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THE ENVIRONMENTAL IMPACT CAUSED BY THE CERAMIC INDUSTRIES AND ASSESSMENT METHODOLOGIES

Abstract: *The manufacturing processes of the ceramic tiles from the raw materials to finished product generate various environmental hazards to the earth and human being. The available literature on the environmental hazards caused by the ceramic industries and assessment methodologies are limited. In this paper, various environmental impacts, the severity of the impacts and various tools used for the assessment of the environmental impacts while manufacturing the ceramic tiles are presented. The details of the ceramic tiles manufacturing process were collected and compiled based on manufacturing process, environmental impacts and assessment methodologies. The results of the study were discussed based on the environmental impact caused by the ceramic industries and the effectiveness of various assessment methodologies. From the literature, it has been identified that manufacturing of the ceramic tiles produces its own amount of harmful and hazardous gases to the environment. It has been observed that an individual ceramic plant produces (15.89 kg CO2-eq) per square meter of the ceramic tiles, which lead to (1.14* $\times 10^{-5}$ *kg CFC 11-eq) ozone layer depletion. Besides, ultrafine and nanosized airborne particles are generated by the production units those particles affect the people. Therefore, it is identified that the ceramic industries provide significant environmental hazards. The literature presented in this paper can be considered significantly for the environmental effects and to have the current status of the environmental impact due to the ceramic industries.*

Keywords:*PerformanceCeramic Tiles, Firing Temperature, Ozone Layer,Environmental Impact, Assessment*

1. Introduction

Environmental pollution is the most significant problem throughout the world. As the world is witnessing the rapid urbanization and industrialization, the need for energy and waste discharges are in an increasing trend. The waste discharge in any form (liquid or gas) causes a severe health problem, greenhouse gas emissions, water pollution and acid rain. In order to cater to the needs of the growing population, various industries have been started and manufacturing different products. These industries procure raw materials, process them and produce the finished products

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Catalina Research (2007). While manufacturing the finished products, these industries also produce various by-products and the world is finding challenges to dispose of those wastes and it causes pollution to the environment. Pollutions are also produced by various industries such as cement industry, fertiliser industry, dye, iron and steel, pesticides, oil refineries, textiles, tanneries, thermal power plant and the ceramic industry Hanif et al. (2005).

The ceramic products are widely used as building material. The clean and good appearances are the special characters of the ceramic product. Hence, the ceramic products are accounted for more than 50 per cent in the building material Catalina Research (2007). The ceramic tiles production across the globe reached 13,056 million in 2016, which was 5.7 per cent higher than the previous year. The world consumers' demand was 12,783 million m^2 in 2016. Furthermore, it is having an average growth of 5 per cent. The world's largest producer, as well as consumer of the ceramic product, is China, which contributes 5.47 billion m^2 equivalents to 42.8 per cent of the world ceramic tiles production. India and Brazil are the next largest producers of ceramic products Bastianoni et al. (1999). Hence, the need for the ceramic products is increasing every year and to cater the need the industries around the world are producing the ceramic products rapidly. The production of the ceramic tiles involves various processes from mining to end product. During these processes also include the transportation of goods and it generates different types of pollutions, which affect the entire ecosystem when the ecosystem is affected, it may deface the world Petersen and Solberg, (2004); Rivela et al. (2007); Asif et al. (2007).

A number of studies have investigated the environmental impact due to the ceramic industry (Fonseca et al., 2016; Almeida et al., 2013; Jaakkola et al., 2011). These studies have analysed the impact due to specific parameters like sintering, smoke and CO2 emission. To study the impact of pollution due to the ceramic industry across the globe, various techniques are used such as Life Cycle Assessment (LCA) methodology (Tikul & Srichandr, 2010), Eco-indicator 95 (Tikul, 2014), Eco-indicator 99 (Tikul & Srichandr, 2010) and Best Available Technique (BAT) (Ibáñez-Forés et al., 2016). However, these studies have not addressed the comprehensive impact of all pollutants, which is caused by the ceramic industry. In addition, the available literature on the Environmental Impact Assessment confining to the ceramic tiles production is limited. Hence, the current work attempts to build on the existing literature by investigating the various types of pollutants, an effect of the pollutants and the methodologies used to assess the environmental impact caused by the ceramic industry are reviewed carefully and presented. The results of this study depict that there is a significant impact on the environment due to the ceramic industries.

2. The Ceramic Manufacturing Process

2.1. Manufacturing Process

DoIn the manufacturing of ceramicproducts, there are many processes involve as shown in Figure 1. The major processesof manufacturing the ceramic tiles are batching, mixing and grinding, forming, firing and glazing. After glazing, the ceramic products are checked for quality and packed (Georgilas and Tourassis, 2007; Framinan et al., 2014).

Batching: Weight batching and volume batching are the two different methods followed universally. The weight batching is often used for precise mixing and to produce good quality tiles. Before batching, batch calculations are done considering the physical and chemical properties of the raw materials (Georgilas & Tourassis, 2007).

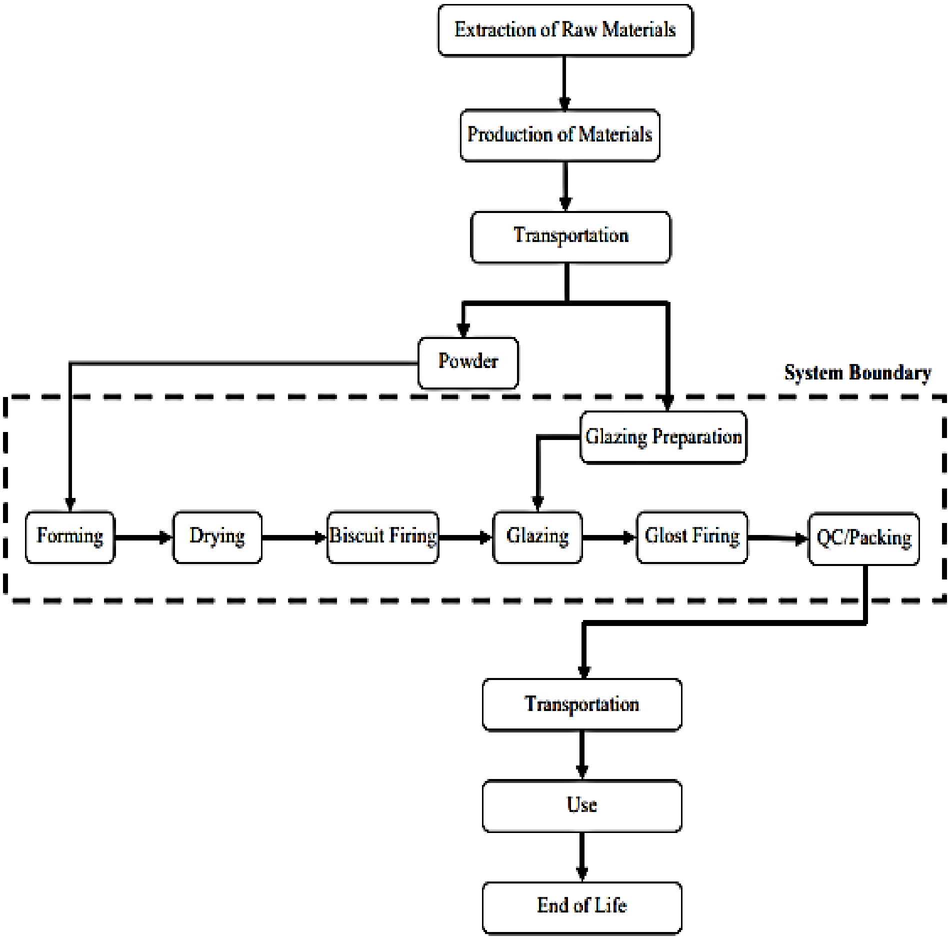

Figure. 1 Process of Manufacturing the Ceramic Tile (Tikul, 2014)

Mixing and Grinding: Once the proper batching is done all the raw materials are mixed and sent to grinding ball mill. In grinding operation, these raw materials are cracked down to further small particles for better forming process. In grinding process, sufficient moisture is maintained hence, it is also called as wet milling (Boussen et al., 2016).

Forming: The shape of tiles is formed by proper pressing by hydraulic pressure. In this process, free-flowing powder with low moisture content is allowed to flow from a hopper to forming die. In the die, the powder material is compressed using hydraulic pressure up to 2500 tons. As the pressure is applied the mixture is ejected from the bottom of the plunger as semi-solid tile (Tikul, 2014).

Drying: The relative humidity of the tiles is maintained throughout the drying process to avoid warping of tiles. The drying process takes a number of days at a slow rate to avoid shrinkage cracks (Tikul, 2014).

Firing: To give strength and to avoid porosity in tiles, it is heated very intensively in kilns. The most common kilns available for the manufacturing of the ceramic tiles are electricity, gas and wood (Sánchez de la Campa et al., 2010). After forming process, the biscuit tiles are heated up to 1200 degree Celsius in the kiln and this process is called biscuit firing. Generally, the biscuit firing process takes 2 to 3 days. In case of the wet milling, roller kilns are used, here the firing is around 60 minutes with the temperature from 1150-1200 degree Celsius. After biscuit firing, tiles are sent for glazing.

Glazing: It is the process of providing an impervious layer over the ceramic tiles. The mix for glazing is calculated and raw materials are batched. The batched raw materials are mixed in a dry or wet mill. The milled glazing materials are applied over the glost fired tiles, and it is fired again at 2050 degree Celsius for one hour in graphite furnace at 1 bar pressure Feilden et al. (2016). After firing, the product has come out with good texture and smooth finish.

2.2. Production Plant

In general, there are two types of ceramic tiles production units, which are medium and small plants. In this, the raw material source of the medium plant is prepared in the plant itself, but in the case of small plant unit, the raw material source is purchased. Then, the small plant units give more impacts to the environment than the medium plant units (Petersen & Solberg, 2004).

Medium Plant: The ceramic tiles are prepared with the feature that the essential raw materials follow natural plant, may prepare over mixes soil powder on-site, purchasing raw materials from its production sources that it then crushes and sends to the spray dryer where they are converted into soil powder (Petersen & Solberg, 2004). The ceramic tile gets its shape from the soil powder then it is conveyed to the dryer for humidity reduction by using a hydraulic machine. This process includes tunnel kilns, glazing kilns where thermal energy can be obtained. The thermal energy is obtained from Liquid Propane Gas. Then, the temperature resistance will be maintained internally around 100 degree Celsius and it is maintained in the drying kiln around 28 hours (h), during this period the humidity is reduced to less than 1% percent. After that, the process has passed on to the biscuit kiln where the ceramic tiles are fired about 38 hours at a temperature of 1120ºC (Jacoby & Pelisser, 2015). By this, the tiles get dehydrates and enhance the ability in absorbing glazing. Subsequently, the process steps into glazing, a glaze is glass material designed to liquefy onto the outside the tile during firing, and which then remains to the tile surface during cooling (Petersen & Solberg, 2004; Jacoby & Pelisser, 2015).

Feldspar, colour stain, zirconium, certain chemicals and frit are mixed in the ball mill in the specified proportions, these materials are vital for glazing. The glazed tiles are fired at 990ºC for approximately 29 hours in a kiln (Petersen & Solberg, 2004). Based on the quality and size, the tiles are separated after the firing process. The ceramic tiles are transferred to glazing conveyor to facilitate for base glazing after biscuit firing. This process prevents from pinholes, which develop on the surface. Next, the tiles are moved to a second glazing facility. This process provides a thicker glaze, and then to a glazing kiln. The ceramic tiles are designated as Grade A or Grade B based on its quality and parcelled in 1 m^2 paper boxes for delivery to the sellers. The balance tiles are taken as the rejected products (Jacoby & Pelisser, 2015).

Small Plant: In a small plant, due to size restrictions and manufacturing cost, the small plant prepares the soil powder. Tiles are conveyed directly to the biscuit kiln and fired without glazing at a temperature ranging from 750 to 800ºC (Petersen & Solberg, 2004) after forming the soil powder using a hydraulic machine. Tunnel kiln is used for this technique. In glazing, the firing temperature of 1200o C produces the real colour and finished tile is inspected for quality standards and packed (Jacoby & Pelisser, 2015).

3. The Environmental Impact of Manufacturing Ceramic Tiles

The major environmental impact of the ceramic tiles is air pollution, which leads to several impacts on earth like, ozone layer depletion, global warming, acidification as well as eutrophication. It also affects the livelihood of human beings directly when they are exposed to the environment filled with Nano and Ultrafine particles produced by manufacturing the ceramic tiles. Other than the major environmental impact, energy consumption also provides a significant impact on the environment that should be noted (Su et al., 2011; Kosugi, 2009). In the manufacturing process of the ceramic tiles, there are several stages from cradle to gate. Each of the stages consumes a considerable amount of energy and the by-products of that energy need to be considered as an environmental impact (OSMEP, 2018).

3.1. Medium and Small Industries

The environmental impacts are compared between small and medium tiles production plants. The emission of CO_2 is the primary pollutant while manufacturing the tiles (Tikul, 2014; Jacoby & Pelisser, 2015). To study the impact on the environment, Eco-indicator 95 method is used. Table 1 shows the environmental impact of medium and small plants.

Table 1. Comparison of the Environmental Impact (Tikul, 2014)

Impact Category	Unit	Medium Plant	Small Plant
Global warming	kg CO_2	22.81	15.89
Ozone depletion	kg CFC11	2.38×10^{-7}	1.14×10^{-5}
Acidification	kg SO_2	0.021	0.21
Eutrophication	kg NO_3	0.021	0.34

From Table 1, it is clearly understood that Ozone layer depletion is about (1.14×10^{-5}kg CFC11-eq), which is produced by small plants.It is greater than medium plants, which contribute (2.38×10^{-7}kgCFC11-eq) and it is resulted in an enormous level of acidification (0.21 kg SO_2-eq) (Tikul, 2014). While comparing eutrophication effect due to medium and small plant, it is observed that small plant produces more impact (0.34 kg NO_3-eq) than the medium plants (0.021kgNO_3-eq) (Tikul, 2014).

Production process also includes consumption of energy, which is also an impact. The various energy consumption levels by medium (M) and small(S) plants are presented in Table 2. From Table 2, it was observed that small plant consumes twice the amount of energy (253.72 MJ), which includes the process of glazing, glazing preparation, forming, drying, biscuit firing, glost firing and packaging (Tikul, 2014).

It is noted that glost firing accounts the major energy consumption, in which small plant consumes 79.77 percentage of the total energy whereas medium plant consumes 35.41 percentage (Tikul, 2014). The next major energy consumption is for biscuit firing. In this process, small industries consume 19.99 percentage and medium industries consume 30.13 percentage of the total energy (Tikul, 2014). The reason for the highest energy consumption by a small plant is due to the quality of kiln and the nature of raw materials. The consumption of higher energy indirectly contributes to environmental pollution.

Table 2. Energy Consumption per m^2 tile Produced (Tikul, 2014)

Unit Process	Electric energy (kWh)		Fuel (l)		Thermal Energy LPG (l)		Total (M)		Total %	
	M	S	M	S	M	S	M	S	M	S
Glazing preparation	0.19	.020	0.66	-	-		25.91	0.17	19.42	0.07
Forming	0.35	0.040	-	-	-		3.17	0.33	2.38	0.13
Drying	-	-	-	-	-		0.00	0.00	0.00	-
Biscuit firing	0.21	0.002	-	-	0.83	1.09	40.20	50.73	30.13	19.99
Glazing	0.09	0.010		-	-		0.79	0.11	0.59	0.04
Glost firing	0.48	0.040	-	-	0.93	4.36	47.25	202.38	35.41	79.77
Packaging	-	-	0.44	-	-		16.10	0.00	12.07	0.00
Total							133.42	235.72	100.00	100.00

3.2. The Environmental Impact due to Sintering activity

In the sintering process, powders are used to coat the ceramic tiles by atomic diffusion driven by capillary forces Zapata et al. (2013). Generally, sintering of the ceramic tiles is performed at a high temperature up to 2250 to 2350 degree Celsius (Ma et al., 2016). To reduce the sintering temperature and sintering time, many theories are developed like liquid phase sintering, pressure assisted sintering, microwave sintering, field assisted sintering, flash sintering (Cologna et al., 2010) and cold sintering (Guo J. et al., 2016; Guo H. et al., 2016).

The emission of Nano particle and Ultrafine particles in the surrounding environment may cause lung problems to the people due to the sintering process (Fonseca et al., 2016). Table 3 shows the sintering activity and pollution caused by Red Clay tiles # 1-3 and Porcelain tiles #4-6.

Table 3. Sintering Activity (Fonseca et al., 2016)

Sintering activity	$N_{8\ h\text{-}TWA}$ (cm^{-3})	$NRV_{8\ h\text{-}TWA}$ (cm^{-3}) (SER,2012)	$N_{8\ h\text{-}TWA}$ / $NRV_{8\ h\text{-}TWA}$	$PM_{1\ 8\ h\text{-}TWA}$ (μg m^{-3})	$PM_{2.5\ 8\ h\text{-}TWA}$ (μg m^{-3})	$PM_{10\ 8\ h\text{-}TWA}$ (μg m^{-3})	$TLV_{8\ h\text{-}TWA}$ (μg m^{-3}) ACGIH (2013)	$PM_{10\ 8\ h\text{-}TWA}$/ $TLV_{8\ h\text{-}TWA}$
#1	3.7 x 10^5	4.0 x 10^4	9	<0.1	1.0	7.7	3.0 x 10^3	3 x 10^{-3}
#2	1.5 x 10^5		4	1.0	2.3	10.5		4 x 10^{-3}
#3	2.0 x 10^5		5	0.2	0.9	4.5		2 x 10^{-3}
#4	1.4 x 10^5		3	3.9	14.4	60.0		2 x 10^{-2}
#5	2.6 x 10^5		7	1.2	3.3	22.6		8 x 10^{-3}
#6	5.3 x 10^5		13	1.0	3.1	21.5		7 x 10^{-3}

While manufacturing the ceramic tiles, electrical energy is widely used for firing and laser tile sintering, the firing produces large Ultrafine particles. To study the impact of pollution, Transmission Electron Microscope/Energy Dispersive X-Ray (TEM/EDX) analysis and High Efficiency Particulate Air (HEPA) filtration system are used (Catalina Research, 2007). The report shows that during thermal treatment the Nano-particle <30nm in diameter is being formed (Hanif et al., 2005). TEM/EDX analyses show some of the ceramic content, some mineral phases and some metal oxide nanoparticles of Zn, Cr, Al and Fe have also been found (Casasola et al., 2012; Jacobs, 1954; Lahoz et al., 2011; Minguillon et al., 2009). Besides that, during sintering process ultrafine and Nano-sized airborne particles are produced and released into workplace in air during sintering process is in the range of 1.4 × 105 cm-3 and 5.3 × 105 cm-3 on a statistically Time-weighted Average (TWA), which exceeds the NRV value (Fonseca et al.,2016; Van Broekhuizen et al.,2012), that affects the respiratory system. This results in the risk of occupation when the workers are exposed to Ultrafine and Nanoparticle during the tile sintering process.

3.3. Emission of Hazardous Materials

In the manufacturing process, the ceramic tile emits various hazardous materials like chemicals, gases and wastes that directly affect the environmentand indirectly affect the livelihood of human beings (Gahm et al., 2016; Gabaldón-Estevan et al., 2016). However, it also affects human health directly when those hazardous materials are in direct contact with human and it is known as human toxicity Ahmad et al., 2016; DECC, 2014). Life Cycle Assessment (LCA) method has been used to evaluate human toxicity and exposure factors related to the nano-particles released during the production in NanoTiO_2 glazed porcelain tile. The ceramic tiles production plants emit harmful titanium dioxide nanoparticles in the environment and it is inhaled by workers. The result of the study by Ferrari et al. (2015) shows that the emission of nanoTiO_2 particles into air may affect the Human Health for 32.33 percentage, the Climate Changes for 34.34 percentage, 4.07 percentage of Ecosystem Quality and generates 5 percentage toxicity in fresh water. The other hazardous chemicals and wastes that affect human and the environment by the manufacturing process of the ceramic tiles are NO_x (0.01 kg/m^2), SO_x(0.02 kg/m^2), CO_2 (4.43 kg/m^2), CO (0.005 kg/m^2), HF (0.003 kg/m^2), HCL (0.009 kg/m^2), Pb (0.00002 kg/m^2), hazardous waste (0.0033 kg/m^2), non-hazardous waste (3.49 kg/m^2), and noise pollution (478.7 dBA) (Ibanez et al., 2011). Table 4 presents the detail report of these wastes.

Table 4. The Hazardous Wastes and Chemicals Produced During the Production of the Ceramic Tiles (Ibanez-Fores et al., 2011)

	Clay preparation	Pressing	Drying	Glazing	Firing	Packing and palletising	Storage	Other activities	Total
Inputs									
Electricity (kWh/m^2)	0.120	0.48	0.12	0.33	0.41	0.07	0.08	0.33	1.94
Fuel oil (l/m^2)	0	0	0	0	0	0	0.0095	0	0.0095
Natural gas (kWh/m^2)	0	0	6.7	0	14.00	0	0	0	20.66
Water (l/m^2)	0.760	0.07	0	4.29	0	0	0	0.74	5.86
Clay and sand (kg/ m^2)	21.90	0	0	0	0	0	0	0	21.90
The ceramic glaze(kg/ m^2)	0	0	0	0.95	0	0	0	0	0.95
Machine oil (kg/ m^2)	0	0.0004	0	0	0	0.0004	0.0004	0	0.0012

Table 4. The Hazardous Wastes and Chemicals Produced During the Production of the Ceramic Tiles (Ibanez-Fores et al., 2011) (continued)

	Clay preparation	Pressing	Drying	Glazing	Firing	Packing and palletising	Storage	Other activities	Total
Inputs									
Cardboard boxes (kg/ m^2)	0	0	0	0	0	0.11	0	0	0.11
Pallets (kg/ m^2)	0	0	0	0	0	0.31	0	0	0.31
Plastic bags (LDPE[b]) (kg/ m^2)	0	0	0	0	0	0.01	0	0	0.01
Plastic packaging (kg/ m^2)	0	0	0	0	0	0.07	0	0	0.07
Plastic strips (kg/ m^2)	0	0	0	0	0	0.0004	0	0	0.004
Adhesives (kg/ m^2)	0	0	0	0	0	0.05	0	0	0.05
Outputs									
PM10 (kg/ m^2)	0.110	0.15	0.0010	0.0007	0.005	0	0	0	0.27
NO_x (kg/ m^2)	0	0	0.001	0	0.008	0	0	0	0.01
So_x (kg/ m^2)	0	0	0.001	0	0.02	0	0	0	0.02
CO_2 (kg/ m^2)	0	0	1.29	0	3.14	0	0	0	4.43
CO (kg/ m^2)	0	0	0.005	0	0.0009	0	0	0	0.005
HF (kg/ m^2)	0	0	0	0	0.003	0	0	0	0.003
HCI (kg/ m^2)	0	0	0	0	0.009	0	0	0	0.009
B (kg/ m^2)	0	0	0	0	0.00005	0	0	0	0.00005
Pb (kg/ m^2)	0	0	0	0	0.00002	0	0	0	0.00002
Waste water (l/m^2)	0	0	0	3.89	0	0	0	0.61	4.50
Hazardous waste (kg/ m^2)	0.000003	0.001	0.000003	0.0010	0	0	0.0009	0.0003	0.0033
Non-Hazardous waste (kg/ m^2)	0.0004	0.250	0.0004	2.08	0.06	0.03	0.04	1.03	3.49
Additional data									
Noise(dBA)	79.20	86.80	80	79.9	78.3	74.5	68.1	58.9	-
Temperature(°C)	-	30.00	190	30	300	-	-	-	-
Flue gas(Nm^3h)	-	70.877	42.448	3069	68977	-	-	-	18537

3.4. Energy consumption

Energies are in two forms: one is a renewable source of energy and the other is a non-renewable source of energy. The energy consumed during the manufacturing process is almost non-renewable resources which mean, the energy that cannot be regenerated again (Picchi et al., 2001). About 80 percent of energy has been used as a raw material to manufacture the ceramic tiles in which most of them are a non-renewable source of energy (Bastianoni et al., 1999; Ibáñez et al., 2016).

The manufacturing process of 1 m^2 of the ceramic tile includes several processes in which each process consume its own amount of energy and the by-product affects the environment (Feilden et al., 2016). From the inventory results (Ibanez et al., 2011), it is reported that electricity (1.94 kWh/m^2), fuel oil (0.0095 $1/m^2$), natural gas (22.66 kWh/m^2), water (5.86 $1/m^2$), clay and sand (21.9 kg/m^2),temperature (550°c), fuel gas (185371 Nm^3/h) amount of inputs have been used for manufacturing the ceramic tiles. Those inputs are shown in Table 4. From Table 4, it is noted that the major consumption of energy is natural gas. It is also noted that volume of hot flue gases produced from kiln is 65000 Nm^3/h with density of 0.5895 kg/Nm^3 and heat capacity of 1.195 kJ/kg ºC (Villaflor et al., 2008).

4. Methodologies Adapted for Assessing the Environmental Impacts

4.1. EDIP Methodology

The Environmental Development of Industrial Products (EDIP) is a method that is used to assess midpoint indicators for environmental impacts (Tikul & Srichandr, 2010). The units of EDIP impact values represent as CO_2 equivalents or CO_2-eq. CO_2 is a reference substance for global warming. Since other substances also contributing to global warming, they are called CO_2-eq and also CFC-11 is used as a reference substance for Ozone depletion, SO_2 for acidification. In that way, all the impacts have to be assessed by EDIP methodology (Wenzel et al., 2000).

Using Eq. (1), the impact values of EDIP is calculated

$$EPj = \Sigma(Q_i \times EF_{ij}) \quad (1)$$

Where,

EP_j: Potential Environmental for an environmental problem. (j)

Q_i: substance Quantity (i)

EF_{ij}: Substance for equivalency factor on the impact of the environmental problem.

Table 5 shows the environmental impact of 1 Mg ceramic tile by EDIP methodology (Tikul & Srichandr, 2010).

Table 5. The Environmental Impact of 1 Mg Ceramic tile (EDIP methodology)

Impact Category	Unit	Total (Tikul & Srichandr, 2010)
Global warming (GWP 100)	kg CO_2	3.73E+03
Ozone depletion	kg CFC11	2.86E-04
Acidification	kgSO_2	1.03E+01
Eutrophication	kgNO_3	1.35E+01
Photochemical smog	kg ethene	1.08E+00
Human toxicity air	m^3	8.29E+05
Human toxicity water	m^3	5.03E+01
Human toxicity soil	m^3	3.26E-01
Ecotoxicity water chronic	m^3	2.51E+03
Ecotoxicity water acute	m^3	2.55+02
Ecotoxicity soil chronic	m^3	1.99E+01

While using EDIP methodology for impact assessment of it is found that global warming and human toxicity are most affected.

4.2. Eco-indicator 95 Methodology

Eco-indicator 95 methodology is a weighting method used for assessing the environmental impact, the ecosystem or human health. This methodology is used to determine the harmful gases like CFC, CH_4, N_2O and CO_2 that affect the environment. And, it also helps to present the LCA results in all levels such as characterisation, normalisation and weighting (Tikul, 2014; Luo et al., 2001; Bribián et al., 2011).

4.3. Eco-indicator 99 Methodology

Eco-indicator 99 methodology is adamage oriented impact assessment method (Tikul & Srichandr, 2010; Iraldo et al., 2014). This methodology measures the endpoint indicators of the environmental impacts. The endpoint indicators are classified as impacts on human health, quality of the ecosystem and resources. The impact units are mentioned as (Pt) (Goedkoop & Spriensma, 2001).

Using the relationships in Eq. (2) and (4) the impact values are calculated in Eco-indicator 99 methodology. Using Eq. (2) the damage scores (DP) of various impact categories are calculated.

$$DP_{ij} = Q_i \times DF_{ij} \quad (2)$$

Where,

DP_{ij}: Damage scores for substance i *and* categories j

Q_i: Substance Quantity i (kg)

DF_{ij}: Impacts of the damage categories j and Substance damage factor i

Using Eq. (3) the damage scores are normalized

$$NP_{ij} = DP_{ij} \times NF_{ij} \quad (3)$$

Where,

NP_{ij}: Normalized scores for substance i and damage categories j

NF_{ij}: Normalization impacts of the damage categories j and Substance damage factor i

Using Eq. (4) Normalized scores are weighted and weighted scores are arrived

$$WP_j = \Sigma(WF_{ij} \times NP_{ij}) \quad (4)$$

Where,

WP_j: Damage categories j, weighted scores of all substances

WF_{ij}: Damage categories j and substance i, Weighted damage factor

The impact of fossil fuel and the effect on respiratory inorganic are studied by using Eco-indicator 99 methodology. Table 6 shows the ceramic tiles production and its environmental impact.

Table 6. The Environmental Impact of the Ceramic Tiles Production (Eco-indicator 99 methodology) (Tikul & Srichandr, 2010)

Impact category	Transp	Body Prep	Forming	Drying	Biscuit Firing	Glazing Prep.	Glazing	Glost firing	Packaging	Total
Carcinogens	1.72E-02	1.13E+01	9.31E-03	0.00E+00	2.08E-02	3.60E-01	2.32E-03	3.99E-02	6.36E-02	1.18E+01
Resp. organics	5.02E-02	2.20E-03	6.37E-05	0.00E+00	5.90E-03	3.34E-03	1.59E-05	6.66E-03	2.61E-03	7.10E-02
Resp. Inorganics	7.45E+00	1.78E+01	2.86E-02	2.56E-03	1.57E+00	8.29E-01	7.14E-03	1.51E+00	4.60E-01	2.96E+01
Climate change	1.13E+00	5.16E+00	2.67E-02	0.00E+00	4.37E+00	1.93E-01	6.67E-03	4.09E+00	1.51E-01	1.51E+01
Radiation	0.00E+00	6.32E-02	9.91E-05	0.00E+00	6.12E-05	1.60E-03	2.47E-05	1.37E-04	2.88E-03	4.10E-02

Table 6. The Environmental Impact of the Ceramic Tiles Production (Eco-indicator 99 methodology) (Tikul & Srichandr, 2010) (continued)

Impact category	Transp	Body Prep	Forming	Drying	Biscuit Firing	Glazing Prep.	Glazing	Glost firing	Packaging	Total
Ozone layer	0.00E+00	4.88E-03	1.21E-05	0.00E+00	7.46E-06	4.63E-04	3.01E-06	1.67E-05	4.57E-04	5.84E-03
Ecotoxicity	1.46E-02	4.39E+00	6.23E-03	0.00E+00	1.46E-01	1.37E-01	1.55E-03	1.39E+00	1.11E-01	6.20E+00
Acidification/ Eutrophication	1.05E+00	3.92E+00	4.21E-03	0.00E+00	2.69E-01	1.69E-01	1.05E-03	2.74E-01	7.51E-02	5.76E+00
Land use	2.96E-01	1.15E+00	5.40E-03	0.00E+00	4.06E-02	6.98E-02	1.35E-03	4.92E-02	4.26E-01	2.04E+00
Minerals	4.03E-03	1.86E+00	3.56E-03	0.00E+00	2.74E-03	4.79E+00	8.88E-04	5.52E-03	3.15E-02	6.69E+00
Fossil fuels	5.57E+01	1.30E-01	2.16E-01	0.00E+00	9.70E+00	4.69E+00	5.38E-02	1.10E+01	4.72E+00	8.62E+01
Total	1.04E+02	7.00E+00	3.00E-01	2.56E-03	1.61E+01	1.12E+01	7.48E-02	1.84E+01	6.04E+00	1.61E+02

From Table 6, it is observed that impact category with the highest value of fossil fuels (8.62E+01Pt) is followed by respiratory inorganic (2.96E+01Pt) and climate change (1.51E+01Pt) is found to be most affected (Tikul & Srichandr, 2010).

4.4. LCA Methodology

In the Life Cycle Assessment (LCA) (Olmez et al., 2016; Salas et al., 2016), the environmental impact assessment is assessed on all the seven stages of tile production viz. (1) clay mining (2) clay atomising (3) Glazes and frits production (4) Ceramic tiles production (5) distribution (6) Usage and installation (7) Construction and demolition of waste (Ibanez-Forés et al., 2011; Boussen et al., 2016). For the Life Cycle Assessment of ceramic tile, $1m^2$ of ceramic tile is taken over and analysed the process over a period of 20 years. This Life Cycle Assessment includes the identification of the environmental impacts such as Global warming, Ozone depletion layer, Acidification, Eutrophication, Human toxicity and Photo Chemical Oxidation (Yoshihiko, 2004; Ibanez et al., 2011; Nitschelm et al., 2016).

All the input and output data have been collected for the Life Cycle Assessment. The input and output data consist of materials, water, energy, airborne emissions, emissions into water and soil as well as solid waste produced from each stage of Life Cycle of the ceramic tiles are collected. Then, it is relating the data to unit process to the functional unit (Goldoni & Bonoli, 2006; Su et al., 2016).

Table 7 shows the mean energy consumptions, main airborne emissions and waste generated and input and output flow of water for the five stages (Mining sector, Atomising plants, Frits and glazes manufacture, Tile factories and C and D waste disposal). From Table 7, it is observed that atomising plant consumes a large amount of natural gas (1.58E+01) and electricity (-2.59+00) (Ibanez et al., 2011). In addition, airborne emissions of CO (2.12E-03), NO_x (1.35E-02) and SO_x (3.30E-03) come mainly from the drying and firing process, which affects human health.

Table 7. Inventory Data for Each Stage of the Life Cycle of 1 m^3 of the Ceramic Tile (**Ibanez-Fores** et al., 2011)

	Mine	Atomising Plant	Glaze Plants	Tile factories	Distribution	Installation and use	C&D waste
Non-renewable energy							
Electricity (kWh/m^2)	6.16E-03	-2.59E+00	9.99E-02	1.95E+00	0	7.88E-02	5.03E-02
Diesel (L/m^2)	2.00E-02	6.86E-03	1.26E-03	9.55E-03	5.07E-01	0	2.46E-02
Natural gas (kWh/m^2)	0	1.58E+01	1.29E+00	1.83E+01	0	0	0
Airborne emission (kg/m^2)							
PM_{10}	6.67E-10	4.65E-03	1.37E-04	2.59E-03	-	-	-
NO_x	0	1.35E-02	2.15E-03	5.25E-03	-	-	-
SO_x	9.90E-08	3.30E-03	2.40E-04	4.19E-03	-	-	-
CO	1.86E-05	2.12E-03	7.72E-05	9.90E-03	-	-	-
HF	0	3.69E-04	6.04E-06	1.80E-05	-	-	-
Pb	0	0	2.59E-05	3.25E-04	-	-	-
As	0	0	5.30E-09	5.48E-08	-	-	-
Hg	0	0	4.41E-09	3.49E-08	-	-	-
Cu	0	0	2.39E-07	2.16E-07	-	-	-
Cr	0	0	6.32E-08	1.46E-07	-	-	-
Hazardous and Non Hazardous waste (kg/m^2)							
HW	5.46E-04	6.23E-04	3.90E-02	2.78E-03	-	-	0
NHW	8.82E-04	1.03E-02	2.17E-03	2.86E+00	-	-	4.15E+00
Water inputs and Outputs (m^3/m^2)							
Incoming water	5.39E-04	1.10E-02	7.25E-04	5.74E-03	-	-	0
Outgoing water	0	1.09E-03	1.84E-04	4.44E-03	-	-	0

4.5. Best Available Techniques (BAT)

Best Available Technique is the method to assess the environmental impacts by different possible methods, which can be applied in the manufacturing process of the ceramic tiles. The outcome of the process is used to reduce the environmental impact. Before applying BAT option, baseline system should be determined with the help of LCA methodology, to determine the major impacts on the environment. And with the guidance of Industrial Emission Directive (IED), the best possible alternative method for the manufacturing process is determined (Ibáñez et al, 2016). After determining the baseline system, all possible and sustainable ways to reduce the impact have been determined by comparing the relevant indicators like economicindicator, the environmental indicator, a technical and social indicator that give several sustainable options for BAT. As a next step, initial screening has been done by applying BAT options in the economic and the environmental performance. Based on the performance, the most efficient options are selected. As a result of this investigation, BAT options have been determined from the Reference Document for the process of manufacturing the ceramic tile (EC, 2007), which is clearly shown in Table 8. And, the investigation also states that cost savings are done up to 30% on the reduction of some life cycle environmental impacts by following BAT options. But, these results are based on the assumption as all the indicators are given equal importance and it is based on the preference of the reviewer (Ibáñez et al, 2016).

Table 8. BAT Options Selected for Targeting the Hot Spots in the Baseline Scenario (Ibáñez-Fores et al, 2016)

Hotspot	BAT	option	Type	Description
Energy efficiency	1	1a	Heat recovery from dirty flue gasses	Heat exchangers recover heat from dirty or clean hot flue gases from the kiln to preheat the combustion air which can be used either in the kiln or the dryer
		1b	Heat recovery from clean flue gasses	
Particulates (stack emissions)	2	2a	Traditional bag filters with pressure – pulse regeneration	Pulse pressure is used to clean the filter bags. Each bag will tolerate different temperature depending on the type of material, eg synthetic bag filter tolerates high temperatures
		2b	High-temperature synthetic filter with pressure- pulse regeneration	
	3		Electrostatic precipitator	Uses electrical forces to move particles from flue –gas stream to collector plates
Particulates (diffuse emissions)	4		Full enclosure of bulk storage areas	By means of the sheds or roofs to reduce diffuse dust emissions
	5		Dust valves with suction and bag filter in bulk storage areas	Dump pits with the dust suction equipment, housing and traditional bag filters
	6		Water spraying	Moistening of bulk storage and dusty traffic areas by using a permanent water spraying installation.
Acid Gases	7	7a	Cascade – type packed – bed adsorber with $CaCO_3$	Flue gas is contacted with $CaCO_3$ or a combination of $CaCO_3$ and $Ca(OH)_2$ in a cascade- type packed- bed reactor to move acid gases
		7b	Cascade – type packed – bed adsorber with $CaCO_3$ and $Ca(OH)_2$	
	8		Module adsorber with $Ca(OH)_2$	Adsorber with several honeycomb modules made of and $Ca(OH)_2$ and located in a simple steel reactor that chemically converts HF in the flue gases to calcium floride(CaF_2) as it passes through them.
	9	9a	Dry flue gas cleaning with and $Ca(OH)_2$	Particles of and $Ca(OH)_2$ or $NaHCO_3$ into the- flue-gas stream in dry form to remove acid gases from the flue gas.
		9b	Dry flue gas cleaning with and $NaHCO_3$	
	10	10a	Wet flue gas cleaning with $Ca(OH)_2$ or $CaCO_3$	A solution of $Ca(OH)_2$, $CaCO_3$ or $Na(OH)_2$ in water pumped into the absorber to remove acid gases from the flue gas
		10b	Wet flue gas cleaning with $Na(OH)_2$	
Noise	11		Sound insulation	An Enclosure of the noisiest units with noise- protection walls

5. Discussion

The ceramic industry is expanding its production by 6 percent every year. The global consumption of the ceramic is also maintaining a steady growth. The ceramic products have heavy demand in the global market and that have tended to produce more tiles and leave harmful pollutants to the earth. Thus, the environmental pollutants affect the entire ecosystem when the ecosystem is affected. It may deface the world's environmentally friendly nature. The environmental pollution starts from mining operation to the packing of tiles. Each phase contributes its own amount of pollutants directly or indirectly to the atmosphere and earth. The indirect means of affecting the environment may be considered as transportation and energy consumption. These indirect activities need to be addressed while assessing the environmental impacts of the ceramic industry globally.

The comparative study between small and medium tile production plants shows that small plants contribute more amounts of pollutions when compared to the medium plants and have a heavy impact on global warming, ozone depletion, acidification and eutrophication. The major reason for the medium plant producing a lesser amount of pollution is due to the usage of the latest technology and equipment. Hence, if the small plants are also updated to the latest technology, use of modern machinery will reduce the environmental impact. On the other hand, the energy consumption levels are also compared between medium and small plants. It is clearly visible that small plant consumes twice the amount of energy than the medium plants (Tikul, 2014). Small plants consume more energy for glost firing whereas the medium plants consume lesser amount of energy for the same work. The next major energy consumption is biscuit firing. In this process also small industries consume more energy for less production, the reason for highest energy consumption by the small plant is observed to be due to the quality of kiln and nature of the raw material (Tikul, 2014). The consumption of high energy indirectly contributes to the environmental pollution because of producing the energy in a thermal power plant, coal mining. It will create environmental pollution. Hence, small industry produces more the environmental problems and consumes higher energy for lesser production of tiles. In addition, both small and medium plants consume 80 percent of energy from the non-renewable source of energy. Using the renewable source of energy may considerably reduce the environmental impact.

The environmental impact assessment due to sintering activity is assessed by TEM/EDX. The results show that Nanoparticle < 30nm (Ahmad et al., 2005) in diameter being formed during the sintering process. The analysis also show that there is a trace of minerals and metal oxide Nanoparticles of (Zn,Cr, Al and Fe) (Casasola, 2012; Jacobs, 1954; Lahoz et al., 2011; Minguillon et al., 2009; Sánchez de la Campa et al., 2010). In addition, Ultrafine Nano sized airborne particles are generated during the sintering process, which exceeds the Nano reference value (Van Broekhuizen et al., 2012) that affects the respiratory system. Hence, it is evident that there is an occupational risk to the workers who are exposed to Ultrafine and Nano particles during the sintering activity. The manufacturing of ceramic tiles also emits various hazardous materials like chemical gases and waste. The life cycle assessment on the ceramic tiles production shows that Nano TiO_2 is released during the process of glazing. These Nano particles of TiO_2 are inhaled by the workers and they are affected without any escape. The release of Nano TiO_2 also affects the climate change and quality of eco-system and increases toxicity in fresh water. The manufacturing process also emits the hazardous gases like NO_X,SO_X,CO_2,CO,HF,HCl,Pb and noise pollution is also generated (EC, 2010; Ibanez-Fores et al., 2011).

To assess the environmental impact, various methodologies are followed globally and each methodology is limited to a minimum number of parameters for study. To assess additional parameters, the assessors need to depend upon the other methodology. The various methodologies widely used are EDIP methodology, Eco-Indicator 95, Eco-Indicator 99, LCA methodology and BAT technique. In which, EDIP methodology studies the ozone depletion, SO_2 for acidification, Eco-Indicator 95, 99 methodologies and those methodologies focus on the human health, quality of Ecosystem and resources. The LCA methodology includes the identification of global warming, Ozone depletion, Acidification, Eutrophication, Photochemical oxidation and human-toxicity (Ibanez-Fores et al., 2011), the BAT technique focuses on energy efficiency and air pollution (Ibanez-Fores et al., 2016). In the present scenario, different methodology is adapted to assess the various parameters of the environmental pollution of the interest of the assessor. In future, a single methodology may be adapted to assess maximum parameters. This will provide a proper assessment procedure for the environmental impact assessment engineers.

6. Conclusion

This paper reviews the manufacturing process of the ceramic tiles and presents the environmental impact caused by the ceramic industries. The environmental impact assessment is reviewed based on the size of the industry, energy consumption, sintering activity and emission of hazardous material through the air. The major effects on the human being are climate change, ecosystem quality and emission of hazardous gases in the atmosphere. The various methodologies used globally are also reviewed and presented in this paper. There are no single methodologies, which address all the environmental issues. Hence in future, a single methodology may be proposed to assess maximum parameters of the pollutions. From the several kinds of literature, it has been identified that the ceramic industries release significant harmful impact on the environment. But, it is unavoidable because of its demand in the global market, the demand of ceramic products increase considerably every year. This causes even more harmful impact to the environment; these pollutants affect entire nature. Therefore, it is the compulsion to the mankind, researchers and the environmental scientists to invent all new methods, technologies, materials to manufacture the tiles without delivering any harmful things to the environment at the same time it has to fulfil the demand of the global market.

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