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# $CO_2$ Emission Calculation and Reduction Options in Ceramic Tile Manufacture-The Foshan Case

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**Abstract**

The purpose of this study is to determine current carbon dioxide emissions in the ceramic tile manufacturing process. A carbon measuring model is established and used to calculate carbon dioxide emissions from key processes and carbon footprint of products. The results show that $CO_2$ emission in the ceramic tile enterprise reached 180000t a year and $CO_2$ emission per unit product is 10% more than the advanced level in the world. About 80% of the total $CO_2$ is emitted during the processes of firing and drying. Several solutions are proposed to reduce $CO_2$ emission from these two processes and substituting coal with natural gas seems to be the most efficient way .



*Keywords:* $CO_2$ emission; ceramic tile; Input-output analysis

## 1. Introduction

Carbon dioxide emission and its reduction is one of the issues of international concern nowadays. The ceramic tile manufacturing is a highly energy-intensive production process and one of the main contributors to $CO_2$ emissions since it contains several stages in which the products is subject to thermal treatment[1]. As the largest producer of ceramic tiles in the world since 1993, China accounted for the maximal proportion of global emissions by ceramic tile manufacturing from fuel use and power generation, which made China the leader in $CO_2$ emissions from the ceramic tile industry. In fact, $CO_2$

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emission from ceramic tile manufacturing reached 100 million metric tons in 2007 due to the production of 50 billion $m^2$ ceramic tiles in China[2].

Many studies have focused on $CO_2$ emission from industries like cement manufactory[3,4], electricity generation[5,6], iron and steel[7], copper[8] and etc, but few literatures focus on $CO_2$ emission from ceramic tile manufacture. Furthermore, these studies usually concentrate attentions on data in macroscopic view(eg. Economic growth, population growth, energy conversion efficiency and so on), and pay little attention to manufacturing process. This paper presents a $CO_2$ emission calculation method from the process of ceramic tile production based on key stages in which $CO_2$ is emitted. Also, reduction options of $CO_2$ emission are presented, as well as the effects that might be accomplished.

## 2. Process introduction of ceramic tile industry

This paper presents one of the most common processes in the modern ceramic tile production, the five-stage ceramic tile production which is situated in Ceramic tile Factory in Foshan, Guangdong, China. The process which is presented in figure.1 incorporates a ball mill, a spray drying tower, a press molding machine, a roller kiln, a machine for glazing and a polisher.

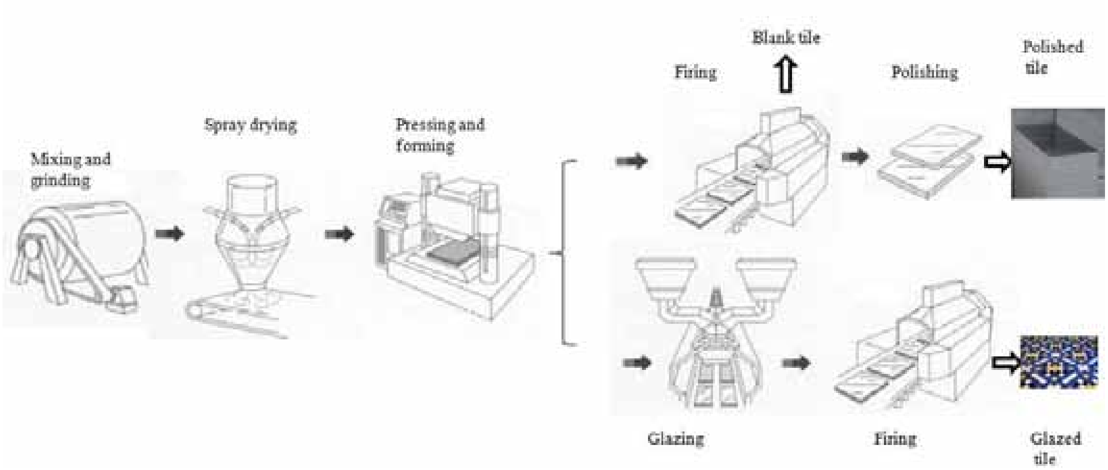


Fig 1. Ceramic tile production process

The production process of ceramic tile typically consists of five stages. The first stage is ball crushing and grounding the raw materials and additives, the exit product is called material slurry. The second stage is spray drying, in this stage material slurry is fed into spry drying tower and is dried to be powder. The third stage is pressing and forming, in which the powder is pressed and formed to be original tile. The forth stage is firing (if the product is glazed tile, glazing is needed before firing), in which the original tile is fired to be blank tile. The final stage is polishing, in this stage, blank tile is polished to be final product.

## 3 Calculation methods of carbon dioxide emission

### *3.1 Carbon accounting Input-output table*

The input-output analysis method is used in order to estimate carbon dioxide emission from the process of cement production. In order to model the embodiment of emissions and energy use, the economic input-output table is modified to a carbon accounting input-output table covering six intermediate products and six key processes. To demonstrate the relationship between the products and processes, an input-output schematic graph is given as shown in figure 2. And the carbon measuring input-output table is shown in table 1.

Table 1 Scheme of the carbon accounting input-output table of ceramic tile enterprise

| Output<br>Input | | Unit | No. | Intermediate product | | | | | | Final product | | | Total output |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Material slurry | Ceramic powder | Original tile | Blank tile | Polished tile | Glazed tile | Sale | Store | Total | |
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | | | | |
| Home-grown inputs | Material slurry | t | 1 | $x_{11}$ | $x_{12}$ | … | $x_{1j}$ | … | $x_{16}$ | | | $Y_1$ | X |
| | Ceramic powder | t | 2 | $x_{21}$ | $x_{22}$ | … | $x_{2j}$ | … | $x_{26}$ | | | $Y_2$ | $X_2$ |
| | Original tile | t | 3 | … | | | | | | | | … | … |
| | Blank tile | $*10^4m^2$ | 4 | $x_{i1}$ | $x_{i2}$ | … | $x_{ij}$ | … | $x_{i6}$ | | | $Y_i$ | $X_i$ |
| | Polished tile | $*10^4m^2$ | 5 | … | | | | | | | | … | … |
| | Glazed tile | $*10^4m^2$ | 6 | $x_{61}$ | $x_{62}$ | … | $x_{6j}$ | … | $x_{66}$ | | | $Y_6$ | $X_6$ |
| | | | | | | | | | | Total consumption | | | |
| Outsourcing inputs | Electricity | $*10^3kWh$ | 1 | $v_{11}$ | $v_{12}$ | … | $v_{1j}$ | … | $v_{16}$ | $G_1$ | | | |
| | Coal | t | 2 | $v_{21}$ | $v_{22}$ | … | $v_{2j}$ | … | $v_{26}$ | $G_2$ | | | |
| | Diesel oil | t | 3 | … | | | | | | … | | | |
| | Natural gas | $*10^3m^3$ | 4 | $v_{i1}$ | $v_{i2}$ | … | $v_{ij}$ | … | $v_{i6}$ | … | | | |
| | Raw material | t | 5 | … | | | | | | $G_i$ | | | |
| | Color material | t | 6 | … | | | | | | … | | | |
| | Glaze material | t | 7 | $v_{71}$ | $v_{72}$ | … | $v_{7j}$ | … | $v_{76}$ | … | | | |
| | Additives | t | 8 | $v_{81}$ | $v_{82}$ | … | $v_{8j}$ | … | $v_{86}$ | $G_8$ | | | |

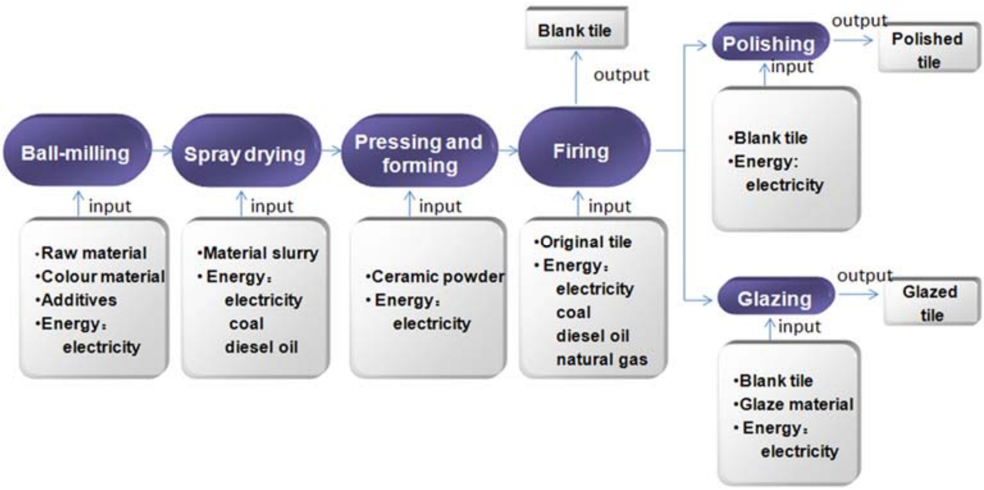


Fig2. Input-output schematic graph of ceramic tile

As illustrated in Table 1, the modified table can be divided into four parts. The home-grown inputs table(the first part) represents usage of intermediate material(denoted by $x_{ij}$ , standing for the *i*th intermediate products consumed in process of *j*th products produced.). The final product and total output table(the second part) represent final usage of products(denoted by $Y_i$ and $X_i$ , standing for quantity of ith final products and total products respectively.). The outsourcing inputs table(the third part) represents usage of raw material, fuel, and electricity (denoted by $v_{ij}$ , standing for the *i*th outsourcing material consumed in processes of *j*th products making.). The total consumption table(the fourth part) represents total usage of outsourcing material (denoted by $G_i$ , standing for the *i*th material consumption through the whole process of final products making).

*3.2 Carbon accounting input-output model*

Table 1 demonstrates numerical relationship among products, materials and energy consumption which can be also described by equation (1), and the technology relationship has to be described by consumption coefficients.

$$\begin{cases} x_{11}+x_{12}+\cdots\cdots+x_{16}+Y_1=X_1 \\ x_{21}+x_{22}+\cdots\cdots+x_{26}+Y_2=X_2 \\ \vdots \quad \vdots \qquad \vdots \qquad \vdots \quad \vdots \qquad \vdots \\ x_{61}+x_{62}+\cdots\cdots+x_{66}+Y_6=X_6 \end{cases} \tag{1}$$

(a) Direct consumption coefficients

In this paper aij denotes the direct consumption from home-grown product j to i and bij denotes the direct consumption from home-grown product j to outsourcing material i. aij and bij can be calculated by equation (2) and (3) respectively.

$$\mathrm{a}_{ij}=\frac{x_{ij}}{X_j}(\mathrm{i},j=1,2,...,6) \tag{2}$$

$$b_{ij}=\frac{v_{ij}}{X_j}(\mathrm{i}=1,2,...,8);j=1,2,...,6) \tag{3}$$

If the coefficient matrix of $a_{ij}$ and $b_{ij}$ are signed as *A* and *B* respectively, and also the matrix of $X_i$, $Y_i$ and $v_{ij}$ are signed as *X, Y and V* respectively, the equation (1),(2) and (3) can be transformed to matrix equation (4), (5) and (6) respectively.

$$AX+Y=X \tag{4}$$

$$W=A\hat{X} \tag{5}$$

$$V=B\hat{X} \tag{6}$$

Where $\hat{\mathbf{X}}$ is diagonal matrix of *X*.

$X=[X_1\,X_2\ldots X_6]^T$, $Y=[Y_1\,Y_2\ldots Y_6]^T$, $\mathbf{W}=\begin{bmatrix} x_{11} & x_{12} & \cdots\cdots & x_{16} \\ x_{21} & x_{22} & \cdots\cdots & x_{26} \\ \vdots & \vdots & \vdots & \vdots \\ x_{61} & x_{62} & \cdots\cdots & x_{66} \end{bmatrix}$, $\mathbf{V}=\begin{bmatrix} \mathrm{v}_{11} & v_{12} & \cdots\cdots & v_{18} \\ v_{21} & v_{22} & \cdots\cdots & v_{28} \\ \vdots & \vdots & \vdots & \vdots \\ v_{81} & v_{82} & \cdots\cdots & v_{88} \end{bmatrix}$,

Equation (4) can be also transformed to (7)

$$X=(I-A)^{-1}Y \tag{7}$$

(b) Complete consumption coefficients

Complete consumption coefficients is usually sum of direct consumption and indirect consumption in process of making unit of final product. In this paper $c_{ij}$ denotes complete consumption from home-grown product *j* to *i* and $d_{ij}$ denotes the complete consumption from home-grown product *j* to outsourcing material *i*. The coefficient matrix of $c_{ij}$ and $d_{ij}$ are signed as *C* and *D* respectively, and can be calculated by equation (8) and (9).

$$C = A(I - A)^{-1} \tag{8}$$

$$D = B(I - A)^{-1} \tag{9}$$

*3.3 $CO_2$ emission calculation method*

Quantity of $CO_2$ emission can be calculated using the following equation (10) according to IPCC methodology[9].

$$Emission_{CO_2} = EF_i \times FC_i \tag{10}$$

Where $EF_i$ is emission factor of *i*th fuel, and $FC_i$ is the quantity of *i*th fuel consumed. Emission factor of primary energy can be calculated according to default factor listed in IPCC(Intergovernmental Panel on Climate Change) Guidelines for National Greenhouse Gas Inventories and heat value of fuel in China. Primary energy consumed in the process of ceramic tile production are coal, diesel oil, and natural gas whose emission factor are listed in table 2. Emission factor of electricity is chosen to be 1.052t $CO_2$/MWh[10].

Table 2 $CO_2$ emission factor of primary energy

| Fuel | Default factor(C) listed in IPCC [7] | Heat value in China(G)[8] | Emission factor(EF=C×G) |
|---|---|---|---|
| Coal | 94600kg$CO_2$/TJ | 20908kJ/kg | 1.978t$CO_2$/t |
| Diesel oil | 74100kg$CO_2$/TJ | 42652kJ/kg | 3.161t$CO_2$/t |
| Natural gas | 56100kg$CO_2$/TJ | 38931kJ/$M^3$(54266.8kJ/kg) | 2.184t$CO_2$/k$M^3$ |

(a) $CO_2$ emission of key procedure in production process

For $CO_2$ emission calculation from key procedure during ceramic tiles producing based on input-output data of ceramic tile enterprise, it is used the following equation (11):

$$Emission_{CO_2} = EF \times V \tag{11}$$

Where *EF* is matrix of emission factor of outsourcing material including energy and materials. *V* is matrix of complete consumption date of outsourcing material.

(b) Carbon footprint of products

Carbon footprint is the total amount of $CO_2$ emitted by fuel consumption over the process of production[11]. According to equation (11), carbon footprint of *j*th product can be calculated by equation (12).

$$CF_j = EF \times D_j \tag{12}$$

Where $D_j$ is column vector of complete consumption coefficients matrix, thus matrix of complete consumption coefficients can be shown as equation (13).

$$D = (D_1, D_2, D_3, D_4, D_5, D_6) \tag{13}$$

(c) Total emission of the ceramic tile enterprise

Total emission of the ceramic tile enterprise can be calculated by summarizing $CO_2$ emission of all the procedure over ceramic tile production, as follows:

$$\text{Emission}_{CO_2} = \sum_{j=1}^{6} Emission_{CO_2-j} \tag{14}$$

## 4 $CO_2$ emission calculation results

Direct consumption coefficient and complete consumption coefficient are calculated according to input-output data in the year of 2009(for the enterprise chosen in this study) and shown in table 3 and 4 respectively. The value of production matrix extracted from the input-output data are also shown in table 5.

Table 3 Table of the direct consumption coefficient

| Input \ Output | | Unit | No. | Intermediate product | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Material slurry | Ceramic powder | Original tile | Blank tile | Polished tile | Glazed tile |
| | | | | 1 | 2 | 3 | 4 | 5 | 6 |
| Home-grown inputs | Material slurry | t | 1 | 0 | 1.56 | 0 | 0 | 0 | 0 |
| | Ceramic powder | t | 2 | 0 | 0 | 0.101 | 0 | 0 | 0 |
| | Original tile | t | 3 | 0 | 0 | 0 | 2257.1 | 0 | 0 |
| | Blank tile | $*10^4m^2$ | 4 | 0 | 0 | 0 | 0 | 1 | 1 |
| | Polished tile | $*10^4m^2$ | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Glazed tile | $*10^4m^2$ | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| Outsourcing inputs | Electricity | $*10^3kWh$ | 1 | 0.022 | 0.009 | 0.003 | 3.87 | 17 | 9 |
| | Coal | t | 2 | 0 | 0.087 | 0 | 44.1 | 0 | 0 |
| | Diesel oil | t | 3 | 0 | 0.0008 | 0 | 0.804 | 0 | 0 |
| | Natural gas | $*10^3m^3$ | 4 | 0 | 0 | 0 | 0.0005 | 0 | 0 |
| | Raw material | t | 5 | 0.632 | 0 | 0 | 0 | 0 | 0 |
| | Color material | t | 6 | 0.022 | 0 | 0 | 0 | 0 | 0 |
| | Glaze material | t | 7 | 0 | 0 | 0 | 0 | 0 | 14.39 |
| | Additives | t | 8 | 0.002 | 0 | 0 | 0 | 0 | 0 |

Table 4 Table of the total consumption coefficient

| Input | Output | Unit | No. | Intermediate product: Material slurry | Ceramic powder | Original tile | Blank tile | Polished tile | Glazed tile |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 |
| Home-grown inputs | Material slurry | t | 1 | 0 | 1.56 | 0.16 | 355.7 | 355.7 | 355.7 |
| | Ceramic powder | t | 2 | 0 | 0 | 0.101 | 228.0 | 228.0 | 228.0 |
| | Original tile | t | 3 | 0 | 0 | 0 | 2257.1 | 2257.1 | 2257.1 |
| | Blank tile | $*10^4m^2$ | 4 | 0 | 0 | 0 | 0 | 1 | 1 |
| | Polished tile | $*10^4m^2$ | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Glazed tile | $*10^4m^2$ | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| Outsourcing inputs | Electricity | $*10^3kWh$ | 1 | 0.022 | 0.042 | 0.007 | 19.66 | 36.66 | 28.66 |
| | Coal | t | 2 | 0 | 0.087 | 0.009 | 63.88 | 63.88 | 63.88 |
| | Diesel oil | t | 3 | 0 | 0.0008 | 8.29 | 0.99 | 0.99 | 0.99 |
| | Natural gas | $*10^3m^3$ | 4 | 0 | 0 | 0 | 0.0005 | 0.0005 | 0.0005 |
| | Raw material | t | 5 | 0.632 | 0.986 | 0.1 | 224.8 | 224.8 | 224.8 |
| | Color material | t | 6 | 0.022 | 0.034 | 0.003 | 7.82 | 7.82 | 7.82 |
| | Glaze material | t | 7 | 0 | 0 | 0 | 0 | 0 | 14.39 |
| | Additives | t | 8 | 0.002 | 0.003 | 0.0003 | 0.71 | 0.71 | 0.71 |

Table 5 Value of production matrix

| Code | | Value of matrix |
|---|---|---|
| Matrix of final output | $Y$ | $[0\ \ 0\ \ 0\ \ 111.2\ \ 722.8\ \ 278]^T$ |
| Matrix of total output | $X$ | $[395501\ \ 253526\ \ 2509901\ \ 111.2\ \ 722.8\ \ 278]^T$ |

According to data from table (3)~(5) and equation from (11) )~(14), $CO_2$ emission from the enterprise in the year of 2009 are calculated and shown in table 6.

Table 6 $CO_2$ emission of in the year of 2009

| | Ball-milling | Spray drying | Pressing and forming | Firing | Polishing | Glazing |
|---|---|---|---|---|---|---|
| $CO_2$ emission of key procedure(t) | 9034.6 | 46522.6 | 7153.6 | 104274.4 | 12926.6 | 2632.1 |
| | Blank tile | | Polished tile | | Glazed tile | |
| Carbon footprint of final products(kg/$m^2$) | 15.02 | | 16.80 | | 15.96 | |
| Total emission(t) | 182543.9 | | | | | |
| $CO_2$ emission per unit product(kg/$m^2$) | 16.42 | | | | | |

## 5 Discussion about carbon dioxide reduction methods

In ceramic tile enterprise chosen in the study, $CO_2$ emission in 2009 is 182543.9t and emission per unit product reaches 16.42kg/m$^2$. That is over 10% more than advanced level which has been announced[12]. That means it is really urgent to reduce $CO_2$ emission of ceramic tile industry.

A general approach of $CO_2$ reduction starts with the identification of the main processes of emissions and after that through good knowledge of processes and energy consumption try to reduce emissions. Through results shown in table 6 and figure 3, it is clear that firing and spray drying are the main processes of $CO_2$ emissions and during these two processes 83% of $CO_2$ are emitted. In that way some solutions are effective when $CO_2$ emission have to be controlled:

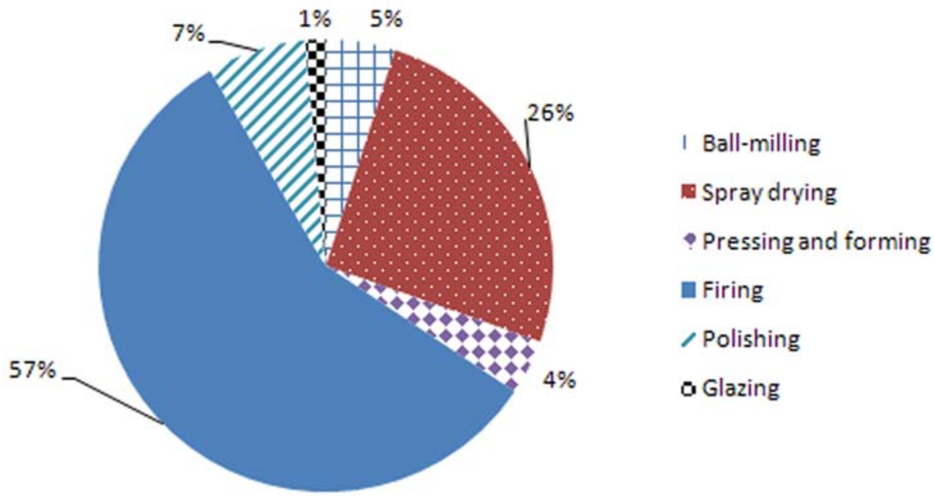


Fig 3 Contribution to $CO_2$ emission from different processes

*Carbon dioxide emission reducing from firing process:*

1)fuel switching from coal to diesel oil or natural gas.

2)energy efficient improvement.

3)applying new technology including low temperature quick fire process, single firing process.

Having in mind that consumption of coal in 2009 is 7.1*10$^4$ ton in the ceramic tile enterprise, by substituting coal with natural gas, annual emission of $CO_2$ can be reduced to 125355.3t. Natural gas has greater value of lower heating value in comparison to coal ($H^{NG}_L$=54266.8kJ/kg $H^{COAL}_L$= 20908kJ/kg); at the same time it has significantly smaller emission factor($e^{NG}_{CO2}$=56100kg/TJ, $e^{COAL}_{CO2}$=94600kg/TJ), implicating that for the production of energy from coal annual emission of $CO_2$ will be 140507.2t, while in case of usage of natural gas 83318.6t will be emitted, which means that annual total emission is reduced 31.3%. With the same reason, if coal was substituted by diesel oil, the annual decrease of $CO_2$ emission would be 30436.98t and that represents decrease of 16.7%.

Installing high-speed burner in furnace for increasing gas flow rate in the firing process, heat transfer between gas and products would be improved, which would cause energy efficient improvement. That method would save fuel supply about 25%~30%[13], thereby reducing emission of $CO_2$ by 25%~30%.

Introduction of automatic control technology to make sure the combustion in furnace is always in best condition is another effective way to improve the energy efficient.

Applying low temperature quick fire technology to reduce firing temperature and the periodic time in the combustion process, the energy consumption would decrease, which would cause the reduction of $CO_2$ emission. i.e. After applying low temperature quick fire technology, the firing cycle time reduced from 70 minutes to 50 minutes and corresponding energy consumption reduced 30%[12]. That would lead to the reduction of $CO_2$ emission about 42152.2t $CO_2$ per year. Single firing technology is another method which would also reduce energy consumption by 30% at least[13], and may lower $CO_2$ emission in firing process.

*Carbon dioxide emission reducing from spray drying process:*

1)applying microwave drying technology.

2)recycling of hot air emitted from drying tower

Microwave drying is a new drying technology with which materials can be heated both inside and outside at the same time and moisture evaporation time can be shortened greatly. With microwave drying technology, production efficiency can be greatly improved , thus energy consumption and $CO_2$ emitted by fuel combustion can be reduced. It is said that substituting conventional drying with microwave drying energy consumption would be reduced 75% and $CO_2$ emitted during the drying process would be reduced 75% as well[12].

If hot gas was recycled after drying ceramic slurry, fuel consumption could be reduced by 15%[14] which would made the $CO_2$ emission following fuel combustion be reduced too. Therefore hot gas recycling is also an efficient way to reduce $CO_2$ emission in drying process.

It is obvious that much better results are achieved with the substituting coal with natural gas in firing process, so attention should be focused on finding ways to use more natural gas in ceramic tile production.

It is clear that carbon footprint of polished tile is larger than other products(as shown in table 6). So substituting polished tile with glazed tile or blank tile is maybe another way to reduce the total $CO_2$ emission in a ceramic tile factory. However, market capacity and economic benefit should be considered before this solution being executed.

## 6 Conclusions

As shown by calculation method used in this paper, $CO_2$ emission from ceramic tile production is mostly come from two processes which are spray drying and firing. Spray drying emits 26% $CO_2$ of total emission and the percentage is 57% for process of firing. Because of that, special attention is focused on the spray drying and firing. Comparing the effects achieved, on one hand are methods including substituting coal with other fuel, energy efficient improvement and new technology applying , and on the other are ways containing bringing in microwave drying technology and recycling of hot air emitted from drying tower, it can be concluded that the most efficient way to reduce $CO_2$ emissions is substituting coal with natural gas. The big potential for $CO_2$ reduction also lies in applying microwave drying technology. Product planning properly is considered to be another way to reduce the total carbon dioxide emission.

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