.1118 kg/hr

Hence, per hour gas supplied will decrease to 20 m^3. **I.e. 1440 m^3 of saving per month.**

Calculating the amount of energy developed in by drop in the surface temperature by 20 °C

A. For Pre-heating Zone

The amount of heat energy within the chamber can be calculated as;

- Q_p = $KA(T_1 - T_2)/L$

Here, KA/L = $K_1A/2L_1 + K_2A/2L_2$
= 195.4 + 212.19
= 407.4

For Zone 1

- Q_{p1} = $KA(Tp_1 - Ts)/L$
  = 407.4(340 – 68.5)
  = 26436 kcal/hr

For Zone 2

- Q_{p2} = $KA(Tp_2 - Ts)/L$
  = 407.4(583-87.17)
  = 48279.4 kcal/hr

Where, K_1 = Thermal conductivity of Brick 1.001 kJ/kg K
K_2= Thermal conductivity of Cerawool 1.087 kJ/kg K
K = Equivalent Thermal conductivity
A = Area of Zone
L = Equivalent Thickness
L_1 = Thickness of insulation (6 inches)
L_2 = Thickness of Brick lining (6 inches)

B. For Firing Zone

The amount of heat energy within the chamber can be calculated as;

- Q_f = $KA(T_1 - T_2)/L$

Here KA/L = $K_1A/2L_1 + K_2A/2L_2$
= 50.7 + 55.07
= 105.77

For Zone 1

- Q_{f1} = $KA(Tf_1 - Ts)/L$
  = 105.77 (1149-96.54)
  = 26605.8 kcal/hr

For Zone 2

- Q_{f2} = $KA(Tp_2 - Ts)/L$
  = 105.77(1220-107.54)
  = 28122.6 kcal/hr

Where, K_1 = Thermal conductivity of Brick 1.001 kJ/kg K
K_2= Thermal conductivity of Cerawool 1.087 kJ/kg K
K = Equivalent Thermal conductivity
A = Area of Zone
L = Equivalent Thickness
L_1 = Thickness of insulation (6 inches)
L_2 = Thickness of Brick lining (6 inches)

For 20°C drop, keeping heat inside the chamber constant, New Thickness of the insulation can be calculated.

Hence, <u>for Pre-heating Zone</u>

	• Q_{p1}	=	$KA(Tp_1 - Ts)/L$
	29436	=	$KA(Tp_1 - Ts)/L$
	L	=	7.007 inch (For Zone 1)
Similarly for zone 2,	L	=	6.532 inch

Taking the maximum of two values for **Pre-heating zone thickness of insulation is 7 inch / 0.7718 m.**

Now, <u>For Firing zone</u>

	• Qf_1	=	$KA(Tf_1 - Ts)/L$
	29436	=	$KA(Tf_1 - Ts)/L$
	L	=	12.48 (For Zone 1)
Similarly for zone 2,	L	=	12.46 inch

Taking the maximum of two values for **firing zone thickness of insulation is 12.5 inch / 0.3175 m.**

5.3.1 Volume of Insulation blanket

- For Pre-heating zone area of blanket required will be:

59.59 * 0.1778	=	11 m^3
For 3 sides	=	11 * 3
	=	33 m^3

- For firing zone,

30.84 * 0.3175	=	10 m^3
For 3 sides	=	10 * 3
	=	30 m^3

- Each piece of insulation is of 7300 x 610 x 25 mm i.e. 0.1 m^3 each.
- Hence for preheating 110 pieces of insulation and for firing 100 pieces are required.

CHAPTER 6: CONCLUSION

6.1 Monetary Savings and payback

6.1.1 Extension of Pre-heating zone

- Here in a day the production capacity is increased by 2.67 carts without any change in the fuel supplied, which is about 11.2% increase in production.
- The amount of gas saved per day (for same production in previous length of kiln).

V_{gas} * 2.67 = 22*2.67

= 58.74 m^3

- Amount of money saved = Cost of PNG per m^3* amount of gas saved

= 37 * 58.74

= 2173.38 Rs per day

- **Monthly savings is just above Rs 65000.**
- Current Manufacturing cost per 100kg of ware = 800 Rs

- New manufacturing cost = Current production rate * Current cost/ New production rate = (24*137.32*8)/(26.67*137.32)

= 7.199 Rs/kg

- New Manufacturing cost per 100 Kg of ware = 720Rs (approx.).
- This shows of about 10% reduction in manufacturing cost.

<u>Total cost of change</u>

- Cost of Extending the kiln = 20,00,000 Rs

- Cost of production loss = 30*8*24*137

= 790000 Rs

- Total cost = 2800000 Rs (approx.)

- Total Saving = Reduction in production cost per day

= 80*26.67*1.3732

= 2929.85 Rs/day

= 87895.78 Rs/month

- This savings are totally calculated on the benefit obtained from the decrease in cost i.e. from 8.00 Rs/kg to 7.2 Rs/kg.
- Payback period calculated solely on the basis of this is as shown below

- Payback period = Total cost/ Total saving
  = 2800000/87895.78 = 31.8
  = 32 months (approx.)
  = 2 years 8 months

- Total investment will be returned in less than 3 years.

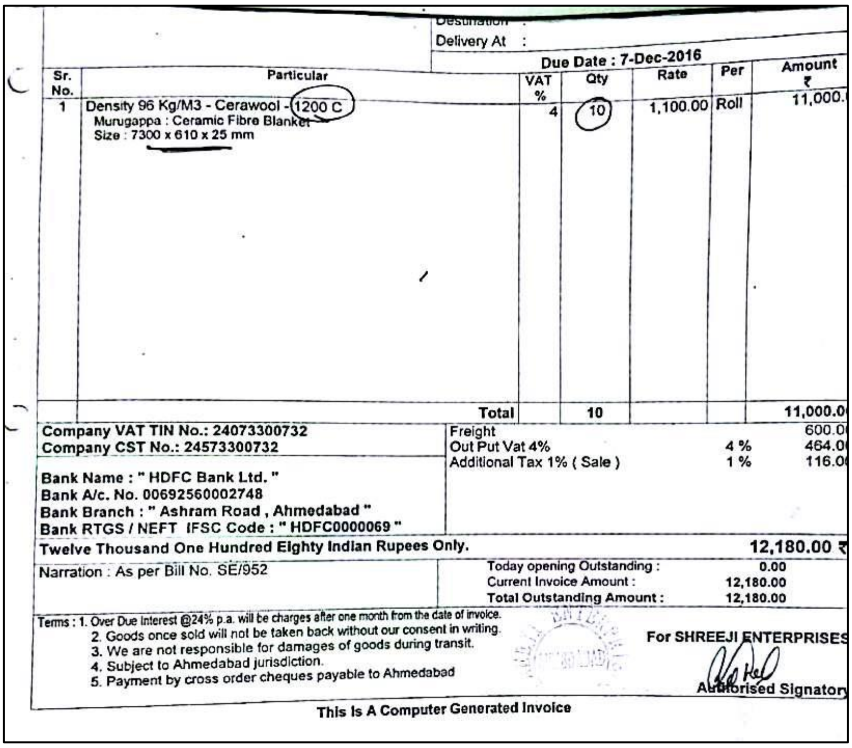
6.1.2 New insulation

- The amount of gas saved is 1440 m^3.
- Hence = Cost of PNG per m^3* amount of gas saved
  = 37 * 1440
  = 53,800 Rs/month

- **Monthly savings are just above Rs 53,000.**

<u>Total cost of change</u>

- For calculating the cost of changing the insulation we can refer to the bill for changing the same. Following is the bill of changing the insulation



Destination :
Delivery At :

Due Date : 7-Dec-2016

Sr. No.	Particular	VAT %	Qty	Rate	Per	Amount ₹
1	Density 96 Kg/M3 - Cerawool - 1200 C Murugappa : Ceramic Fibre Blanket Size : 7300 x 610 x 25 mm	4	10	1,100.00	Roll	11,000.
	Total		10			11,000.0

Company VAT TIN No.: 24073300732
Company CST No.: 24573300732

Freight		600.0
Out Put Vat 4%	4 %	464.0
Additional Tax 1% (Sale)	1 %	116.0

Bank Name : " HDFC Bank Ltd. "
Bank A/c. No. 00692560002748
Bank Branch : " Ashram Road , Ahmedabad "
Bank RTGS / NEFT IFSC Code : " HDFC0000069 "

Twelve Thousand One Hundred Eighty Indian Rupees Only. 12,180.00 ₹

Narration : As per Bill No. SE/952

Today opening Outstanding : 0.00
Current Invoice Amount : 12,180.00
Total Outstanding Amount : 12,180.00

Terms : 1. Over Due Interest @24% p.a. will be charges after one month from the date of invoice.
2. Goods once sold will not be taken back without our consent in writing.
3. We are not responsible for damages of goods during transit.
4. Subject to Ahmedabad jurisdiction.
5. Payment by cross order cheques payable to Ahmedabad

For SHREEJI ENTERPRISES

Authorised Signatory

This Is A Computer Generated Invoice

Figure 6.1: Bill of changing insulation

- For Pre-heat 110 pieces of insulating material must be ordered.
  - = Cost of each piece * total pieces
  - = 1100 * 110
  - = 1,21,100 Rs

- For Firing of 100 pieces of insulating material must be ordered.
  - = Cost of each piece * total pieces
  - = 1400 * 100
  - = 1,40,000 Rs

- Production losses = 142 kg per carts i.e. 3408 kg per day
  - = 3408 * 8
  - = 4,08,960 Rs

- Total losses = 4,08,960 + 1,40,000 + 1,21,100
  - = 7,00,000

- Payback period = 7,00,000/53,800
  - = 13.01 months
  - = **1 year and 1 month**

6.2 Guidelines for construction of a new kiln

- For a new kiln to be constructed from a scrap following:
  - Length of Pre-heating zone must be kept enough in order to have a constant temperature gradient.
  - Temperature gradient refers to uniform increase in the temperature; if the temperature growth is not uniform it can result into breakage and in crack formation of the cups.
  - Length of the preheating zone should be such that, that the energy loss due to chimney is less than 15% of the total energy supplied. This can be easily determined by taking the help of CER's 'Best available Techniques' for ceramic industries research document.
  - The temperature gradient can also be effectively regulated by varying air pressure at individual air nozzles and this could lead to reduction in amount of gas consumed.
  - Residence time should be 32.5 to 3.5 hours.
  - Decreased residence time will lead into brittle products.
  - Cooling zone must be kept between 45-60 feet. This is to provide enough cooling time for cups.
  - Above the factors are largely responsible for deciding the pushing time of the cart.
  - The gas consumption can also be reduced by reducing area of firing zone and increasing the heat concentration in the zone. This will help us reach the maximum temperature quickly.

- The efficiency of burning can be increased if high velocity burners are used. This will lead to reduction in gas consumption.
- Insulation material must be covered with asbestos plates.
- Zirconia Coating present on the inner lining of the bricks will increase life of insulation.

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APPENDIX

A. Nomenclature

M_{raw}	=	Mass of raw clay load on the cart
M_{load}	=	Total mass on the cart
M_{brick}	=	Mass of the HFK bricks used in the cart body
M_{cart}	=	Total mass of the cart
M_w	=	Mass of water lost
T_a	=	Ambient temperature
T_{p1} , T_{p2}	=	Temperature at outer surface of kiln in preheating zone
T_{f1},T_{f2}	=	Temperature at outer surface of kiln in firing zone
T_{c1},T_{c2}	=	Temperature at the outer surface of kiln in cooling zone
T_{co}	=	Temperature of cart outlet
T_{ex}	=	Temperature of exhaust gases in chimney
$C_{p(clay)}$	=	Specific heat of clay
$C_{p(sagger)}$	=	Specific heat of sagger
$C_{p(trolley)}$	=	Specific heat of trolley
K_p	=	Overall thermal conductivity of insulation in preheating zone
K_p	=	Overall thermal conductivity of insulation in preheating zone
K_c	=	Overall thermal conductivity of insulation in cooling zone
σ	=	Stefan-Blotzmann constant
L_w	=	Latent heat of evaporation of water
C.V.	=	Calorific value of PNG
m_f	=	Mass of fuel consumed per hour
Q_{clay}	=	Heat lost in clay due to high exit temperature
Q_{sagger}	=	Heat lost in sagger due to high exit temperature
$Q_{trolley}$	=	Heat lost in cart due to high exit temperature

Q_{cart}	=	Total heat lost at cart exit
Q_{p1} ,Q_{p2}	=	Conduction heat loss through insulation in preheating zone
Q_{f1} , Q_{f2}	=	Conduction heat loss through insulation in firing zone
Q_{c1}, Q_{c2}	=	Conduction heat loss through insulation in cooling zone
$Q_{conduction}$	=	Total heat lost due to conduction from insulation
R_{p1}, R_{p2}	=	Heat lost due to radiation from insulation in preheating zone
R_{f1} , R_{f2}	=	Heat lost due to radiation from insulation in firing zone
R_{c1} , R_{c2}	=	Heat lost due to radiation from insulation in cooling zone
$Q_{Radiation}$	=	Total heat lost from insulation due to radiation
Q_{water}	=	Heat lost by evaporation of water from the clay
$Q_{chimney}$	=	Heat lost from chimney
$Q_{opening}$	=	Heat lost from kiln openings
Q_{ground}	=	Heat lost in the ground
$Qs_{(0-1)}$,$Qs_{(1-2)}$	=	Heat gained by clay (Zone 0-1 and Zone 1-2)
$Qs_{(2-4)}$,$Qs_{(4-5)}$	=	Heat gained by clay (Zone 2-4 and Zone 4-5)
Q_{sinter}	=	Total heat required for clay in heating and sintering
V_{gas200}	=	Volume of gas at 200°C
V_{gas}	=	Volume of gas at ambient temperature
Q'	=	Energy lost in Chimney when flue gas temperature is 200°C
$Q_{open200}$	=	Opening loss at the inlet of kiln when flue gas temperature is 200°C
T_{200}	=	Temperature of flue gas(200°C)
E_{saved}	=	Energy saved by extending the length of kiln
T_c	=	Existing cycle time
T_c'	=	New cycle time
R_{p1}', R_{p2}'	=	Heat loss from new insulation in preheating zone
R_{f1}',R_{f2}'	=	Heat loss from new insulation in cooling zone

R_{c1}', R_{c2}'	=	Heat loss from new insulation in cooling zone
Q_{inlet}'	=	New amount of input energy
M_f'	=	Changed quantity of fuel supplied
K_1	=	Thermal conductivity of Brick
K_2	=	Thermal conductivity of Cerawool
K	=	Equivalent Thermal conductivity
A	=	Area of respective Zone
L_1	=	Thickness of insulation
L_2	=	Thickness of Brick
L	=	Equivalent Thickness