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Wear Resistant Ceramic Liner for Coal Nozzle and it's LCA Analysis

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ABSTRACT

Coal nozzles are critical components in coal-fired boilers or burners, where pulverized coal is injected into the furnace for combustion. These nozzles help control the direction, velocity, and distribution of the coal-air mixture entering the combustion zone. Coal Nozzle which is placed at inlet of Boiler to assist the flow of air and fuel (Pulverized coal) mixture into combustion chamber. It is used to increase the velocity or pressure of the fluid at exit one end of Nozzle. Pulverized coal is fed from the Bowl Mill through coal conveying pipes, Coal nozzle and nozzle tip into combustion chamber of Boiler. Flow of pulverized coal through Coal nozzle causes heavy wear and tear on the flow surface. Wear and tear of coal burners depends on flow velocity and grade of coal. Higher the flow of velocity, higher the wear rate. And lower the grade of coal, higher the wear rate. Wear and tear caused by continuous flow of coal results in frequent replacement of Steel casing. To check the coal particle erosion on Coal Nozzle metal surface, material is hard-faced on Coal Nozzle inner surface by Gas Metal Arc Welding (GMAW) by using solid wire electrode and flux cored wire electrode. And to check the erosion at Nozzle tip, Chromium Carbide overlay by Shielded Metal Arch Welding (SMAW). Different research shows that Hard facing is conventional method to check the erosion of Coal Nozzle in operation.

In India major power plants are built by BHE which has its indigenous design for all power plant equipments. BHEL has been designing Coal Nozzle for various ratings Power Plant from last more than six decades. Base material for Coal Nozzle is Cast steel and for Nozzle tip it is Stainless Steel. Hard facing on cast steel is provided for erosion resistance due to pulverised coal flow through it. The life of these hard-faced Coal Nozzle in India is around 8-12 months depending upon type of coal, burner design and the degree of abrasion. However, this may be up to 2 years but for high grade coal. In India low to medium grade coal is primarily used in thermal power plants which has 25 to 45% ash content. So life expectancy of Coal Nozzle hardly goes beyond 1 year.

In order to achieve high life expectancy of Coal Nozzle and reduce the environmental impact of product (as Steel has higher emission factor in comparison to Ceramic liner), High Alumina ceramic ($Al_2O_3 \geqslant 90\%$) liner is developed. Alumina ($Al_2O_3 \geqslant 90\%$) has high hardness and high resistance to abrasion, which makes them ideal for use in coal nozzle. In a thermal power plant, ceramic liners must withstand the high temperatures associated with coal and air flow. Materials like alumina can maintain their properties at temperatures up to 1000°C. Coal can carry significant kinetic energy, so ceramic liners need to have some level of impact resistance to prevent cracking or chipping from impacts. In addition to abrasion, ceramic liners may also need to resist corrosion from the acidic nature of coal dust or exposure to high moisture levels in the conveying system. Ceramic liner is designed with a smooth surface to reduce friction and improve the flow of coal, thus minimizing the wear on both the liners and the conveying equipment.

Ceramic liners protect the inner surface of coal nozzle and extend their operational life. By protecting the equipment from wear and tear, ceramic liners can reduce the frequency and cost of repairs. Wear-resistant ceramic liners help in preventing failures that might cause sudden breakdowns or hazards in coal conveying system. Using high alumina ceramic liner for wear resistance inside Coal Nozzle, improves the service life with more than 2 folds and LCA study reflects that the environmental impact (greenhouse gas CO_2 emission) reduces by approx. 52%.

Keywords: Wear, Ceramic liner, Alumina (Al_2O_3), Coal Nozzle, LCA

1. INTRODUCTION

Tangentially coal-fired boilers, prominently utilized in modern thermal power plants, are known for their comprehensive flame coverage within the furnace volume, granting good flame stability and adaptability for various coal ranks and loads. The coal, pulverized to fine grains and mixed with air, is conveyed pneumatically to burners, forming the heart of the combustion process. The efficiency of the boiler and, by extension, the power plant, depends on the complete combustion of this coal dust, which is achieved by controlling the feeding rate and air availability through sophisticated computer systems [3].

The pulverized Coal Nozzle is a crucial component in this process, facilitating the injection of coal-air mixtures into the combustion zone. Designed from high-quality steel bifurcated plates, these nozzles direct the flow of pulverized coal, with the geometry of the burner and the velocity ratio of the fuel and air jets being pivotal for stable combustion and efficient fuel burnout. The pulverized coal is fed into the furnace from four corners at various heights, create a cylindrical combustion zone with a strong swirl that promotes turbulence and combustion in a central flame zone. However, the pulverized Coal

Nozzle are subjected to severe erosive conditions due to the high-speed coal particles and extreme temperatures within the combustion zone. The tips of the nozzles, especially the baffle or splitter plates, experience rapid erosion, which is further exacerbated by the heat of the flame, leading to warping and cracking, even in regular operations. In India, the coal's large ash content, including abrasive minerals like quartz and feldspars, intensifies the erosion suffered by these components. This solid particle erosion (SPE) is a progressive loss of material, quantified by the volume or mass removed by impacting particles, resulting from several mechanisms like cutting wear, plastic deformation, and thermal fatigue [3,4].

The costs associated with SPE in thermal power plants are significant, with erosion leading to frequent replacements of nozzles and pipes, which account for a substantial portion of production costs and plant downtime. This research is focused on design and development of a wear resistant liner for Coal Nozzle which reduces the solid particle erosion so downtime and repair cost along with negative environmental impact. [3]

There are various method to combat solid particle erosion, one is apply hard-facing layers to the components subject to erosion [4] and another is chromium carbide overlay in erosive components [5]. These methods are generally used for solid particle erosion resistance in Coal Nozzle but service life of the Coal Nozzle is not as desired by thermal power plants.

Using ceramic liners in coal pipes of thermal power plants can significantly help reduce environmental impacts in several ways. These benefits stem from both operational and environmental improvements that ceramic liners offer compared to traditional materials used in coal pipe systems. Ceramic liners are highly resistant to abrasion and wear, which is particularly beneficial in coal pipes where the coal particles can cause significant erosion of the pipes over time. This durability helps in extending the lifespan of the coal pipes, reducing the need for frequent replacements and thus minimizing waste and resource use associated with pipe manufacturing and disposal.

Ceramic liners can help maintain the integrity of the coal pipe system, the flow of coal through the system remains smoother and more efficient. This can result in better coal delivery to the furnace, which improves the combustion process and reduces inefficiencies. Optimized fuel use reduces the amount of coal burned for the same amount of energy generation, thereby reducing greenhouse gas (CARBON) emissions and improving the overall carbon footprint of the plant.

1.1 Wear Resistant Ceramic Liner for Coal Nozzle

A **wear-resistant ceramic liner** for Coal Nozzle is a highly effective solution designed to protect the components in pulverized coal flow system. Coal Nozzle experience extreme wear and tear due to the abrasive nature of coal particles during transportation through it. Ceramic liner to be designed for Coal pipe will enhance the lifespan of product, improve operational efficiency, and reduce environmental impacts.

Pulverized coal transportation and combustion is a combination of high temperature corrosion and erosion by hard abrasive particles flows (e.g. Coal) and thermal shock. Ceramic materials, especially with high alumina as a base, is known for their exceptional hardness and resistance to abrasion. Coal particles and other solid materials moving through the system can cause significant erosion, which ceramic liners effectively mitigate.

Ceramic materials can withstand extremely high temperatures, making them ideal for use in thermal power plants, where components are subjected to continuous exposure to high heat. Thermal power plants often deal with highly corrosive environments due to moisture, sulphur in the coal, and other chemical by-products. Ceramic liners are chemically inert and resistant to corrosion, which helps in maintaining the integrity of the Coal Nozzle over long periods.

The combination of abrasion, thermal, and corrosion resistance allows ceramic liners to last much longer than other traditional material like steel. This extended lifespan means fewer replacements and less downtime for maintenance. Ceramic liners are often designed to be modular and easy to install or replace, which helps in reducing downtime during maintenance activities.

In summary, wear-resistant high alumina ceramic liner for Coal Nozzle is crucial for protecting equipment from abrasion, heat, and corrosion, which increases the longevity of the item, reduces downtime, and ultimately improves the overall efficiency and cost-effectiveness of the operation.

1.2 High Alumina based Ceramic Liner (≥ 90% Alumina)

Ceramic materials are widely recognized for their exceptional chemical inertness, superior thermal stability, and low thermal conductivity. These properties make ceramics ideal candidates for wear protection in mechanical parts or equipments [13]. Aluminium oxide or alumina is an oxide ceramic material with a wide range of applications in industry and technology. The material based on aluminium oxide is divided into groups according to the Al_2O_3 content, which range from ~80 to 90% for simple electrical insulation and mechanical components, ~90–99% for sophisticated applications in technology including wear protection, and over 99% for specialized electrical components and mechanical components requiring extreme high reliability [4]. Alumina or Alumina-based ceramic are mostly employed for the considered application not only due to their high mechanical properties, but also because of their rather low cost and availability of commercially produced raw materials [11]. Also ceramic liners are commonly used for wear resistance due to their excellent hardness, durability, thermal stability and resistance to abrasion.

- **Composition**: There are a large variety of commercial alumina grades, which can contain between 85% and 99.999% Al_2O_3 [5]. Alumina based ceramic liners are composed of a high percentage of alumina (usually 90% or greater), making them ideal for applications that require extreme wear resistance. Alumina ≥ 90% based ceramic liner is composed of min. 90% Al_2O_3 and rest clay and flux.

- **Properties**: High hardness (around 8 on the Mohs scale), Bulk density min. 3.2 g/cc, less than 0.5% water absorption, cold crushing strength min. 3000 kg/sq. cm., flexural strength min. 2200 kg/sq, cm. and co-efficient of thermal expansion min. 0.0000072 mm/°c and excellent resistance to abrasion and corrosion [16].
- **Applications**: Used in industries like **thermal power plants**, cement plants, and mining operations, where abrasion from bulk materials is a significant concern.

1.3 Factors affecting the wear resistance property of high Alumina wear resistance ceramic liner

Manufacturing high-alumina wear-resistant ceramic liners presents several challenges, given the material's hardness, the precision required in production, and the demanding performance standards these liners must meet. Below are some of the key factors that affects the wear resistance property of ceramic liner:

1.3.1 Raw Material Particle size

Ceramic material prepared well only when grinding into fineness, more delicate the prepared material is, the colour and lustre of the finished product can be ensured, the density will be more higher, wear resistant property will better. [21]

1.3.2 Sintering temperature and stability

The best sintering temperature is different for different ceramic materials. if temperature is too high, ceramic molding time is too short, ceramic is relatively lack of toughness. If temperature is too low, not burn through ceramic, internal and external finished ceramic quality is different. Now the fire ceramic tunnel kiln and shuttle kiln is commonly used in the majority, the temperature at the ends of kiln is not same, so production will undertake collocation according to the actual situation of their products. [21]

1.3.3 Porosity

Porosity increase inevitably leads to reduce the high temperature strength. And at high temperature, due to reasons such as passivation of the crack tip, the ceramic material for cracks and the sensitivity of the micro defects are low, this is mainly embodied in the impact on the fracture toughness. [21]

1.4 Scope of research

In this research 10 mm wear resistant ceramic liner is to be developed considering existing design boundary of Coal Nozzle. Mechanical properties of wear resistant ceramic liner are to be tested w.r.t. required parameters. After establishing the desired parameters for 10 mm thick wear resistant ceramic liner, it is to be fixed at inner surface of Coal Nozzle. Environmental impact (Greenhouse gas CO2 emission) has to be assessed based on self-established LCA (life cycle assessment) model.

1.5 Chapter layout

The dissertation has been divided into six (06) chapters for better and systematic understanding of its content.

Chapter One Summarizes the overview of the research, literature review and objective of the research.

Chapter Two presents a holistic review of the literature related to wear in various industries and wear resistant ceramic liner for Thermal power plants.

Chapter Three describes the philosophy of wear resistant ceramic liner for Coal Nozzle body, structure of Coal Nozzle body and philosophy of Life Cycle Assessment.

Chapter Four describes the methodology adopted in present work e.g. design & development, manufacturing, comparison between existing and developed system, tests and LCA analysis.

Chapter Five describes the results and discussion of present work it includes test results of ceramic lined Coal Nozzle and its LCA analysis results.

Chapter Six describes the conclusions along with references

2. LITERATURE REVIEW

This chapter presents a review of the literature on wear in mechanical components of various industries and high alumina wear resistant ceramic liner for thermal power plants.

2.1 Wear: A burning problem in various industries

Wear is a degradation process of a material in service and occurs because of the progressive loss of material from the contact surface or the relative movement of a solid in relation to another solid or a liquid or gas [5]. The reason for and the mechanisms that cause wear in materials depend on the combinations of the parts involved and are approached in a more complex manner using the tribological system, which includes the damaged surface, the wear agent and the medium containing the involved parts [5]. In certain mechanisms, the hardness and fracture toughness are considered the most important properties in meeting wear requirements. Abrasive wear starts with the removal of material from a surface by the movement of hard particles. The wear rate depends on the degree of abrasive penetration into the surface of the material under abrasion [5]. Particles that cause wear usually have sharp edges to cut or shear the solid under wear. The damaged surface is under high loads because a small area is involved, thereby creating fractures in the surficial hard phases and plastic deformation of the matrix. The wear rate is affected by the properties of the wearing surface and the abrasive and the nature of the interaction between them. Erosive abrasion is caused by a fluid that transports solid particles by entrainment, and these particles collide with the surface under investigation [5].

Wear between a particle and solid material is caused by: [17]

1. Erosion: Due to impact of particles against a solid surface. [17]
2. Abrasion: Due to loss of material by the passage of hard particles over a surface. [17]

Wear Rate depends On -

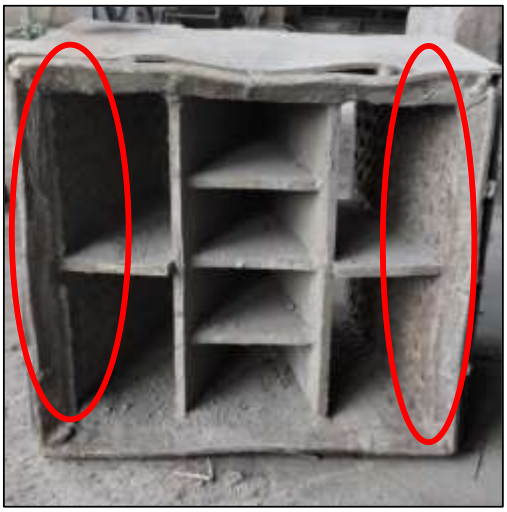
- Chemistry of Erosive & Abrasive Media Particles
- Morphology of Particle.
- Velocity of Flow.
- Angle of Impingement.
- Physico-Chemical Characteristics of material subjected to Wear.

After effects of wear:

- Frequent Material Replacement
- Extra Man-hours
- Lost Production/ Generation
- Increased Cost of Production/Generation

2.1.1 Wear in Pulverized Coal Nozzle

Erosion of pulverized Coal Nozzle due to solid coal particle during operation is very common behaviour. In a coal based thermal power plant, the pulverized coal from the mill is carried to the boiler by pneumatic conveying using primary air which is maintained at a temperature of 80 to 90 °C. In a tangentially fired PF boiler, coal burner nozzles are provided in the burner zone at seven different elevations which connect the PF pipe from the mill outlet to the boiler. The coal burner nozzles connected at the end of each PF pipe injects the coal particles into the boiler combustion zone. Indian coals contain nearly 45 to 50 % ash. The amount of coal used per MW of generation is nearly double than that of Western and Australian coal based plants. Also, the ash contains a high amount of abrasive minerals such as quartz which are responsible for the erosion of coal handling components. The heat radiated in the combustion zone increases the service temperature of the burner nozzles located at each corner of furnace wall of the boiler. The high erosion propensity of coal combined with elevated service temperatures of burner tip components leads to severe erosion and reduced life Conventionally, the austenitic stainless steel of 310 grade is widely used as the burner tip material and the service life, in a typical 210 MW is only 4-6 months, depending on the ash content in the coal. The material used for burner nozzle tips should have the characteristics of adequate erosion resistance at elevated temperatures and should perform at least for a continuous period of two years, coinciding with the overhaul of the unit [18].

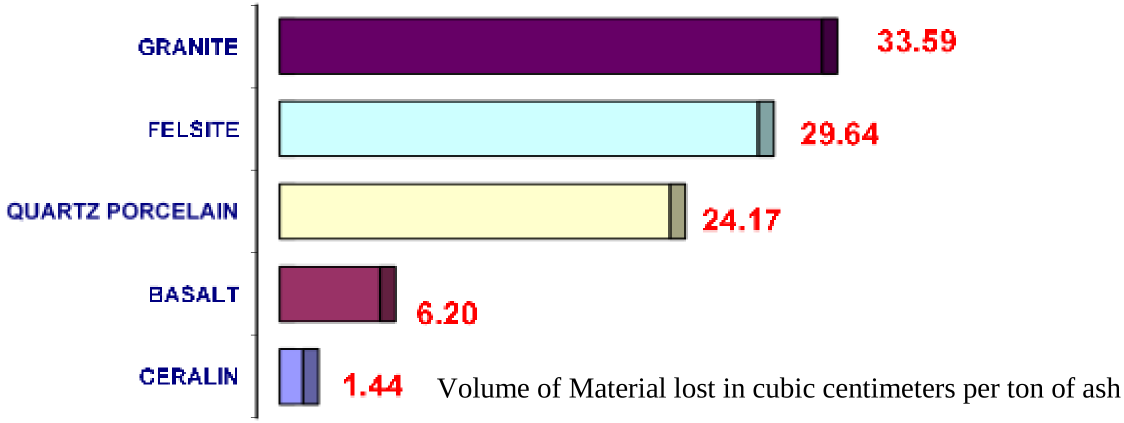


Ceramic Liner?

Ceramic Liner is a wear resistance abrasive material (Alumina based) which is manufactured in form of tiles which are assembled as lining on surface to be protected against the wear.

Why Ceramic liner?

EROSION RATE TEST RESULTS:



TEST CONDITIONS:

Particle Velocity: 50 m/sec

Erodent: Ash concentration of 0.25 Kg/ Nm3

Period of Test: 60 min

Angle of Impingement: 450

The proper selection of wear-resistant materials increases the useful life of equipment and considerably reduces maintenance cost. Alumina is the most commonly used material in applications requiring wear resistance. Its various attractive properties include high chemical inertia, considerable fracture toughness, relatively low cost, great hardness, high erosion resistance, good behaviour at high temperatures, high electric resistance and great availability [5].

2.2 Literature on Wear Resistant Ceramic Liner in Thermal Power Plant

Introduction

Thermal power plants rely heavily on the efficiency of their components, including coal handling systems, pulverizers, boilers, and other key machinery exposed to harsh environments. A significant challenge in these plants is the wear of equipment due to the abrasive nature of coal, ash, and high-temperature gases, which can lead to high maintenance costs, downtime, and failure of machinery. To mitigate these issues, wear-resistant materials, particularly ceramic liners, have been increasingly used to protect critical components.

Ceramic liners are used in thermal power plants to protect equipment, such as pipes and chutes, from wear and tear caused by coal and ash handling. India's thermal power sector grew significantly post-independence, with key plants like Bokaro Thermal Power Plant established in 1953. [19]

Given the global development of ceramic linings by the 1950s, as seen in early research, it's probable that Indian thermal power plants adopted them around this time. The first thermal

A 1953 NASA technical report on ceramic linings for gas-turbine combustion chambers indicates that by this time, ceramic materials were being tested for high-wear, high-temperature environments in power generation. This suggests that ceramic lining technology was available and being adopted in the 1950s, which aligns with India's expansion of thermal power infrastructure.

This global context suggests that India, with its rapid industrialization and collaboration with Western countries (e.g., Bokaro's collaboration with the USA and West Germany), likely adopted similar technologies shortly after, extending their use to coal-fired thermal power plants.

In 1980s BHEL started manufacturing of Ceramic liners for thermal power plants. First power plant built by BHEL was Badarpur thermal power plant and first power plant commissioned by BHEL was at Obra, Uttar Pradesh in 1980, later in 1982 BHEL started construction of first NTPC Thermal power plants at Singrauli which is currently one of major power plants in India. These reflects major technology advancement in Ceramic application for thermal power plants in India in 80s.

This literature review explores the advancements in wear-resistant ceramic liners in thermal power plants, focusing on their applications, materials, design considerations, and performance.

1. Overview of Wear in Thermal Power Plants

Wear in thermal power plants is primarily caused by abrasive, erosive, and corrosive forces that arise from the handling of solid fuels like coal, fly ash, and the constant flow of hot gases. The key areas where wear occurs include:

- **Coal Handling Systems:** Coal transportation systems, crushers, and pulverizers experience significant wear due to the abrasive nature of coal particles.
- **Boiler Components:** The high-temperature gases that pass through the furnace can erode and damage boiler tubes, heat exchangers, and ducts. [22]
- **Piping Systems:** The movement of pulverized coal, ash, dust, and gases can cause significant abrasion in pipes. [23]

The wear of equipment leads to an increase in operational and maintenance costs, downtime, and a decrease in the plant's overall efficiency. Therefore, addressing wear issues is crucial for enhancing the reliability and longevity of thermal power plants.

2. Ceramic Materials for Wear Resistance

Ceramic materials have been used to meet many engineering requirements, such as in energy production and the aerospace industry, because of their chemical stability and relatively high hardness, lower density compared to metals, high mechanical resistance and resistance to high temperatures. Compared to other materials, ceramics are also less prone to damage caused by corrosive environments. The strong interatomic ionic bonds of these oxides make it possible to obtain these properties [5]. The types of ceramics commonly used in thermal power plants include:

- **Alumina (Al_2O_3):** Among different oxide ceramics, Alumina or Alumina based ceramics are mostly employed for the considered application not only due to their high mechanical properties, but also because of their rather low cost and availability of commercially produced raw materials.
- **Silicon Carbide (SiC):** This ceramic material is highly resistant to abrasion and erosion and is often used in environments subject to high-impact wear, such as Body Armour, refractories, precision application such as automotive components, speciality wear components, aerospace components, thermal power plants components (coal mills and pulverisers), semiconductor wafers, bonded abrasive, siliconized graphite etc.
- **Zirconia (ZrO_2):** Zirconia ceramics have high fracture toughness, making them ideal for applications where both wear and mechanical impact are concerns.
- **Titanium Di-boride (TiB_2):** This material is known for its hardness and resistance to both erosion and corrosion.

These ceramics are often used as liners in critical components to protect against wear and extend the service life of equipment.

3. Applications of High Alumina Ceramic Liners in Thermal Power Plants

High Alumina Ceramic Line, we call it **CERALIN**.

It is panacea for all wear related problems of material carrying Components during transportation of Material. Further, The ash content in the Indian Coal is in the range of 32-45 %. This ash content erodes the pipe & components in the flow path. It makes CERALIN very useful for Specific application for fuel piping in Thermal Power Plant

It Protects Industrial Components against:

- Erosion
- Abrasion
- High Temperature

Common applications include:

- **Coal Handling System:** Coal pulverizers are highly prone to wear due to constant grinding of coal particles. Ceramic liners are used in the grinding chamber and other wear-prone areas to extend the lifespan of the pulverizers and improve their efficiency.

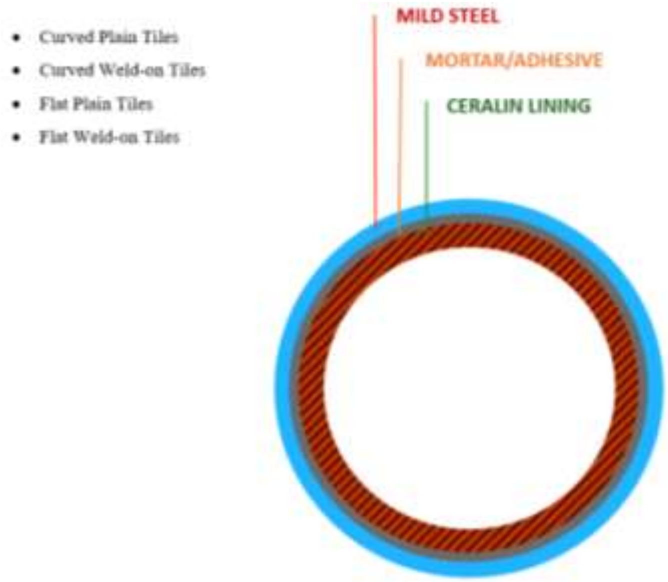
Case Study (India): A thermal power plant in Maharashtra saw a dramatic reduction in wear on coal conveyors after installing alumina-based ceramic liners. The maintenance cycle was extended by 40%, and repair costs were reduced by 25%.

- **Coal Pipes/Bends:** The abrasive coal particles of can cause significant wear on inner surface of coal pipes, bends, elbows and orifices. Ceramic liners are applied to inner surface of these components to protect them from erosion and increase their operational life.
- **Ash Handling Systems:** Ash, dust, and high-velocity gases contribute to the erosion of ducts and pipes. Ceramic linings are used in these systems to enhance their durability and reduce maintenance costs.

Research (China): A study on the use of wear-resistant ceramic linings in ash handling systems showed a significant reduction in wear rate by 60%, extending the life of the pipelines and reducing operational downtime.

- **Coal Mills components:** The movement of coal from pulverizers to coal pipe through Inner Cone, Outlet Ventury Collar, Outlet Ventury, Multi Port Outlet, Valve Body/ Valve Adapter etc. causes abrasion. Ceramic liners protect these mechanical parts from excessive wear.

CERALIN is manufactured in the form of tiles which are assembled as lining on the surface to be protected against the wear. Different technological routes are can be utilized for the manufacturing of components with different shapes and sizes. Uniaxial pressing, where ceramic press-powders obtained mostly by spray drying are compacted under high pressed in steel dies of hydraulic presses, is widely used for manufacturing of components have rather simple shapes, e.g. tiles, discs, short cylinders (monolithic or with inner hollows). Ceramic tiles can be of different shapes & sizes depending upon the geometry & functional requirements.



5. Case Studies and Real-World Applications

Several case studies highlight the successful application of ceramic liners in thermal power plants:

- **BHEL's Ceramic liners for thermal power plants:** BHEL has been at the forefront of developing and integrating advanced materials into thermal power plants. Their ceramic lining solutions, along with other wear-resistant technologies, are part of their broader strategy to improve the operational lifespan and efficiency of power plants. BHEL's expertise in combining material science with engineering ensures that their ceramic liners meet the specific needs of thermal power plant operations [24].
    - **Kingfisher Ceramic Liner in Coal-Fired Power Stations:** Kingfisher Industrial addressed wear challenges in a coal-fired power station's clinker handling system. Previous linings failed under severe abrasion and corrosion from conveying hot coarse clinker. Kingfisher's K-ZAS ceramic lining system, composed of zirconia, alumina, and silicon, demonstrated enhanced durability and performance [25].
    - **Kingcera's ZTA Ceramic Liners in Iron Ore Transfer Chutes:** An Australian iron ore mine faced high maintenance costs due to rapid wear of transfer chute liners. Initially using 92% alumina ceramic tiles, the liners wore through after just 7 weeks. Kingcera's custom ZTA ceramic liners, 50mm thick, installed as 63mm composite wear plates, extended service life to 24 weeks, significantly reducing maintenance needs [26].

6. Future Directions and Challenges

The use of wear-resistant ceramic liners in thermal power plants is expected to grow as power plants seek ways to reduce maintenance costs and improve operational reliability. Future research is likely to focus on:

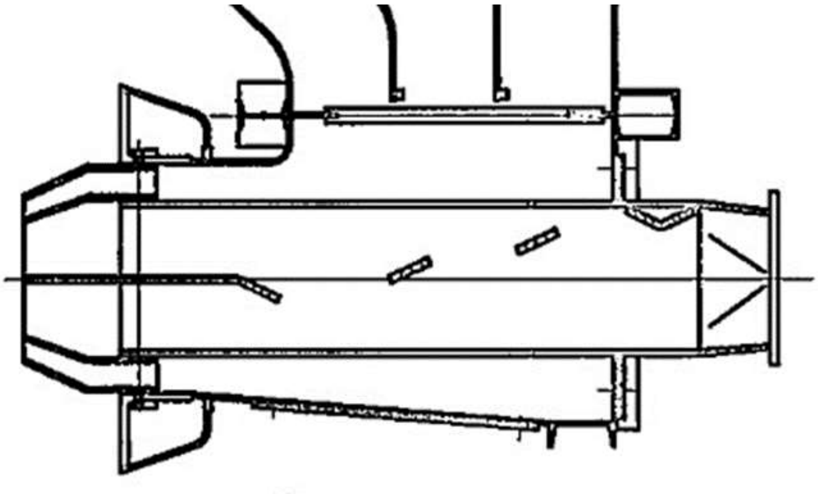
- **Development of new ceramic materials** with enhanced toughness and better impact resistance.
- **Advanced coating technologies** for easier application of ceramic liners in hard-to-reach areas.
- **Cost-effective production techniques** to make ceramic liners more affordable and accessible to a wider range of power plants.
- **Integration with predictive maintenance systems** to optimize the replacement and maintenance schedules of ceramic liners.

3. PROBLEM IDENTIICATION OF WEAR IN COAL NOZZLE

3.1 Philosophy of Wear Resistant Ceramic Liner for Coal Nozzle

Coal Burner Transition Piece is nothing but Coal Nozzle which is placed at inlet of Boiler to assist the flow of air and fuel (Pulverized coal) mixture into combustion chamber. It is used to increase the velocity or pressure of the fluid at exit one end of Nozzle. Pulverized coal is fed from the Bowl Mill through coal conveying pipes, Coal nozzle and nozzle tip into combustion chamber of Boiler. Flow of pulverized coal through pipes, bends and nozzle causes heavy wear and tear on the flow surface. Wear and tear of coal burners depends on flow velocity and grade of coal. Higher the flow of velocity, higher the wear rate. And lower the grade of coal, higher the wear rate.

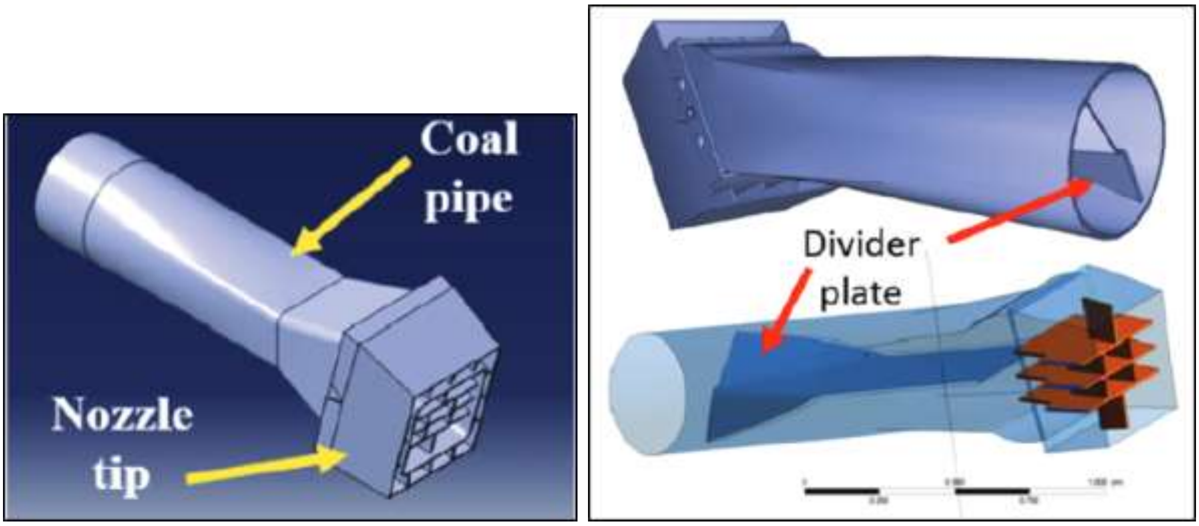
Coal Burner area of Boiler is high temperature zone and flow velocity of pulverized coal is also very high. Due to this, Coal Burner Transition Piece are subjected to very high wear and tear and results in frequent replacement of Steel casing of Coal Burner Transition Piece. Here erosion and abrasion due to continuous flow of Pulverized coal is higher and this require a wear resistant material on flow surface to check the erosion and abrasion with maximum extent



Coal Nozzle Assembly (Transition Piece for Coal Nozzle and Coal Nozzle Tip)

3.2 Structure of Coal Nozzle body

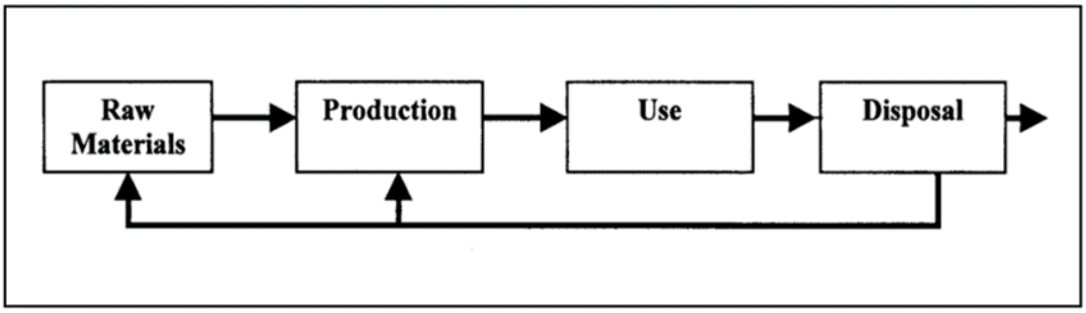
For Coal Nozzle Body, considering geometry and functional requirement of the product, 10 mm flat weld-on Ceramic liner is required. At body portion 16 mm Hardened plate was used, after changing the design considering the requirement of wear resistant ceramic liner, the plate size changed from 16 mm to 6 mm. Now 6 mm Mild Steel Plate will be used with 10 mm Ceramic liner including 1 mm Adhesive, keeping it close to original body thickness i.e. 16 mm. Considering flow area and outer dimension of body we have to maintain Ceramic liner thickness to 10 mm without affecting the total flow area.



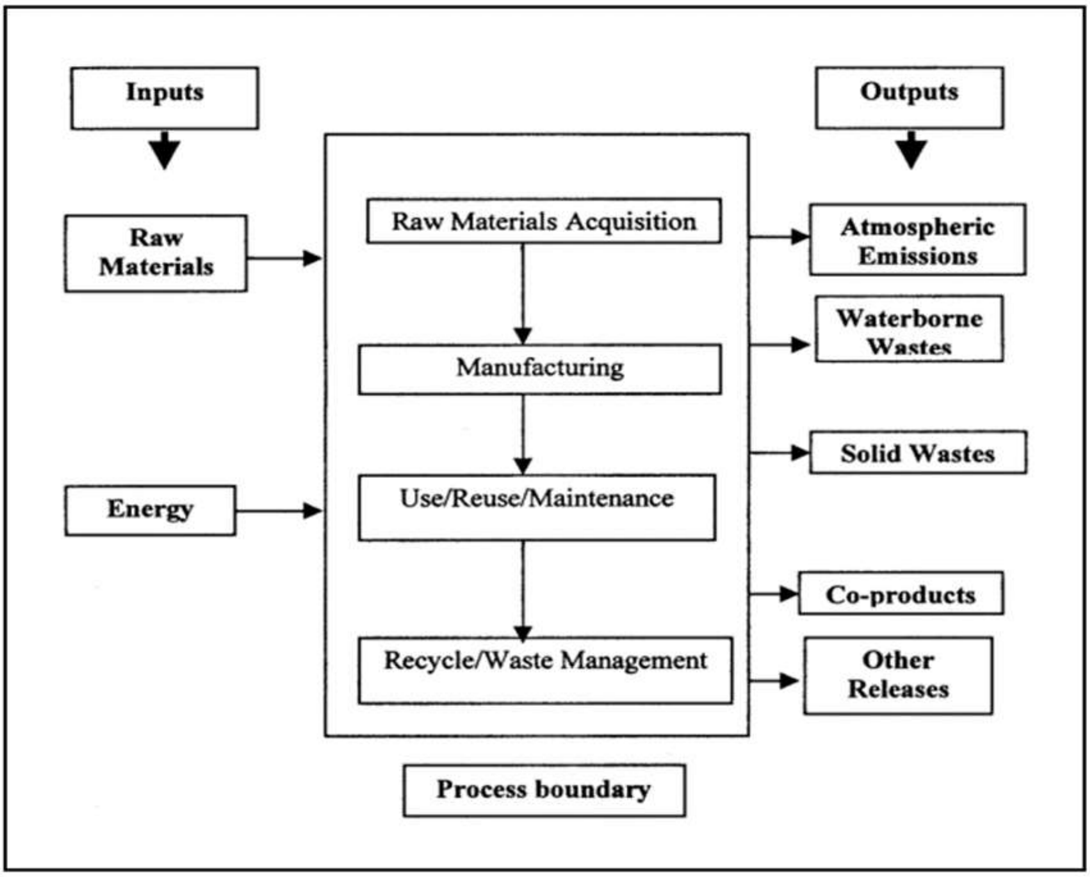
3-D Model of Coal Nozzle Body

3.3 Philosophy of Life Cycle Assessment

Life cycle assessment (LCA) is a tool to evaluate the environmental effects of a product or process throughout its entire life cycle. An LCA entails examining the product from the extraction of raw materials for the manufacturing process, through the production and use of the item, to its final disposal, and thus encompassing the entire product system [27]. A schematic representation of a product life cycle is given in following figure:



LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave) [27]. their environmental impact and evaluating opportunities for improvement as illustrated below:



There are four phases in an LCA study:

a) the goal and scope definition phase,

b) the inventory analysis phase,

c) the impact assessment phase, and

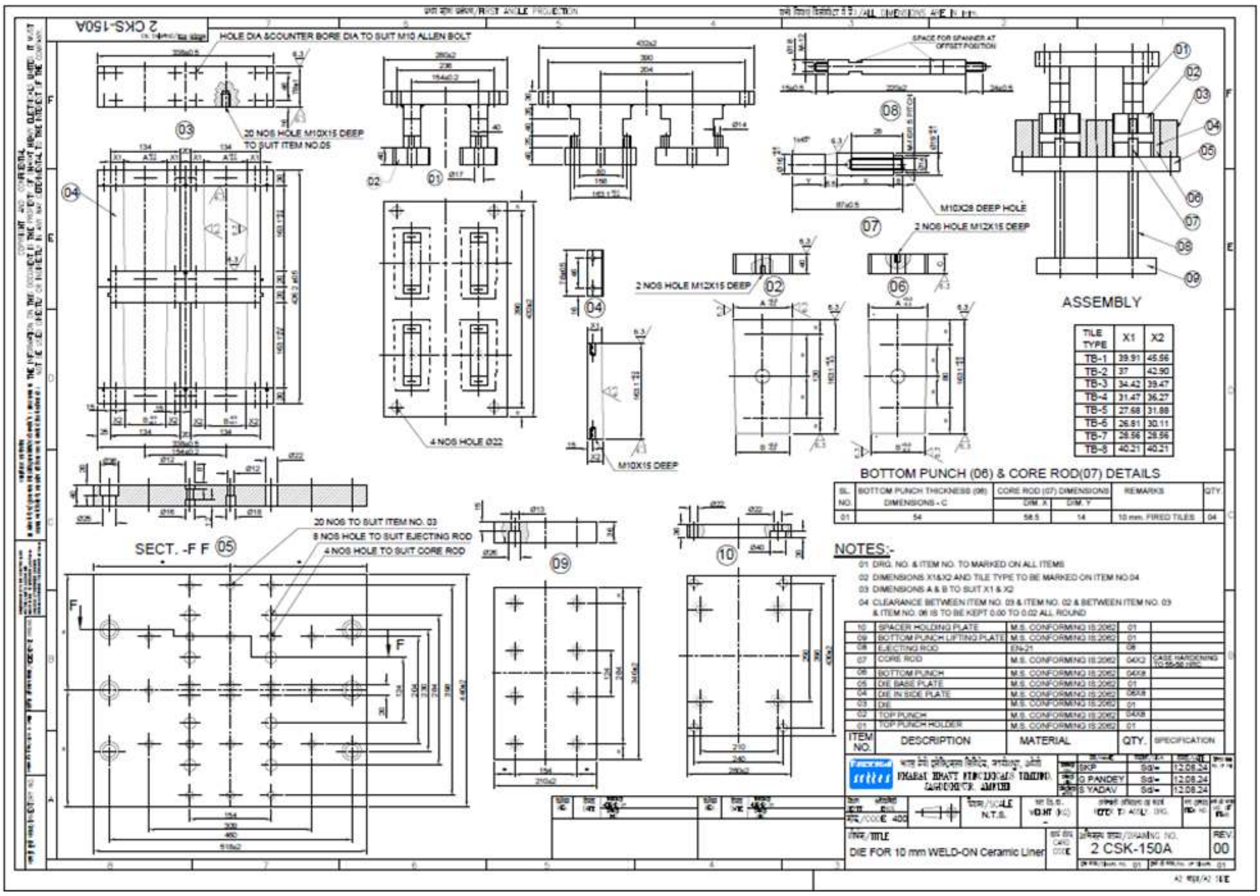
d) the interpretation phase. [27]

The unique feature of this type of assessment is its focus on the entire life cycle, rather than a single manufacturing step or environmental emission. The theory behind this approach is that operations occurring within a facility can also cause impacts outside the facility's gates that need to be considered when evaluating project alternatives.

4. METHODOLOGY

4.1 Designing of Die/Tool for 10 mm wear resistant Ceramic Liner

Designing of Die is crucial activity for manufacturing of Ceramic liner because required shape and size of Ceramic liner is obtained by appropriate designed die during formation. One of main critical tool in Die is Core rod which serves the purpose of making tapered hole in ceramic liner during formation. This tapered hole is formed for fitting and welding of weld plug on base plate or casing during Ceramic liner assembly. Die drawing developed for 10 mm weld-on tile is given below.



Die for 10 mm weld-on Ceramic Liner

4.2 Manufacturing of 10 mm Ceramic Liner for Coal Nozzle

4.2.1 Constituents of Ceramic Liner

a) Calcined Alumina (Al_2O_3)- Calcined Alumina is a white colored crystalline substance that is prepared by heating alumina at high temperature.

b) Bikaner Clay- A purified ball clay variety that has been thoroughly washed to remove impurities and excess fines. It offers high plasticity and purity, making it ideal for quality ceramic production.

c) Manganese Di-Oxide (MnO_2)- In ceramics, it is used primarily in clays and glazes to achieve fired speckle (including the brick industry)

4.2.2 Composition required for Ceramic Liner

For min. 90% Alumina Ceramic liner

Calcined Alumina – 88%

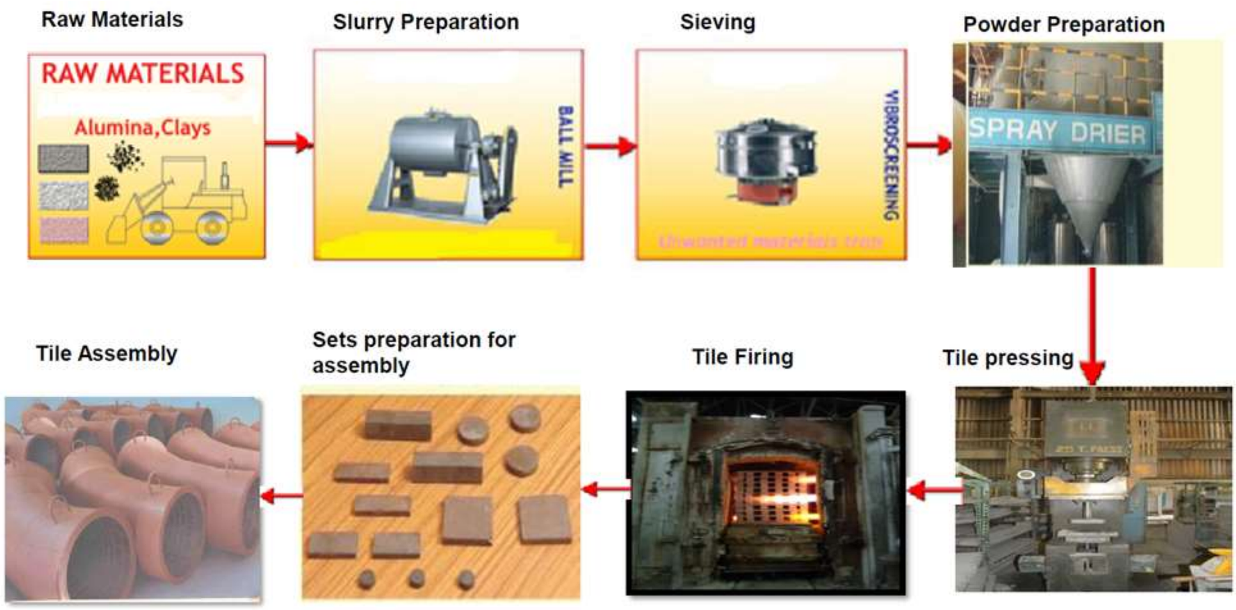
Bikaney Clay- 7%

MnO_2- 5%

4.2.3 Properties required for 90% Alumina Ceramic Liner

Property	**Specification**
Bulk Density	Min. 3.20 gm/cc
Water Absorption	Less than 1%
Abrasion (Vol. loss) (in RAI)	Min. 12
Hardness on MOH’s Scale	Min. 8
Cold crushing strength	Min. 3500 Kg/cm^2
Flexural Strength (MOR) (at room temp.)	Min. 2200 Kg/cm^2
Flexural Strength (MOR) (at 250° C temp.)	Min. 2000 Kg/cm^2
Co-efficient of Thermal Expansion	$7x10^{-6}$ to $9x10^{-6}$/°C

4.2.4 Process flow chart of 10 mm weld-on Ceramic liner manufacturing



i. Raw Material weighment as per composition

ii. Slurry preparation in Ball Mill

iii. Sieving for unwanted material trap

iv. Spray drying to make powder

v. Pressing of powder at hydraulic press for Tile formation

vi. Firing for pressed tiles in furnace

vii. Sets preparation for assembly

viii. Assembly of Ceramic Liner with Coal Nozzle body

Control of process parameter is very critical during manufacturing of Ceramic Liner. Green bulk density of Ceramic Liner has to be maintained at 2.4 to 2.6 g/cc3 in order to achieve fired bulk density of 3.2 to 3.4 g/cc3. Particle size, Moisture content, Hydraulic pressure of press and Firing environment play the crucial role for maintain the bulk density of the Ceramic liner.

10 mm thick weld-on Ceramic liner for Coal Burner

4.3 Assembly of Ceramic Liner inside Coal Nozzle Body

Constituents for Assembly:

i. Casing of Coal Nozzle Body (Transition Piece for Coal Brner)

ii. Ceramic liner (weld-on tile)

iii. Silicon Adhesive (paste for fixing of Ceramic tile on metallic casing)

10 mm thick weld-on Ceramic liner fitted inside surface of Coal Burner Transition Piece

4.4 Design & Development Input and Output

4.4.1 Design & Development Input

DESIGN AND DEVELOPMENT INPUT			
Sl. No.	**PARTICULARS**	**CUSTOMER'S REQUIREMENT / OTHER INPUTS**	**REMARKS (IF ANY)**
1.	FUNCTIONAL & PERFORMANCE REQUIREMENTS		
(i)	Total length of item	1830±2 mm	
(ii)	Length of Transition Piece	290 mm	
(iii)	Flange OD	600 mm	
(iv)	Casing thickness of tiled body portion	6 mm	
(v)	Flange PCD	540 mm	
(vi)	Flange thickness	12 mm	
(vii)	Hole dia	18 mm	
(viii)	Rectangular flange thickness	8 mm	
(ix)	Deflector Vane Item 4 & 5 thickness	6 mm	
(x)	Splitter Plate Item No. 6 thickness	4 mm	
(xi)	Splitter Plate item no. 7 thickness	20 mm	
(xii)	Inlet dia at transition piece	446±2 mm	
	Inner dimension at outlet of transition piece	404±1 and 372±2	
(xiii)	Tile thickness	10 mm	
(xiv)	Tile Alumina content	90%	
2.	APPLICABLE STATUTORY & REGULATORY REQUIREMENTS(IF ANY)	NIL	
3.	CRUCIAL CHARACTERISTICS FOR SAFE & PROPER FUNCTIONING OF PRODUCT	Tip Dimensions, Total Length, Flange PCD, Flange Hole dia, Inner dimension after transition from inlet of Transition piece	

4.4.2 Design & Development Input

DESIGN AND DEVELOPMENT OUTPUT			
Sl.No.	**PARTICULARS**	**CUSTOMER'S REQUIREMENT / OTHER INPUTS**	**REMARKS (IF ANY)**
1.	FUNCTIONAL & PERFORMANCE REQUIREMENTS		
(i)	Total length of item	1829-1831 mm	
(ii)	Length of Transition Piece	290-291 mm	
(iii)	Flange OD	600-601 mm	
(iv)	Casing thickness of tiled body portion	6 mm	
(v)	Flange PCD	540 mm	
(vi)	Flange thickness	12 mm	
(vii)	Hole dia	18 mm	
(viii)	Rectangular flange thickness	8 mm	
(ix)	Deflector Vane Item 4 & 5 thickness	6 mm	
(x)	Splitter Plate Item No. 6 thickness	4 mm	
(xi)	Splitter Plate item no. 7 thickness	20 mm	
(xii)	Inlet dia at transition piece	446±2 mm	
	Inner dimension at outlet of transition piece	404±1 and 372±2	
(xiii)	Tile thickness	10 mm	
(xiv)	Tile Alumina content	90.73%	
2.	APPLICABLE STATUTORY & REGULATORY REQUIREMENTS(IF ANY)	NIL	
3.	CRUCIAL CHARACTERISTICS FOR SAFE & PROPER FUNCTIONING OF PRODUCT	Tip Dimensions, Total Length, Flange PCD, Flange Hole dia, Inner dimension after transition from inlet of Transition piece	

4.5 Comparison of Ceramic Lined Coal Nozzle Body & Non-ceramic Lined Coal Nozzle Body

Comparative Analysis: To organize the findings, the following table compares key aspects based on available data:

Aspect	**Ceramic Lined Nozzle Body**	**Non-Ceramic Lined Nozzle Body**
Wear Resistance	High (RAI > 10, low erosion at 700°C)	Lower, likely wears out faster in abrasive conditions
Thermal Shock Resistance	> 25 cycles (800°C to room temperature)	Lower, metal may deform under high temperatures
Lifespan	Over 2 years in 500 MW boilers, likely more than twice non-ceramic	Estimated 6 months to 1 year based on industry discussions
Initial Cost	Higher due to ceramic material and installation	Lower, simpler construction

Aspect	**Ceramic Lined Nozzle Body**	**Non-Ceramic Lined Nozzle Body**
Maintenance Costs	Lower long-term maintenance costs due to reduced replacement frequency	Higher long-term maintenance costs due to frequent replacements
Installation Complexity	More complex, requires bonding ceramic to metal	Simpler, standard metal fabrication
Sustainability	Potential use of earth material e.g. Alumina, bottom ash for lining, reducing waste and lower environmental impact	Standard metal production, potentially higher environmental impact

This table encapsulates the core differences, highlighting the trade-offs between initial cost and long-term performance.

4.6 Testing of Ceramic Liner

1 Sample preparation for Bulk density and Water absorption

2. Sample for CCS (Cold Crushing Strength) & Flexural Strength 3. Sample for Hardness and Coefficient of Thermal Expansion

4. Sample for Relative Abrasion Index (RAI)

5. Sample for Alumina Content

All these tests are conducted at BHEL Ceramic Lab.

4.7 Test report of Ceramic Lined Product (Coal Nozzle)

Bharat Heavy Electricals Limited
FABRICATION STAMPING & INSULATOR PLANT (FSIP)
I.A.JAGDISHPUR, AMETHI (EARLIER SULTANPUR)–227817,U.P.
Format No.: QAC:4303

TEST REPORT FOR CERALIN PRODUCTS

INSPECTION REPORT NO.: FSIP/QAC/2024-25/056 DATED: 07.09.2024

1.1	PRODUCTS	CERAMIC LINED TRANSITION PIECE FOR COAL BURNER	
1.2	CUSTOMER	SAI WARDHA POWER GENERATION PVT. LTD.	
1.3	PO NO. / CONTRACT NO.	4200002198 DT. 24.04.2024	
1.4	WORKORDER	W-1239000170	
1.5	DRAWING NO.	2-986-06-01169 REV 01	
1.6	PATTERN NO.	WPCL-M-CLM-0122	
1.7	QUANTITY ACCEPTED	15 NOS.	
2.0	**TEST RESULT OF MS CASING** TC NO.906329367 DT 10.07.2024 FOR 06 MM PLATE, TC NO.80760879 DT 05.07.2023 FOR 16 MM PLATE		
	AS PER IS-2062 E250	AS PER SPEC.	AS OBSERVED
2.1	% CARBON	0.23% (MAX)	0.046 % & 0.15 %
2.2	YS	250 MPA (MIN)	426 MPa & 327 MPa
2.3	UTS	410 MPA (MIN)	461 MPa & 468 MPa
2.4	% ELONGATION	23% (MIN)	33 % & 26 %
3.0	**VISUAL EXAMINATION**	**SATISFACTORY**	
3.1	WELDER QUALIFICATION & REGISTRATION NUMBER	IIC1, IIC2	
3.2	DYE PENETRATION TEST	SATISFACTORY	
3.3	DIMENSIONS	SATISFACTORY AS PER APPROVED DRG.	
3.4	GAP BETWEEN TILES	SATISFACTORY	
3.5	SURFACE UNEVENNESS	SATISFACTORY	
3.6	VISUAL APPEARANCE	SATISFACTORY	
3.7	PAINTING	SATISFACTORY	
4.0	**CERAMIC TILES**	**AS PER SPEC.**	**TEST RESULTS**
4.1	BULK DENSITY OF CERAMIC LINER	Min 3.2 gm/cc	3.48 gm/cc
4.2	WATER ABSORPTION	<0.5%	0.04%
4.3	MOH'S SCALE HARDNESS	>8	8+
4.4	% ALUMINA CONTENT	≥90%	90.73%
4.5	RELATIVE ABRASION INDEX	≥12	20.16
4.6	COLD CRUSHING STRENGTH	>3000 KG/CM^2	3750 KG/CM^2
4.7	FLE. STRENTH (ROOM TEMP.)	2200 KG/CM^2	2464 KG/CM^2
4.8	CO. EFFICIENT OF T.E.	7.0X10^{-6}/^{0}C AT 650 ^{0}C	8.52X10^{-6}/^{0}C

PREPARED BY
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17/09/24

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4.8 Life Cycle Assessment of Coal Nozzle

- Based on the Internal LCA, we have established **Coal Nozzle Carbon emission model** and determine the **boundary of the calculation** system as

  a. Ceramic liner raw material acquisition stage,

b. Manufacturing stage,

c. Transportation stage,

d. Operation stage,

e. End of life

- Using the data of one Coal Nozzle Body to calculate the **Carbon emissions in the life cycle** i.e. Raw material acquisition stage, Manufacturing stage, Transportation stage and Operation stage**.**
- The ***analysis of the Carbon emissions is carried out*** by adopting the LCA method for the Coal Nozzle.

A. Method and system boundary

- The Coal Nozzle LCA model is carried out with follows the **ISO 14040 and 14044 standards.**
- The determination of the system boundary has a great influence on LCI data and the calculation results.
- The **Carbon emissions calculation process includes**
  - Formulating the calculation process,
  - Determining the system boundary,
  - Putting LCI Data
  - Calculating the emissions

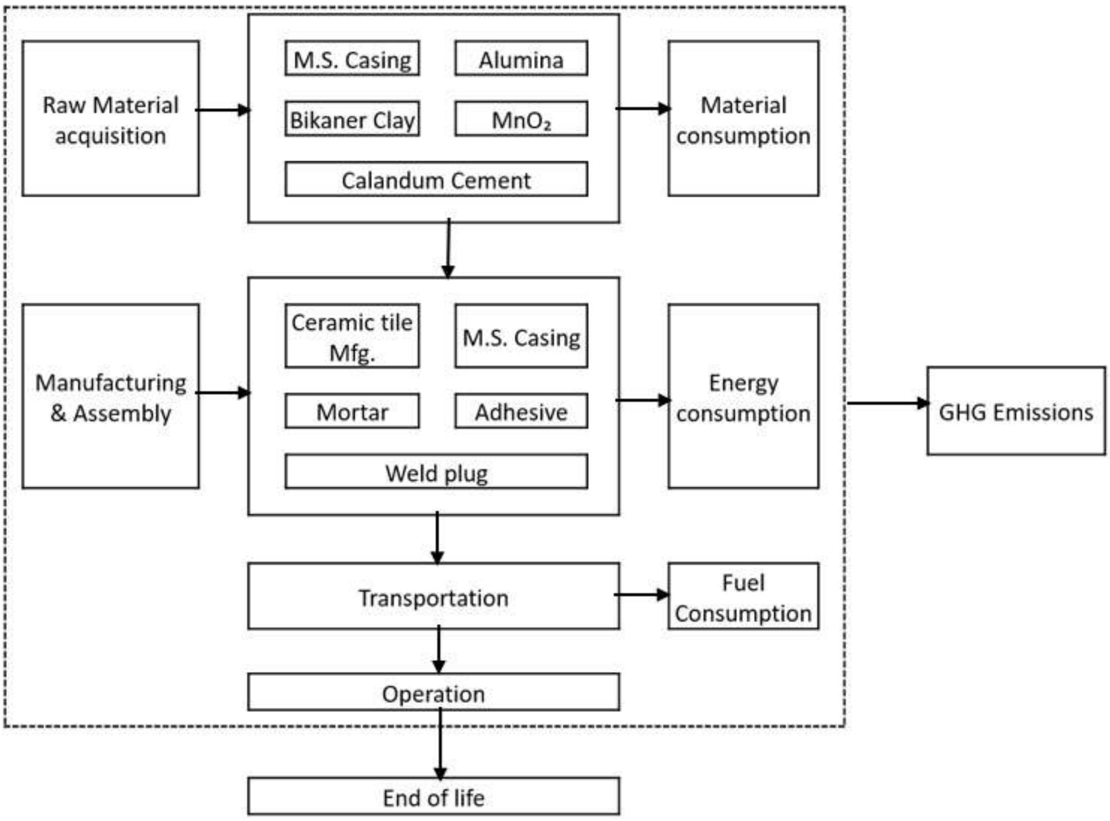


Figure shows the system boundary of Mill outlet elbow GHG emissions calculation.

I. Raw material acquisition stage

- In the raw material acquisition stage, all raw materials required for a Coal Nozzle Body in the production process should be considered.
- Coal Nozzle Body is produced by assembling of **Ceramic liner**, **M.S. Casing** (manufactured by **M.S. Plates**), **Silicon Adhesive** (for pasting of Ceramic weld-on liner at inner surface of body) and **M.S. weld plug** (for fixing of weld-on liner).
- The main raw materials of Ceramic liners are **Alumina, Bikaner Clay and MnO_2.**

- The main components of the Coal Nozzle Body are the **Ceramic liner, M.S. Casing, Adhesive & M.S. Weld plug.** The calculation of Carbon emissions at this stage mainly considers the amount of raw materials used.

II. Manufacturing stage

- The manufacturing stage considers the Carbon emissions during the process of **Ceramic liner manufacturing after obtaining raw materials and assembling of Ceramic liner with M.S. Casing of Coal Nozzle Body using adhesive paste.**
- This stage is mainly carried out in two different work stations: **Ceramic liner manufacturing shop and Assembly shop.**
- The Carbon emissions calculation needs to consider **the total power and Gas consumption of each shop** in the process of Coal Nozzle manufacturing.

III. Transportation Stage

- The GHG emissions in the transportation stage are related to the type of shipping, and the distance from the manufacturing location (BHEL Jagdishpur) to the Customer sites.

IV. Operation Stage

- There is no GHG emissions of Coal Nozzle in the operation.
- Only erosion of Ceramic tile due to operational wear and tear.

B. Special Condition to calculate total Carbon Emission

- CARBON **emission sources** whose emission contribution rate **is less than 1% are not counted.**
- In addition, other carbon emissions that are **not included in the boundary** also include **Labour in the Production, Assembly, Transportation Process, and Transportation of raw Materials when Purchase.**
- **Metal parts of the raw materials (Mild Steel) are recycled & recycling rate is 90%.**
- When calculating Carbon emissions at the **raw material acquisition stage**, the **recycling rate** should be considered and the value used in the calculation is **90% of the original value.**
- **Recycling rate of Adhesive is nil.**
- The **Ceramic liner is non-recyclable** and **get eroded at the end of life**.
- Casing fabrication requires equal amount of work at manufacturing **so emission value at manufacturing stage is not considered in LCA analysis**

C. LCA MODEL

According to the above description, the Coal Nozzle life cycle Carbon emissions can be calculated according to the following equations.

$Er = \sum Mi * EF1i$

$Ea = \sum Ei * EF2i$

$Et = \sum D * L * EF3$

$Eo = 365 * P * T * EF4$

$E(total) = Er + Ea + Et + Eo$

- **Er is Carbon emission** in raw materials acquisition stage (tCO2e), **Mi is the amount of raw materials** used in **category i** consider recycling rate, **EF1i is the emission factor** of raw material i.
- **Ea is Carbon emission in manufacturing stage, Ei is the amount of energy consumption of energy** i in this stage, **EF2i is the emission factor** of energy i.
- **Et is Carbon emission in transportation stage**, D is unit fuel consumption, L is transportation distance, EF3 is emission factor of fuel.
- **Eo is Carbon emission in the operation stage**, P is power loss, T is operation time, and EF4 is the electricity emission factor of the operation region.
- **E(total) is the total Carbon emission of the Coal Nozzle life cycle.**

D. Life Cycle Inventory (LCI) data

Raw Material Acquisition Stage Data:

Component	**Material**	**Coal Nozzle Body**
M.S. Casing (considering no ceramic liner at inner surface of body)	Mild Steel	516.2
M.S. Casing (considering ceramic liner at inner surface of body)	Mild Steel	341.5
Ceramic Liner	Alumina	77.62
	Bikaner Clay	6.15
	MnO_2	4.43
Adhesive paste	Silicon Adhesive	2.5
Weld plug	Mild steel	1.63

Table 1. Raw material data of Coal Nozzle (kg)

Manufacturing, Transportation and Operation Stages Data:

Stage	**Inventory**	**Coal Nozzle Body**
Assembly	Power consumption of Ceramic tile manufacturing and Ceramic tile assembly shop (kWh)	381
	RLNG Gas Consumption in Ceramic Tile firing (scm)	205
Transportation	Fuel consumption (L) of final product sent to site	13.34 L for per Coal Nozzle- without ceramic liner and 11.21 L for per Coal Nozzle- with ceramic liner (310 L (930 Kms.) considered for 20 MT freight vehicle and 12 MT actual loading weight)
Operation	Power loss (kW)	0

Table 2. LCI data in Manufacturing stage

Emission Factor:

The emission factor of different materials and energy used in this work-out is collected from the related database and the electricity emission factor adopts the value of CEA (Central Electricity Authority). The specific values are shown in Table-3.

Materials or energy	**Emission factor**
Steel	2.46 Kg CO2 Eq / KG (As per ICE V 3.0 Beta 2019)
Ceramic Tile	0.78 Kg CO2 Eq / KG (As per ICE V 2.0 2011)

Cement Mortar	0.912 Kg CO_2 Eq/ KG (As per ICE V 3.0 Beta 2019)
Diesel	2.6444 Kg CO_2 Eq/ Ltr (As per IGHGP)
Electricity	0.716 Kg CO2 Eq / KWH (As per CEA)
RLNG	1.96 Kg CO_2 Eq/ SCM (As per US EIA)
Adhesive	0 (As per ICE V 2.0 2011)

Table 3. Emission factor of different materials and energy.

E. Calculations for Carbon emission

(A) CARBON EMISSION- Raw material acquisition stage (Coal Nozzle with Ceramic Liner)				
	Composition	**Coal Nozzle Body**	**Emission Factor**	**Total CO2 (tCO2)**
M.S. Casing (Kg)	Mild Steel	341.5	2.46	0.84 tCO2e
Ceramic tile (kg)	Alumina, Bikaner Clay, MnO_2	88.2	0.78	0.07 tCO2e
Adhesive (kg)	Silicone Adhesive	2.5	0	0
Weld Plug (Kg)	Mild Steel	1.63	2.46	0
Total				**0.91 tCO2e**

Table 4. Carbon emission calculation at Raw material acquisition stage (with Ceramic)

(A) CARBON EMISSION- Raw material acquisition stage (Coal Nozzle without Ceramic Liner)				
	Composition	**Coal Nozzle Body**	**Emission Factor**	**Total CO2 (tCO2)**
M.S. Casing (Kg)	Mild Steel	516.2	2.46	1.27 tCO2e
Total				**1.27 tCO2e**

Table 5. Carbon emission calculation at Raw material acquisition stage (without Ceramic)

(C) CARBON EMISSION- Manufacturing stage				
		Coal Nozzle Body	**Emission Factor**	**Total CO2 (tCO2)**
Power consumption in Manufacturing (kWh)	Ceramic tile Mfg. & Assembly shop	381	0.82	0.27 tCO2e
Fuel (RLNG) consumption in Firing (SCM)	HTK & Bickley	205	1.96	0.40 tCO2e
Total				**0.67 tCO2e**

Table 6. Carbon emission calculation at Ceramic Liner Manufacturing stage

(C) CARBON EMISSION- Transportation stage				
		Coal Nozzle	**Emission Factor**	**Total CO2 (tCO2)**
Transportation (with ceramic)	Fuel consumption (Litre)	11.21	2.6444	**0.030 tCO2e**
Transportation (without ceramic)	Fuel consumption (Litre)	13.34	2.6444	**0.035 tCO2e**

Table 7. Carbon emission calculation at Transportation stage

(D) CARBON EMISSION- Operation stage				
		Coal Nozzle	**Emission Factor**	**Total CO2 (tCO2)**
Operation	No power loss	0	0.716	**0**

Table 8. Carbon emission calculation at Operation stage

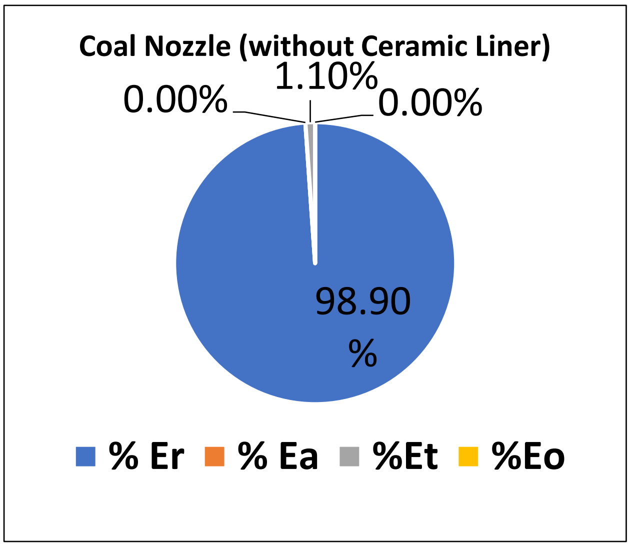
(E) TOTAL CARBON EMISSION						
Item	**At raw material acquisition stage.** **In Ton CO2 equivalent (tCO2e)**	**At ceramic liner manufacturing stage.** **In Ton CO2 equivalent (tCO2e)**	**At Transportation stage.** **In Ton CO2 equivalent (tCO2e)**	**At Operation stage.** **In Ton CO2 equivalent (tCO2e)**	**Total** **In Ton CO2 equivalent (tCO2e)**	**Lifespan of Coal Nozzle**
Coal Nozzle **(with ceramic liner)**	0.91	0.67	0.030	0	**1.61**	**24 months** **(min.)**
Coal Nozzle **(without ceramic liner)**	1.27	0	0.035	0	**1.31**	**9 months**

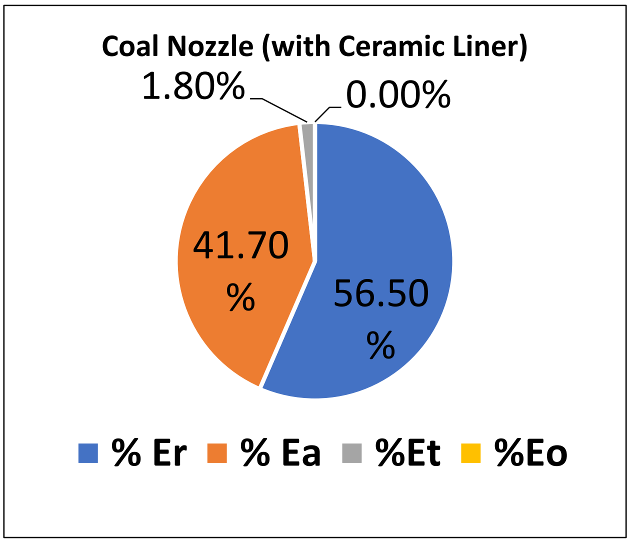
Table 9. Total Carbon emission for Coal Nozzle

Carbon Emission per year	**Coal Nozzle (without Ceramic Liner)**	**Coal Nozzle** **(with Ceramic Liner)**
TOTAL CARBON EMISSION- Raw material acquisition stage (Er) (in tCO2e)	**1.69**	**0.46**
TOTAL CARBON EMISSION- Ceramic Liner Manufacturing stage (Ea) (in tCO2e)	**0**	**0.34**
TOTAL CARBON EMISSION- Transportation stage (Et) (in tCO2e)	**0.018**	**0.015**

TOTAL CARBON EMISSION- Operation stage (Eo) (in tCO2e)	**0**	**0**
Total Emission E(total)= Er + Ea + Et + Eo (in tCO2e)	**1.708**	**0.815**
% Emission in Raw material acquisition stage	**98.9 %**	**56.5%**
% Emission in Manufacturing stage	**0%**	**41.7%**
% Emission in Transportation stage	**1.1%**	**1.8%**
% Emission in Operation stage	**0%**	**0%**
% Reduction in Carbon Emission per year due to introduction of ceramic liner	**52.3%**	

Table 10. Carbon emission analysis





5. RESULTS & DISCUSSIONS

5.1 Test results of Ceramic Lined Coal Nozzle

Reference: Inspection Report No.: FSIP/QAC/2024-25/056 Dt. 07.09.2024

Component	**Desired (as per Spec.)**	**Observed (actual)**	**Remarks**
Steel Casing (6 mm M.S. Plate and 16 mm SAIL Hard Plate)			
% C	0.23 % (Max.)	0.046 % & 0.15 %	Meeting the min. requirement
Yield Strength	250 MPa (Min.)	426 MPa & 327 MPa	
Ultimate Tensile Strength	410 MPa (Min.)	461 MPa & 468 MPa	
% Elongation	23 % (Min.)	33% & 26%	
Ceramic Liner (10 mm thick)			
Bulk Density	3.4 gm/cc (Min.)	3.48 gm/cc	Meeting the min. requirement
Water absorption	<0.5%	0.04%	

Moh's scale hardness	>8	8+	
% Alumina	≥90%	90.73%	
Relative abrasion index	≥12	20.16	
Cold crushing strength	>3000 Kg/cm^2	3750 Kg/cm^2	
Flexural strength (Room Temp.)	>2200 Kg/cm^2	2464 Kg/cm^2	
Co-efficient of Thermal expansion	$7.0x10^{-6}$/°C to $9.0x10^{-6}$/°C	$8.52x10^{-6}$/°C	

5.2 Results of LCA study

I. Raw material acquisition stage

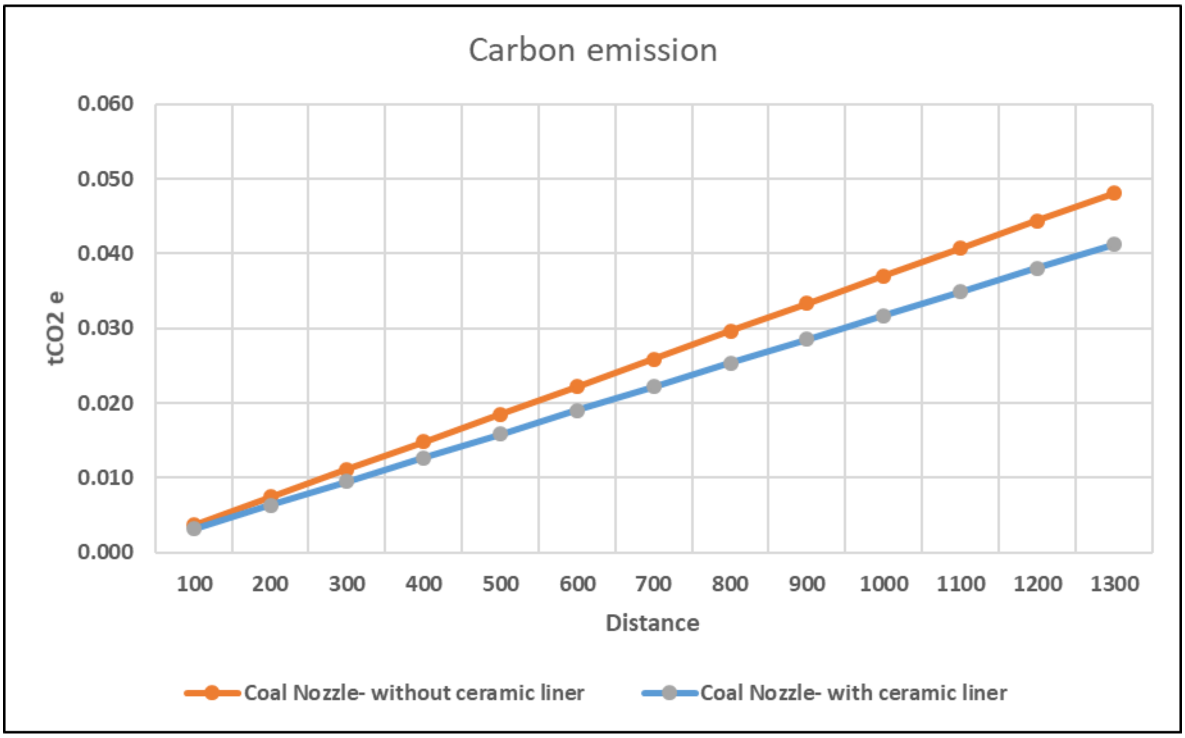
- At the raw material acquisition stage, metal and ceramic tile are the main Carbon emission sources.
- For Coal Nozzle- without ceramic liner, Steel contributes 100% in carbon emission (refer Table 5).
- For Coal Nozzle- with ceramic liner, Steel contributes 92% and Ceramic liner 8% in carbon emission (refer Table 4).
- Emission factor of Ceramic liner (0.78 Kg CO2 Eq./Kg) is much less than Steel (2.46 Kg CO2 Eq./Kg), so introduction of ceramic liner in Coal Nozzle reduces the overall emission per year at raw material acquisition stage (refer Table 10).
- Thus total carbon emission per year at raw material acquisition stage accounts 98.9% for Coal Nozzle- without ceramic liner and 56.5% for Coal Nozzle- with ceramic liner.

II. Manufacturing stage

- The Carbon emissions in the manufacturing stage are mainly the power consumption of Ceramic tile Manufacturing & Assembly operation and Gas consumption during Ceramic tile sintering process.
- Ceramic tile manufacturing shop has various machineries e.g. Bowl Mill, Spray Dryer, Presses and Furnaces which require sufficient power to run the manufacturing of Ceramic Tiles. But gas consumption in Furnaces during firing of Ceramic tile is the most Carbon emitting source i.e. 60% in manufacturing stage (refer Table 6).
- Thus total carbon emission per year at ceramic liner manufacturing stage accounts 41.7% for Ceramic lined Coal Nozzle (refer Table 10). Casing manufacturing also accounts some carbon emission but not considered here as emission value will be same for both Coal Nozzle- without ceramic liner and Coal Nozzle- with ceramic liner.

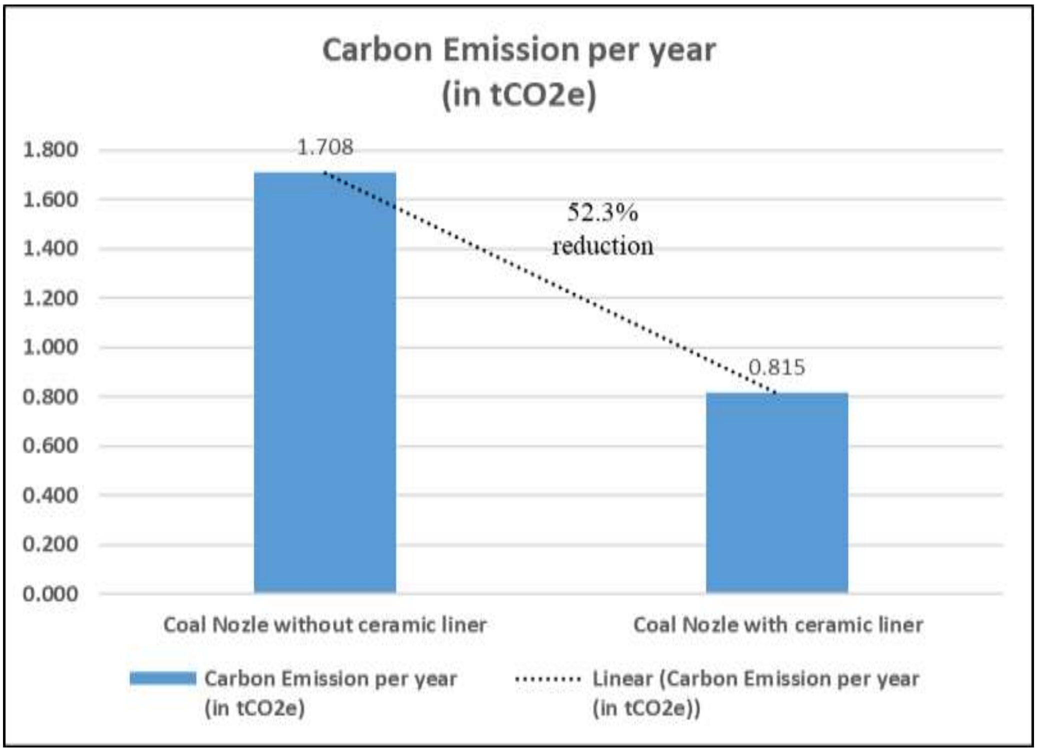
III. Transportation Stage

- In the transportation stage, the transportation distance and the weight of the Coal Nozzle have a significant impact on diesel consumption.
- The Carbon emissions at different distances are shown in the Figure.
- With the increase in transportation distance, Carbon emissions show a linear increase, but the overall emissions of this stage are not large, merely 1 to 2% (refer Table 10).
- For larger size and weight of items, their Carbon emissions are relatively higher due to their heavier weight.



IV. Operation Stage

- The expected design life of the ceramic lined Coal Nozzle is generally 2 to 3 years. Once it is put into operation, it will continue to work unless there is a fault and an overhaul.
- The Carbon emissions of this stage is zero as there is no power loss during operation.



Comparison of carbon emission per year of Coal Nozzle with & without ceramic liner

i. Wear resistance of Coal Nozzle improved due to ceramic liner.

ii. Product weight optimized (M.S. density is 7.85 and Ceramic density is 3.4)

iii. Product life cycle improved from less than 01 years to 02 - 03 year (expected).

- **iv.** Material saved due to product life cycle improvement
- **v.** Carbon emission reduced by 52.3% due to ceramic liner.

6. CONCLUSIONS AND FUTURE WORK

In this study by Life cycle assessment model we have studied the environmental impacts of Coal Nozzle due to introduction of wear resistant ceramic liner.

6.1 Main Conclusions:

The following aspects found in line with study of Wear Resistant Ceramic Liner for Coal Nozzle and its LCA analysis:

1) Ceramic liner has good resistance to erosion and abrasion against coal particle flowing through Coal Nozzle.
2) Ceramic liner provides good life to Coal Nozzle and reduces the maintenance frequency of Coal conveying system in Thermal Power Plant
3) Lifespan of the Coal Nozzle has improved by 2 to 3 times due to introduction of wear resistant ceramic liner.
4) Maintenance cost of Coal Nozzle has reduced due to improved lifecycle.
5) Ceramic liner has lesser density than Steel so product weight of Coal Nozzle optimised and material saved.
6) Ceramic liner has less emission factor w.r.t. Steel so overall Carbon emission per year has reduced by 52.3% thus lesser negative environmental impact of the product.

Research as of now, suggests that ceramic lined coal nozzle bodies offer significant advantages in wear resistance, thermal stability, and lifespan, making them suitable for the harsh conditions of thermal power plants. While they have higher initial costs and installation complexity, their reduced maintenance needs and potential sustainability benefits, such as using earth material e.g. Alumina, bottom ash, make them a compelling choice. Non-ceramic lined nozzles, while cheaper initially, may not perform as well under abrasive conditions, leading to higher long-term costs. The choice depends on plant-specific operational needs, budget constraints, and sustainability goals, with ceramic lined nozzles likely preferred for long-term efficiency and positive environment impact.

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