International Journal of Current Trends in Engineering & Technology
www.ijctet.org, ISSN: 2395-3152
Volume: 08, Issue: 05 (September -October, 2022)

Clean and Environment-Friendly Technology for Brick Production

Dr Rajesh Kumar
Department of Civil Engineering
K.N.S. government polytechnic, Samastipur Bihar
rajroserabihar@gmail.com

Abstract-For the construction of buildings, one of the major materials used is bricks. With the booming infrastructure in India, 140 billion bricks were produced in 2001 and 250 billion bricks in 2012. The production growth of the bricks is estimated at a rate of 4% per year. Clay bricks with more than a hundred thousand brick kilns are used in India, and it is the second largest producer in the world. Brick production is known to have diffused and seasonal environmental impacts along with social and economic impacts. This work shows an overview of the origin of brick-making, its socioeconomic importance, the environmental impacts, and improvements made in the art of brick-making over the years. This work also thoroughly studies the clean and environment-friendly technology used to make bricks in this century.

Keywords: Bricks making, Environmental pollution, Health issues, green technology.

1. Introduction

Despite its contribution to environmental pollution, the brick-making industry plays a major role in the economic growth of many nations, with traditional technology accounting for a significant proportion of the total clay brick production. The environmental impacts of brick-making cannot be overruled. However, these impacts could be minimised and managed by adopting more sustainable and environmentally friendly firing. The last 50 years have seen a surge in the use of burnt clay bricks for house construction. The number of households living in burnt clay brick houses doubled from 5.16 crore households in 1991 to 11.73 crore households in 20111. Apart from wide-scale availability and affordable prices, technical reasons that make burnt clay bricks popular include.

- **Long life:** Properly baked clay bricks can last hundreds of years, as shown by the 4,000-year-old bricks found in excavations of Harappan settlements.
- **Good structural strength:** good quality burnt clay bricks have a high compressive strength between 100 kg/cm2 and 300 kg/cm2.
- **Safety in natural disasters:** Burnt clay bricks are incombustible and resist spreading fire. They also withstand rains and flooding quite well. Bricks absorb moisture through pores when wet and dry quickly once the water recedes.
- **No toxicity:** Burnt clay bricks are made from natural materials and generally do not contain any toxic material. Hence, they do not pollute the environment.

2. Historical Perception of Brick Making

The art of masonry and 'stone dressing' from time immemorial to about 2500 BC originated in Ancient Egypt [1]. Clay bricks began from Mehrgarh in 7000 BC during the pre-Harappa time [2]. Mason and Lee [4] stated that mud deposition, which cracks and forms cake on the Nile, Euphrates, or Tigris rivers after flooding, initiated moulding into crude building units to construct sheds. Availability, flexibility and economical production of clay bricks compared with stones resulted in a gradual shift in construction material from stone to clay brick [3]. The first true building of sun-baked brick was made about 4000 BC in Mesopotamia, now known as Iraq [4]. Primitive brick units, basically made up of a mixture of mudbricks with straw, were extensively used before technological advancements resulted in the production of fired bricks. Baked brick technology emerged in the Indus Valley culture [3]. Recently, fired clay bricks which are more durable, heat resistant and tough, are produced via the combustion of mud bricks in kilns [5]. The Mesopotamians were reported to have developed more rigid and more durable bricks. The toughness and durability of bricks produced in Mesopotamia were attributed to the baking of bricks produced from the combination of clay and straw [1]. Amanda emphasised that the toughness and lightness of the bricks make it relatively easier to stack, loading and transport without damage, an added advantage of fired brick over the use of stone. Fired clay bricks were introduced in South Africa during the first year of Jan van Riebeek's arrival in Cape. In August 1654, the first house made with red-fired bricks was constructed in Cape. Mass production of bricks was initiated in Africa in 1655 [6]. However, Clay brick production became popular in South Africa during British occupation in 1795 [7].

The most common brick dimension for construction is 5.5 × 9.5 × 20 centimetres. In the 19th century, various innovations serving as the bedrock for the current industrial brick-making technology were invented in Europe and the USA. The innovations include an extruder and press for shaping bricks, Hoffmann and tunnel kilns for burning bricks and a chamber drier [2]. Industrial revolution conceived the transition from manual method to automated mass production of bricks resulting in the explosion of brick as a modern building material, hence the preferred material for commercial buildings [8]. Indian Brick Industry Industries making bricks are micro and small enterprises located in rural and peri-urban areas. Brick-making is a seasonal industry with kilns operating during the dry season from November to June. An estimated 1.4 lakh brick enterprises operate in the country, and the annual production is estimated at around 25,000 crore bricks, making India the second largest producer of bricks in the world after China. Burnt clay bricks are manufactured in almost all states of the country. However, there are considerable variations in the quality and availability of the primary raw material, brick earth, the scale of production, the technology employed and the quality of bricks produced.

The calculations are based on data on the number of units and the typical production capacity collected from brick industry associations and literature [9]. Indian states are accordingly divided into three categories: a) States with High Intensity of Brick Production: States with high-intensity brick production (Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal & Tripura) are almost all located in the Indo-Gangetic plains, where good quality clay is abundantly available, and the availability of other natural building material like stone is scarce. The intensity of brick production varies from 200 bricks per person per year to 450 bricks per person per year. Some of these states manufacture bricks for their consumption and export bricks to neighbouring states (for example, Uttar Pradesh to Uttarakhand and Madhya Pradesh and Punjab to Himachal Pradesh). The total number of brick-manufacturing enterprises in these states is estimated to be between 35,000 and 40,000. Each enterprise produces anywhere between 3 million and 8 million bricks per year. These states account for almost 50 percent of the country's total burnt clay brick production. The brick kiln technology is either Fixed Chimney Bull's Trench Kiln (FCBTK) or its improved variation, the zigzag kiln. Due to the excellent availability of high-quality brick earth, the quality of bricks produced is the best in the country.

The brick industry in these states employs some local workers but depends predominantly on migrant workers from states such as Uttar Pradesh, Bihar, Jharkhand, Chhattisgarh and Odisha. States having Medium Intensity of Brick Production: These states and union territories have annual per capita brick production ranging from 100 to 200 bricks per person per year. These include some extensive and populous states such as Tamil Nadu, Maharashtra, Gujarat, Rajasthan and Assam, and less crowded smaller states & Union Territories such as Jharkhand, Uttarakhand, Himachal Pradesh and Jammu & Kashmir. These states have isolated large clusters (mostly FCBTK kilns) in and around cities or regions with good quality brick earth availability. Some of these states, like Maharashtra and Gujarat, also have many smaller clamp-type kilns. All have good availability of stone and other alternate walling materials such as concrete blocks or fly ash bricks. States having Low-Intensity Clay Brick Production: These states and Union Territories have annual clay brick production lower than 100 bricks per person per year. This means these states also have a substantial supply of alternate walling materials such as stone, concrete blocks or fly ash bricks. These states also include Kerala, known for its clay brick and tile industry, but where environmental concerns have drastically reduced the availability of clay. Similarly, some states, such as Karnataka and Odisha, have several significant brick kiln clusters. Many brick-making units in these states employ clamps as firing technology, while down-draught, Hoffmann and FCBTK technology are also employed.

3. Influence of Brick making on Climate Change

In addition to air pollutants released from brick making is the generation of Greenhouse gases (GHGs), mainly from fossil fuel combustion. Significant releases of GHGs such as carbon dioxide, nitrogen oxides (NO_x), nitrous oxide (N_2O), nitric oxide (NO) and methane are partly responsible for the unusual changes in climatic conditions [9]. About 70% of total GHG emissions are attributable to fossil fuel burning from the industrial sectors. On a similar note, South Africa was announced as the 14th chief emitter of GHGs. In 2016, the global annual emission report indicated CO_2 as the key player in global emissions, contributing 74.4% of total emissions. Other GHGs, methane, nitrous oxide and fluorinated compounds, accounted for 17.3%, 6.2% and 2.1%, respectively [10]. The continual increase in anthropogenic emissions of GHGs, as it is currently being experienced, is dynamically modifying the climatic conditions, both at the international and local levels. Today, climate change is becoming a global issue owing to its increasingly multifaceted and interconnected adverse effects. The effects of climate change on meteorological processes and environmental events are well documented. Extreme weather events such as water scarcity, severe drought, high precipitation and tropical cyclones result in increased instability in food production in many localities. These effects become progressively intense, prompting injuries, severe infectious diseases and mortalities [12].

Key Environmental Challenges Facing the Brick Industry A discussion on the green initiatives in Indian brick kilns requires understanding the brick industry's key environmental challenges. While discussing the environmental challenges, it would be useful to distinguish between low output brick producing units with less than 10 lakh bricks per year located in rural areas and to produce bricks for rural consumption on one hand and medium to large output units manufacturing ten lakhs to 1 crore bricks per year on the other. The latter are often found in clusters located around urban centres. In terms of the negative environmental impact, it is these clusters that are seen to pose a more significant challenge [13]. Environmental challenges facing the Indian brick industry can be broadly classified into three categories:

3.1 Air Pollution and Health Air pollution

The presence of substances (gases, particulates, and biological molecules) in the atmosphere harms the health of humans and other living beings or causes damage to the climate or materials4. There are several sources of air pollution in brick kiln operations. The combustion or burning of fuel, mainly coal and biomass, for brick firing produces air pollution. Pollutants consist of particulate matter of various particle sizes (PM2.5, PM10) produced due to incomplete combustion (thus giving a black colour to the smoke) along with gaseous pollutants such as Sulphur dioxide (SO_2), carbon monoxide (CO) and hydrogen fluoride (HF).

Combustion-related pollution is often called stack emission. In addition to stack emission, dust pollution is caused by a large amount of clay, ash and powdered fuel trapped in the air at the brick-making site and by the movement of machines such as trucks and tractor trolleys on the unpaved and dusty roads around a brick kiln. Air pollution is a major environmental health problem, and India is one of the most polluted countries in the world in terms of the concentration of particulate matter (PM2.5, PM10) in the air. Particulates are the deadliest form of air pollutants due to their ability to enter the lungs and bloodstream. PM10 are inhalable coarse particles between 2.5 micrometres (μm) and 10μm, and PM2.5 are fine particles with a diameter of 2.5μm or less. The latter are more harmful as they can easily penetrate the bloodstream via the lungs. A recent report shows 21 of the world's 30 cities with the worst air pollution are in India.

Most of those Indian cities are located in the Indo-Gangetic plain. Vehicles, industries, thermal power plants, construction, biomass burning, diesel gen-sets and commercial and domestic fuel use are identified as significant sources of air pollution. Many brick kilns are located in clusters around major urban areas in India, and these clusters contribute to air pollution. A recent study6 has identified the presence of around 1,500 brick kilns surrounding Delhi, which were found to contribute to air pollution in the region.

3.2 Emission of CO2 and Global Warming

The greenhouse effect is warming the earth's surface and the troposphere, the lowest layer of the atmosphere, caused by carbon dioxide, water vapour, methane, and other gases in the air. This global warming is leading to changes in the earth's climate, impacting rainfall patterns, agriculture, forests, biodiversity and human health. The main reason for global warming is the increasing concentration of carbon dioxide in the earth's atmosphere due to burning fossil fuels such as coal and petroleum. Fossil fuels contain carbon, which on combustion, produces carbon dioxide. Coal is the primary fuel for brick kilns in India, and the brick industry in India is estimated to contribute between 6.6 crore tonnes and 8.4 crore tonnes of CO_2 emissions per year, eight about 3 percent of the total CO_2 emissions of the country

3.3 Removal of Clay from Agricultural Fields and its Potential Impact on Agriculture Clay

It is generated from the decomposition of rocks and is one of the most abundant natural mineral materials on earth. It is the primary raw material for manufacturing bricks. The clay used for brick manufacturing must have specific properties, such as plasticity, which permits it to be moulded when mixed with water. It should also have the ability to retain its shape while drying and should vitrify so that it can be appropriately fired. Brick-making clays are either surface clays or shales. While surface clays are found near the earth's surface, shales are clays that have been subjected to high pressures under the earth's surface and must be mined. In India, brick production depends on surface clays such as clay obtained from agricultural fields and washed into water bodies and recovered by desilting or river deltas. India's annual production of 25,000 crore solid bricks requires approximately 75 crore tonnes9 of brick earth or clay, with most coming from agricultural fields. There are concerns about a loss in agricultural productivity and land degradation due to unplanned clay mining.

4. Green Technology Options and Potential

A list of green technology options has been developed based on discussions and interactions throughout the study and in the recent past with various stakeholders, including brickmakers, government officials, industry experts and CSOs. These options are discussed in the following paragraphs.

4.1 Converting FCBTKs to Zigzag Kilns and Other Cleaner Brick Kiln Technologies

Zigzag kilns in the form of High Draught kilns were introduced to India around 50 years ago by the Central Building Research Institute (CBRI) as an alternative to the FCBTKs. The main difference between the two kilns is in the brick setting and the airflow. In a zigzag kiln, the bricks for firing are set or loaded so that the air in the kiln follows a zigzag path, while in a BTK, the air follows a straight-line path. The introduction of a fan in the original design of the High Draught kiln also provided more air for combustion. Coal is crushed or powdered and is fed in small quantities. These changes aid efficient heat transfer and better fuel burning. A zigzag kiln uses between 20 and 25 percent less fuel, resulting in up to 50 percent reduction in particulate matter emission. In addition, the yield of good-quality bricks is improved. The initial investment for constructing a new, high-quality zigzag kiln is estimated to be around ₹40 lakhs. Zigzag kiln technology spread slowly for several decades. It was further modified and simplified by innovative brickmakers. The requirement for a fan and hence the need for a diesel engine or electricity was a significant hindrance in the initial years. Later, a version that worked on natural drafts from chimneys was developed.

However, only around 1,750 kilns were constructed in the first 40 years, with most in West Bengal. Since then, the technology has seen rapid adoption, particularly in Punjab, Haryana, Western Uttar Pradesh near the NCR, Bihar and some districts of Eastern Uttar Pradesh. During this period, the technology was introduced in Tripura, Rajasthan, Maharashtra and Odisha. It is estimated that around 7,000 kilns have been converted or constructed during the last five years, mainly driven by SPCB mandates. The cost of converting an existing FCBTK to a zigzag kiln can range from ₹10 lakh to ₹30 lakh. Among brickmakers, there is agreement on the many benefits of zigzag kilns. The conversion of FCBTK to zigzag kilns benefits entrepreneurs as higher profits can accrue due to savings on fuel and as additional revenue due to a better yield of good quality bricks. A survey carried out among brickmakers in Patna after the completion of one season of brick-making after the enforcement of the zigzag kiln mandate found that around 65 percent of brickmakers could realise the technology's benefits.

In contrast, around 35 per cent faced problems with the new technology. This survey and interactions with brickmakers indicate that for a successful conversion, it is essential to have access to standard kiln designs, trained construction masons and supervisors and workers for kiln operation. The zigzag kiln is one of those cases where there is a win-win situation for both the brickmakers and the environment. However, the natural dissemination of the technology takes considerable time. For example, zigzag kiln technology was introduced in Tripura in 2 kilns under the EU-supported program in 2017-18. As per the latest information, till November 2020, around seven kilns out of around 300 kilns have adopted the technology.

Thus, the technology adoption rate has remained slow despite most converted zigzag kilns reporting good results. There are potentially around 40,000 to 50,000 existing FCBTKs yet to be converted to the zigzag kiln. The most significant number of unconverted kilns is in Uttar Pradesh. Taking a conservative estimate of savings of 100-150 tons of coal per year per kiln, if all the remaining kilns are converted, that will result in savings of around 5 to 7.5 million tons of coal every year. It is expected that mandatory regulations by State Pollution Control Boards will force these conversions over the next five years or so. However, there is a strong case for coordinated awareness generation among brickmakers, making standard designs and trained human resources for construction and operations and providing financial access to smaller brickmakers to adopt the technology. Apart from the conversion to zigzag kiln technology, another option to reduce air pollution and improve brick quality is converting existing FCBTKs to Hoffmann kilns or Tunnel kilns. A tunnel kiln is a continuous moving ware kiln in which the clay products to be fired are passed on cars through a long horizontal tunnel. The firing of products occurs at the central part of the tunnel. The tunnel kiln is considered to be the most advanced brick-making technology. The main advantages of tunnel kiln technology lie in its ability to fire a wide variety of clay products, better control over the firing process and the high quality of the products. Typical construction costs of tunnel kilns range from ₹ five crores to ₹ ten crores. In India, there are only about ten operational brick-making tunnel kilns.

The Hoffman kiln is a continuously moving fire kiln in which the fire is always burning and moving forward through bricks stacked in a circular, elliptical or rectangular-shaped closed circuit with an arched roof. The firing movement is caused by the draught provided by a chimney or a fan. The typical construction cost of a Hoffmann kiln and its new variant, the Hybrid Hoffmann kiln, ranges from ₹1.5 crores to ₹ five crores. Hoffmann kilns have been primarily used in India to produce clay roofing tiles. More than 100 are estimated to be operational in Kerala, Karnataka and Balaghat in Madhya Pradesh. Both these options require significant capital investments. If these technologies are used only for firing standard solid bricks, the high costs will make it difficult for brick enterprises using these technologies to compete with zigzag kiln enterprises. The viability of these kilns improves if they are primarily used to produce value-added products such as hollow and perforated bricks and clay tiles.

4.1.1 Converting FCBTKs to Zig-zag Kiln Technology main features

Environmental Benefits:

• Reduction in coal consumption (20 percent to 25 percent) and associated CO2 emissions
• Reduction in emission of particulate matter (up to 50 percent)
• Reduction in wastage and improved quality

Investment Requirement • `10 lakhs to `40 lakhs per kiln

Status & Potential

• Adopted by around 10,000 kilns by 2020
• 40,000-50,000 FCBTKs yet to adopt; can result in savings of 50 lakh to 75 lakh tonnes of coal per year

Action Points

- Intense awareness campaign amongst brick enterprises
- Making available standard designs
- Skill training of kiln masons
- Skill training of supervisors and workers involved in brick setting and fuel feeding
- Financing arrangements for smaller kilns

4.2 Mixing Fly Ash, Other Industrial Wastes and Internal Fuel with Clay

In clay brick-making, the addition of fly ash and other industrial wastes, such as boiler ash, is widespread in central, western and parts of southern India. The mixing is part of clay mix preparation before brick moulding. The addition of fly ash and wastes in clay helps reduce the amount of clay required for brick-making. Moreover, fly ash, which contains some unburnt carbon, helps reduce brick-making fuel. The addition of fly ash in black cotton soil, found widely in central and western India, helps reduce soil plasticity and consequent breakages during drying and firing. In addition, to fly ash, internal fuel such as powdered coal, rice husk, bagasse and boiler ash is also added to the clay, which can help reduce kiln air pollution. It can also help in reducing brick density and therefore improve thermal insulation. Material mixing uses a mechanical mixer or pug mill, depending on the technology employed to do this work. The investment can range from a few lakhs to ₹20 lakhs. With multiple environmental benefits, there is an enormous potential for scaling up the mixing of fly ash, industrial wastes and internal fuel with clay, particularly in the Indo-Gangetic region, where the use of internal fuel can also help reduce air pollution. It is to be noted that the amount of fly ash, industrial waste and internal fuel which can be mixed with clay varies depending on the clay. For example, while mixing more significant quantities of fly ash in central and western India is possible, only smaller amounts of fly ash can be mixed in clays in northern and eastern India. An organised initiative is needed to map available industrial wastes and potential internal fuel and work out feasible mixes of clay, waste and internal fuel. Some improvements and modifications in mixing technologies and machinery may also be required depending on the type of waste and the production scale.

4.2.1 Mixing Fly Ash, Other Industrial Wastes and Internal Fuel with Clay features Environmental Benefits

- Utilisation of industrial and other wastes
- Reduction in clay consumption
- Reduction in fuel consumption
- Reduction in PM stack emissions
- Potential to produce porous bricks with better insulation

Investment Requirement • Up to `20 lakhs per kiln

Status and Potential • Common practice in parts of Central, Western & Southern India

- Potential to expand to around 60,000 FCBTKs or zigzag kilns in the Indo-Gangetic plains.

Action Points

- Testing clays
- Mapping the availability of waste and internal fuel
- Demonstrating viable mixes of clay, waste and internal fuels.
- Adapting mixing technology as per the requirements of the Indo-Gangetic plains
- Skill training of supervisors and workers involved in brick setting and fuel feeding
- Financing arrangements for smaller kilns

4.3 Use of Mechanical Coal Feeding System in Zigzag and Hoffmann Kilns

Coal or fuel feeding in existing FCBTK, zigzag and Hoffmann kilns is done manually by firefighters. They usually take coal in a spoon and feed it into feeding holes. At a time, coal is fed by one or two firefighters. Usually, coal feeding is not continuous, and coal is fed for around 10 minutes, followed by a non-feeding interval of 15-20 minutes, after which the coal/fuel feeding is repeated. It can be observed that the burning of accumulated fuel produces periodic higher concentrations of carbon dioxide and carbon monoxide. Concentration levels return to base values after the accumulated coal has burned. Similar patterns are expected for PM emissions. The results show that continuously feeding properly sized fuel in zigzag kilns will reduce both coal consumption and emissions by ensuring cleaner combustion. Various mechanised coal stoking systems or solid fuel burners can be employed. Solid fuel burners of particular types are shown in Figure 9. They include a fuel crushing and distribution unit that delivers solid fuel mixed with positive airflow, ensuring perfect and consistent firing. A trickle feeder to feed biomass fuel in a Hoffmann kiln firing clay tiles in Balaghat in Madhya Pradesh is shown in Figure 10. Using mechanical coal feeding systems will reduce the air pollution from brick kilns and improve working conditions for firefighters. Currently, the firefighters walk on the kiln surface to feed fuel and are exposed to excessive heat between 80o C and 120o C. Zigzag kilns and FCBTKs offer some specific challenges for feeder use as they do not have permanent roofs. A technical solution is needed for the placement and movement of the feeder system.

4.3.1 Use of Mechanical Coal Feeding System in Zig-zag and Hoffmann Kilns features Environmental Benefits

• Reduction in fuel consumption
• Reduction in emission of particulate matter in stack gases
• Improvement in the quality of bricks

Investment Requirement
• `10 lakh to `40 lakhs per kiln, depending on the type of system

Status and Potential
• Trickle feeder in use on Hoffmann kilns at Balaghat
• Designs available, yet to be tested on zigzag kilns
• Potential to expand to kilns located in NCR and other heavily polluted regions in the Indo-Gangetic plains.

Action Points
• Pilot testing
• Making available, affordable technology
• Training of owners and workers in operation

5. Conclusions

The assessment of the process of brick production indicated that this process is very energy intensive. Most environmental emissions are attributed to energy use directly at the site, with coal combustion in kilns and diesel combustion in transportation. CO2 emissions constitute the most significant percentage of all releases to the atmosphere. The most likely offending pollutants of the traditional kiln are particulates and Sulphur oxides (SOx), both of which can be minimised by the complete combustion of coal, which will increase the coal efficiency and reduces the problem of emissions.

References

1. Littlejohn, A. Who Invented Bricks, Mortar, and Co ncrete? Owlcation, 5 March 2019.
2. Maithel, S.; Heierli, U. Brick by Brick: The Hercule an Task of Cleaning up the Asian Industry, 1st ed.; Osborn, P., Ed.; Swiss Agency for Development an d Cooperation (SDC), Natural Resource and Envir onmental Division: Berne, Switzerland, 2008; pp. 1–132.
3. Aurangzeb, K.; Carsten, L. Bricks and Urbanism in the Indus valley rise and decline. Am. J. Arch. 2013 , vol.1, pp.1–13.
4. Mason, T.O.; Lee, J.A. Brick and tile (building mate rial). Encyclopedia Britannica, 24 May 2019.
5. Emery, V.L. Mud-brick architecture. UCLA Encycl. Egyptology. vol.1, pp.1–14, 2019.
6. Jackson, M. The building blocks: A brief history of brick. The Journal of the American. Institute of Ar chitects Magazine, 1 March 2018.
7. Swiss Contact and Clay Brick Association of South Africa. SADC Countries-Clay Brick Production Sur vey; Swiss Contact Report; Swiss Contact and Clay Brick Association of South Africa: Pretoria, South Africa, 2017; pp. 1–36. Available online: www.swi sscontact.org (accessed on 20 November 2020).
8. Rice, G.A.; Vosloo, P.T. A life cycle assessment of th e cradle-to-gate phases of clay brick production in South Africa. Eco-Archit. V Harmon. Archit. Nat. 2 014, pp.142-474.
9. Shakir, A.; Mohammed, A.A. Manufacturing of bric ks in the past, present and future: A state of the Ar t Review. Int. J. Adv. Appl. Sci. IJAAS 2013, vol.2, p p.145–156.
10. Lalchandani, D.; Maithel, S. Towards Cleaner Brick Kilns in India A win-win approach based on Zigza g firing technology, Greentech Knowledge Solutio ns Pvt. Ltd., A Shakti Sustainable Energy Foundati on Supported Initiative; ADCS (Academic and Dev elopment Communication Services): Chennai, Indi a, 2013; pp. 1–21.
11. Sumathi A., Sarvana k., "Compressive Strength of Fly Ash Brick with Addition of Lime, Gypsum and Quarry Dust", International Journal of ChemTech Research, ISSN: 0974-4290, Vol.7, No.01, 2014-15 , pp.28- 36.
12. Prasad H. N., Prasad H.G., Hamsagar C., Gowda D., Lobo N.M., Gowda S.P., "An approach for an altern ative solution in brick Manufacturing", Internatio nal Journal of Science, Environment and Technolo gy, ISSN 2278-3687, Vol. 3, No 3, 2014, pp.1105-1 114.
13. Ramachandra TV, Jain R, Krishnadas G. Hotspots o f solar potential in India. Renewable and Sustaina ble Energy Reviews, 2011, 15(6), pp.3178–3186.