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Environmental Life Cycle Assessment of Traditional Bricks in Western Maharashtra, India

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Abstract

Bricks are one of the major materials used for the construction of buildings. With the booming infrastructure in India; 140 billion bricks were produced in 2001and 250 billion bricks in 2012. The production of bricks is estimated to be growing at a rate of 4% per year. India is the second largest producer of fired clay bricks with more than hundred thousand brick kilns in operation. Brick production is known to have diffused and seasonal environmental impact along with the social and economic impact. A life cycle assessment (LCA) study, to identify and quantify the environmental performance of the brick as a product, is carried out for the traditional brick kilns in and around the Sangli - Karad area of western Maharashtra, India. The LCA software, SIMAPRO 7.3.3, has been used to carry out the LCA impact studies. The LCA methodology adopted in the study has a scope from ''cradle to gate'', including the raw material acquisition and transportation along with brick production. Energy use and emissions are quantified and the potential environmental burdens such as the GHG emissions, resource depletion, and loss of biodiversity, are assessed.

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Keywords: Clay bricks; LCA; Western Maharashtra; Brick kiln

1. Background

In India, the history of making bricks is almost 5000 years old. The Indus valley civilization was discovered by the archaeologists with the help of old bricks found during the construction of railway track from Karachi to Punjab in mid 19th century. Fired clay bricks being one of the most important building materials, India is the second largest

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producer of bricks, accounting for over 10% of the global production. It is estimated that India has more than 100,000 brick kilns producing about 250 billion bricks annually, employing about 15 million workers and consuming about 35 million tonnes of coal annually [1]. The brick industry is growing as the demand for bricks is increasing in the towns and villages due to the fast economic growth, urbanization and prosperity. It is alarming to note that 300 mm depth of fertile top soil in India will be consumed for burnt clay brick production in about 60 years [2]. Usually, brick kilns are situated in rural and/or periphery of urban areas in the country. India's brick sector is characterized by traditional firing technologies; high dependency on human and animal labour and low mechanization rate; dominance of small-scale brick kilns with limited financial, technical and managerial capacity and limited alternatives to raw materials such as clay and coal [3].

Green bricks are composed of 80-85% clay and remaining organic material along with 10-12% of moisture content. Mining of clay and extraction of other related raw materials is very labour-intensive as well as environmentally degrading. The organic material such as bagasse and rice husk is used as a binding material in green bricks and used as fuel for internal combustion of green brick in kiln. A large part of the production cost is spent on human labour (craftsmanship) rather than material or energy use.

A number of studies have been carried out which compare various brick kiln technologies in terms of energy usage, efficiency of kiln and GHG emissions. Amongst them, are the works carried out in Vietnam [4], in India[5, 6],and in European countries [7], which showcased the use of various renewable and alternative fuels in the clay brick industry.

Various types of brick kilns and their traditional practices were studied for Bangladesh [8], in India [1], and for other Asian countries [9]. As per the researchers, brick manufacturing is a cottage industry and employs traditional kilns, which are energy inefficient and polluting. There is a need to employ technologies such as the Hoffman Kiln and the Vertical Shaft Brick Kiln (VSBK), which reduce GHG emissions by 42 and 29 % respectively, compared to the existing Bull Trench Kiln (BTK) technology [1].

Life cycle assessment studies have been carried out for Greece [10] and for USA [11] to know the impact of brick production on environment in all phases of raw material acquisition, industrial production, packaging and transportation. Energy use and emissions were quantified and the potential environmental effects were assessed. As per these studies, the main energy inputs to the production system were electricity, diesel and solid fuel (Pet-Coke). The environmental burdens that arise from the operation of a brick industry were mainly due to air emissions derived from fossil fuel utilization. Another study focused on the role of labour efficiency in promoting energy efficiency and economic performance with reference to small scale brick enterprises (Intermittent Downdraught Kiln type) cluster in Malur, Karnataka State, India [6]. The study concludes that more the labour efficiency, less is the energy cost.

Traditional brick clamps used in Western Maharashtra region have an advantage of lower capital cost, access to the traditional knowledge, flexibility in locating where the raw material (soil) is available, and least dependency on mechanization. Thus, the traditional brick clamps are expected to be around for years to come and at the same scale of operations even though other technologies are being promoted. Hence, it is all the more necessary to have these traditional kilns reduce their environmental impacts. Though several studies has been done on efficiency of coal combustion, types of kilns (i.e. VSBK, BTK, Tunnel kiln and mechanized brick production plant) and the related environmental, socio-economical issues; no such study has been done for the traditional brick clamp in India. This study attempts to quantify the environmental impacts of bricks by cradle to gate approach through a life cycle assessment (LCA) of every stage of the brick production in traditional clamp kilns in Western Maharashtra.

2. Research methodology

2.1. Study Area

The western part of Maharashtra in India includes districts of Pune, Solapur, Satara, Sangli and Kolhapur. Perennial rivers such as Krishna, Warana, Koyana and Panchganga flow through the western Maharashtra region and bring good alluvial soil along with the water. The deposited soil along the banks of these rivers is very useful for agriculture as well as a large amount is excavated to produce bricks. Alluvial soil needs less amount of coal for burning. The bricks from western Maharashtra are well known for good quality.

The study has been carried out on 16 traditional brick kilns located in Sangli and Satara district; of which 12 kilns are from rural area of Palus block in Sangli and 4 are from urban area of Karad in Satara district. The villages of Bhilawadi and Ankalkhop from Palus block in Sangli district are situated on the banks of Krishna River. The yearly production of bricks in Bhilawadi is approximately 4.5 million and that in for Ankalkhop area is about 8.0 million. The average production rate of bricks in Bhilawadi is 0.6-0.8 million bricks per year per brick kiln and that in Ankalkhop area is 1.5-1.8 million bricks per year per brick kiln. The Karad block from Satara district has approximately 300 kilns operating each season with 50% in urban area. The average production rate of bricks in Karad block is 0.6-1.2 million bricks per year per brick kiln and the total annual production is approximately 270 million bricks.

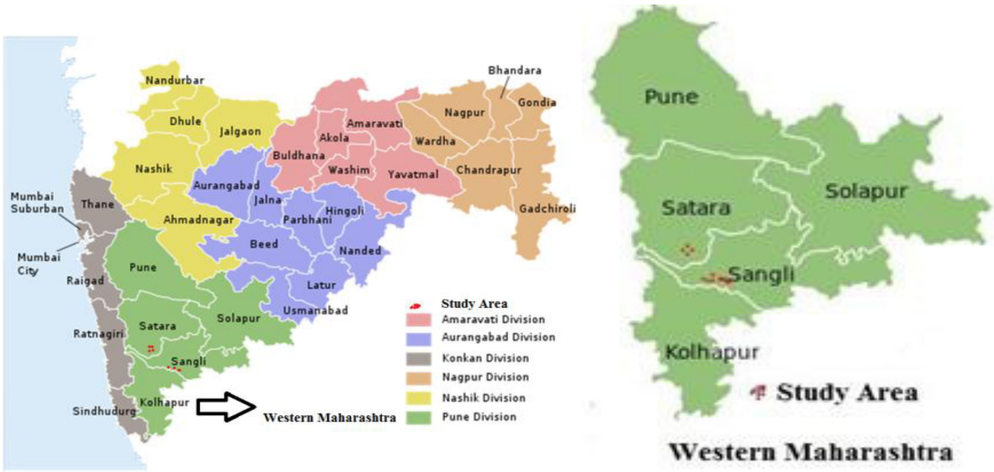

Fig. 1. Study area in Western Maharashtra, India

LCA study of traditional brick was initiated with data collection of qualitative and quantitative parameters about raw material, type and efficiency of fuel used in the brick kiln. The data on the energy and material consumption in the kiln processes, heat lost and gaseous emissions, was collected from visits to 16 brick kiln sites in western Maharashtra as well as through publications and is summarized in Table 1. The development of the LCA model included the establishment of an inventory database containing quantitative and qualitative information about energy use and airborne emissions.

Table 1. Data collection sources

Sr. No.	Process	Source of data for inventory	
		From Study area	From Secondary Data
1	Raw material collection		
	Soil	Quantity in brass/1000 bricks, Source- Krishna River basin	Properties of soil [13]
	Coal, Coal Powder	Quantity in ton /1000 bricks, source- Quarries from Chandrapur	Emissions and fuel efficiency [4,14,16,22] Calorific value [11]
	Bagasse	Quantity in ton /1000 bricks, source- Sugar factory, Sangli	
	Foundry Sand	Quantity in brass/1000 bricks, Source- Foundry, MIDC Sangli	
2	Mixing process- dry and wet	Mix proportion, water content	Methods, labour work efficiency [18]
3	Moulding process	Methods	Various methods used [8,12,16,18]
4	Drying	Solar drying space available	Solar energy [16]
5	Burning process in kiln and emissions to air, water and soil.	Kiln methods, use of fuel	Emissions [1,4,14,15,19,20,21]
6	Ready to transport	Methods of transport	Emissions from transport [4,14,17]

Note- 1 brass = volumetric unit equivalent to 10 ft ×10 ft × 1 ft

2.2. The traditional brick kiln technology

For brick making, various naturally occurring material are used as raw materials including soil, coal and coal powder and waste from industries such as bagasse, rice husk and foundry sand are used. While clays vary considerably in physical properties, colour, hardness, and mineralogical content; they do, have a property in common, namely the ability to be crushed and mixed with water to form a plastic material which can be moulded into various shapes, and fired to a high temperature, during which process it attains a hard, weather resistant characteristic [12,13]. Bagasse is the low cost material (by product of sugar factory), fibrous in nature and acts as a binding material in green brick and helps in internal burning of bricks to achieve required compressive strength of burnt clay brick. Coal used for firing of bricks is of low quality and average gross calorific value of coal as 18.8 MJ/kg (4500 kcal/kg). Waste foundry sand is clean, uniformly sized, high-quality silica sand that is bounded to form moulds for ferrous (iron and steel) and non-ferrous (copper, aluminum, brass) metals.

In the study area, the raw material for brick production is sourced from different areas. Soil is taken from the banks of Koyna and Krishna River and allied streams which also are the source of water. Loose bagasse is sourced from sugar factories in a radius of 50 km from kiln site. Coal, used as the primary fuel in the kiln, and the coal powder used as the internal fuel in the green bricks are brought from the quarries of Chandrapur and Wani in Maharashtra, about 500 km away from kiln sites. The raw materials are mixed in the ratio, soil: Bagasse: Coal Powder (3680 kg: 140 kg: 120 kg) using water about 600 to 800 litre into a thick paste, mostly manually. The green bricks are manufactured using hand moulds by women, two bricks at a time. The green bricks are dried in an open area with the help of solar energy. Foundry sand is sprinkled and the bricks are levelled with a wooden plank. The foundry sand prevents the sticking of green brick to the mould and to the wooden planks. Bricks are dried for 4 days on the ground and then stacked in the staggered fashion and allowed to dry for another week. Base of brick kiln is prepared with two layers of burnt clay bricks. A single green brick layer is provided with gaps filled with coal, and then four layers of green bricks are placed over it. One more layer of green bricks with coal filled into gaps is arranged. In all, three sets of 12, 10, 6 layers of green bricks are placed over the base prepared and separated by 2.5 cm thick coal powder layer. The whole assembly is covered with burned bricks and the gap in between the burnt and green bricks is filled with ash from burnt coal from kiln site itself to minimize the heat loss from kiln.

The summary of data collected from study sites is given in Table 2. Data is collected with the help of questionnaire survey for brick kiln owners, onsite labourers, raw material suppliers, transporters/agents and people residing around the area of brick kiln. Data collected from study site shows that traditional kilns are labour intensive and dependent on great extent on migrant workers (75%). On each kiln site, approximately 50 labourers are working per day.

Table 2. Summary of data collection from site

	Sample Brick Kiln site in Western Maharashtra (BK)											
	BK1	BK2	BK3	BK4	BK5	BK6	BK7	BK8	BK9	BK10	BK11	BK12
Source of water	Stream	well	Stream	Stream	River	stream	River	River	River	River	River	River
Number of kilns on the site	4	5	4	4	3	5	4	5	3	5	4	2
Normal size of the kiln (in million)	0.25	0.15	0.08	0.15	0.07	0.15	0.25	0.3	0.05	0.3	0.2	0.05
No of *Garekari* (Moulders)	8	6	5	4	3	5	11	13	5	14	10	6
No of *Bhatkars* (Firemen)	1	1	1	1	1	1	1	1	1	1	1	1
No of Casual labours - Loaders / Unloaders	5	4	4	4	4	4	5	4	4	4	4	4
No. of migrated workers families	9	5	5	5	4	6	12	14	6	15	12	7
Approx. Yearly brick production (in hundred thousands) (Size 3x4x9)	14	8	9	8	3	11	20	25	4	21	18	6
Approx. Yearly brick production (in hundred thousands) (Size 6x4x9)	3	1	0.5	0	0	0	0	0	0	0	0	0
Land ownership	Own	own	own	Own	own	own	lease	lease	lease	lease	lease	lease
Details of the raw materials used for the green brick making												
Total Consumption in one year												
Soil (in brass)	1800	1000	1000	800	300	1100	2000	2500	400	2100	1800	600
Foundry Sand (in brass)	120	40	30	50	10	20	120	80	30	100	40	30
Bagasse (in tonnes)	210	130	140	90	50	140	210	130	140	90	70	140
Coal powder (in tonnes)	120	80	80	60	25	100	120	80	80	60	30	80
Consumption per 1000 bricks (in terms of 3x4x9)												
Soil (in brass)	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Foundry Sand (in brass)	0.06	0.04	0.03	0.06	0.03	0.02	0.06	0.08	0.03	0.13	0.13	0.03
Bagasse (in tonnes)	0.11	0.13	0.14	0.11	0.17	0.13	0.11	0.13	0.14	0.11	0.23	0.14
Coal (in tonnes)	0.04	0.035	0.04	0.03	0.02	0.03	0.04	0.035	0.04	0.03	0.02	0.04
Coal powder (in tonnes)	0.08	0.08	0.03	0.06	0.03	0.05	0.08	0.08	0.03	0.06	0.03	0.03

3. Life cycle assessment of traditional bricks

Life Cycle Assessment (LCA) is becoming an increasingly important methodology for assessing any product by understanding the production related impacts of materials, as well as the potential trade-offs among the various life cycle stages. The tool was used to quantify the inputs and outputs from the raw materials extraction and manufacturing of the bricks (i.e., cradle to gate) to assess the overall environmental impacts of traditional brick kilns in Western Maharashtra. The data input for LCA study by SIMAPRO 7.3.3, based on consumption per 1000 bricks of raw material, labour working and emissions from brick kiln by the summary of data collection from site.

The social as well as economical impact of brick kiln site has been assessed through the interaction with local public. The cradle to gate LCA was carried out by using SIMAPRO 7.3.3 software. The LCA was conducted using Eco-Indicator-99 impact assessment method. First, the embodied energy of the materials was calculated using a data library of Eco-invent unit process. The LCA is carried out with method of Eco-indicator 99 and normalization/ weighing set given in SIMAPRO 7.3.3. [23]

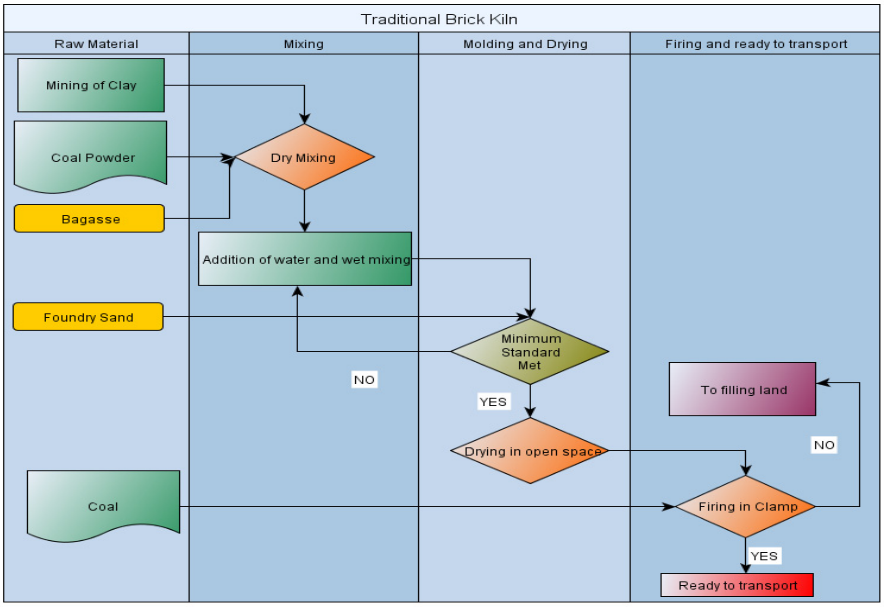

Fig. 2. System boundaries of LCA study

4. Result of LCA study

The Eco-indicator 99 method was used to study impact assessment categories as carcinogens, respirable organics, respirable inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification/ eutrophication, land use and minerals. Eco-indicator 99 method, individualist version is the method used to calculate environmental impact assessment along with Eco-invent 2.2 data library as unit processes with links to other processes, including uncertainty data given in SIMAPRO 7.3.3.

The emission from fossil fuel combustion has been estimated by the following IPCC (Inter Governmental Panel on Climate Change) guidelines [14, 15], where Total emissions = (Actual fuel consumption)*(emission factor)*(Fraction of carbon/ sulfur /nitrogen oxidized)*(Molecular weight ratio).

Coal available in Chandrapur quarries consists of more than 50 percent by weight and more than 70 percent by volume of carbonaceous material including moisture. The mixture of Bituminous and Sub-Bituminous coal is available in Chandrapur area. Mostly low grade coal is used as fuel in brick kiln. An emission factor given by IPCC for coal=0.55 (metric tonne (mt) of CO_2)/mt, for sulphur emission factor is 0.003 (mt of SO_2)/mt for coal, nitrogen emission 0.018(mt of NO_x)/mt for coal. The molecular weight ratio of carbon, sulphur and nitrogen emission is 3.66, 2 and 3.28, respectively.

The brick kiln emission and the derived emission factors are estimated by Secondary data. Emission of individual air pollutant varied significantly during a firing batch and between kilns. Average emission factors per 1,000 bricks were 6.35–12.3 kg of CO, 0.52–5.9 kg of SO_2 and 0.64–1.4 kg of particulate matter (PM). PM emission size distribution in the emitted gas was estimated from IPCC data. Impacts of different emission scenarios on the ambient air quality (SO2, PM, CO, PM dry deposition flux) were assessed.

The cradle to gate system of LCA study of traditional brick is focused on raw material (e.g. clay, coal, coal powder, Bagasse and foundry sand/ silt from river) and process of moulding and kiln burning of bricks. The burning of coal in kiln is emitting gases, SPM and RSPM particulate matter, also represents environmental impact, specifically in the carcinogens, respirable organics, respirable inorganics and climate change.

Eco Indicator 99(I) v 2.08/Europe EI 99 I/I/ Normalisation gives the values of various impact categories for brick as well as for various raw material used in making of brick.

Table 3. Normalization results

Impact category	Total *E-8	Bricks *E-5	Hard coal mix, at regional storage/UCTE U *E-08	Transport, combination truck, diesel powered/US *E-15	Bagasse *E-8	Disposal, building, brick, to final disposal/CH S *E-10
Carcinogens	4.65	0	3.78	112	0.862	0.0866
Resp. organics	0.413	0	0.316	8.99	0.00936	0.0329
Resp. inorganics	9180	9.08	87.1	1000	16.6	341
Climate change	445	0.363	71.9	2000	8.9	28.5
Radiation	0.00711	0	0.00414	0	0.00296	0.00092
Ozone layer	0.00284	0	0.00096	0.0000282	0.00185	0.00274
Ecotoxicity	0.0774	0	0.436	2.19	0.0334	0.035
Acidification/ Eutrophication	267	0.257	8.85	322	1.47	6.54
Land use	-180	-1.9	20.8	0	18.6	-3.4
Minerals	75.7	0	32.7	0	42.7	24.9

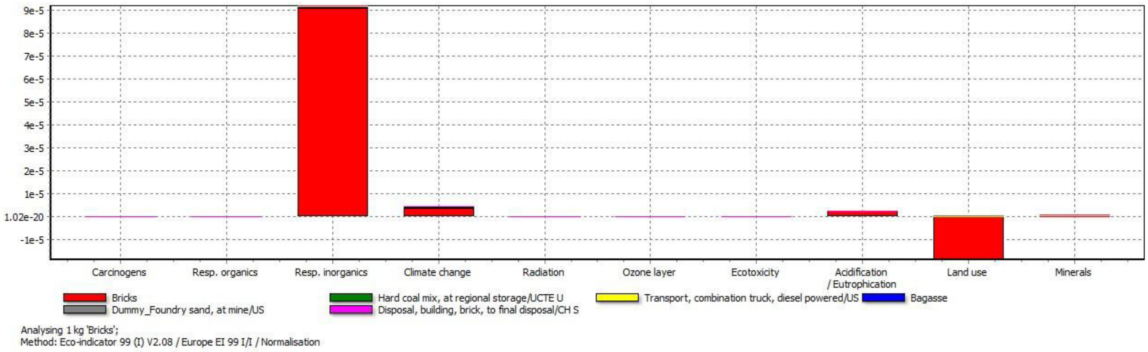

Fig. 3. Normalization results with respect to Impact category

The single score system of impact assessment gives the emissions by process wise. Fig. 4 shows that the emissions are maximum from brick kiln firing. The coal combustion process in kiln produces 0.050503 mpt resp. inorganics per brick.

The resp. inorganics are generated in large quantity because of incomplete combustion of coal in brick kiln. The respirable inorganics exceeds the limit as per given by 0.012 for VOC emission limits given by USEPA AP-42 Section 11.3 (1997).

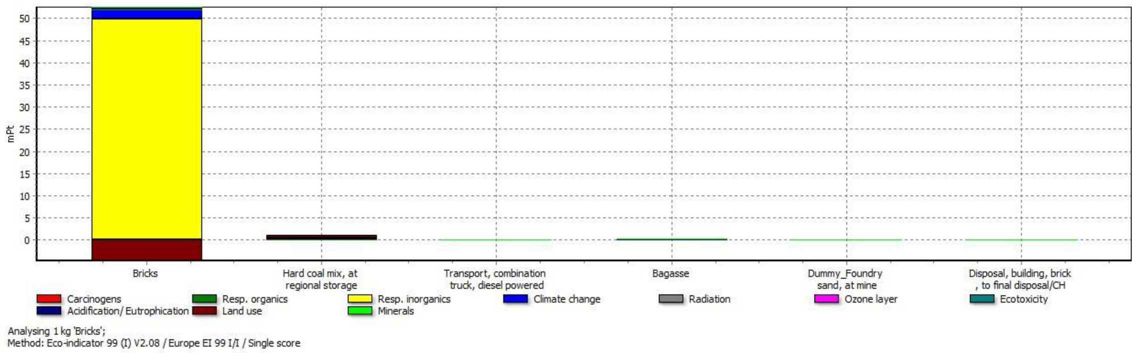

Fig. 4. Single score results with respect to process and raw material

Table 4. Single score results

Impact category	Unit	Total *E-5	Bricks	Hard coal mix, at regional storage/UCTE U *E-5	Transport, combination truck, diesel powered/US *E-10	Bagasse *E-5	Disposal, building, brick, to final disposal/CH S *E-7
Total	Pt	4923.9	0.047898	103.8	18	28.2	210
Carcinogens	Pt	2.56	0	2.08	0.616	0.474	47.6
Resp. organics	Pt	0.227	0	0.174	0.00492	0.0515	0.181
Resp. inorganics	Pt	5050.3	0.049914	47.9	5.52	9.14	188

Climate change	Pt	244.5	0.001999	39.6	11	4.89	15.7
Radiation	Pt	0.0391	0	0.0227	0	0.0163	0.00506
Ozone layer	Pt	0.0156	0	0.00528	0.00000155	0.0102	0.0151
Ecotoxicity	Pt	0.193	0	0.109	0.00547	0.0835	0.0875
Acidification/ Eutrophication	Pt	66.8	0.000642	2.21	0.804	0.367	1.63
Land use	Pt	-456	-0.00466	5.2	0	4.65	-0.86
Minerals	Pt	15.1	0	6.54	0	8.54	4.97

5. Conclusions

The assessment on the process of brick production indicated that this process is very energy intensive. Most of the emissions to the environment are attributed to the energy use, directly at the site with the combustion of coal in kiln and diesel combustion in transportation. The CO_2 emissions constitute the biggest percentage of all releases to the atmosphere. When it comes to the effect of the environmental impacts, acidification has the highest value. This is mainly due to the fact that at the manufacturing stage low-grade fuel with high sulfur content has been used. The combustion of this fuel produces large amounts of SO_2 and particulate matter. The use of an efficient method of burning fuel would reduce very much the environmental impact of the production process. The coal consumption in clamp in Asia is 32-71 Tons/100,000 bricks, for India it is 16-19 Tons/100,000 bricks [9] and study in western Maharashtra shows 12-15 Tons/100,000 bricks. The study shows that coal consumption efficiency depends upon type of soil, method of coal burning in kiln.

The study shows that traditional brick kiln is efficient in coal usage in western Maharashtra. However, there is a need to transform into a more environment friendly technology. Despite all the attention given to traditional brick kiln pollution, no serious effort to accurately quantify it has ever been made. The most likely offending pollutants of traditional kiln are particulates and sulphur oxides (SO_x), both of which can be minimized by complete combustion of coal that will increase the coal efficiency and reduces the problem of emissions.

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