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COMPARATIVE ASSESSMENT OF CO_2 EMISSION FACTORS ESTIMATED USING STACK FLUE GAS MEASUREMENT DATA FOR TWO TYPES OF BRICK KILN: A CASE STUDY IN PHU THO PROVINCE, VIETNAM

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ABSTRACT

In Vietnam, the brick production sector is one of the construction material production sectors that has large emission of CO_2 – the major greenhouse gas, since it consumes a large amount of fossil fuels. This research aims at preliminarily estimating the CO_2 emission factors for two major kiln technologies used in brick production sector in Vietnam, namely tunnel and vertical shaft brick kiln (VSBK). For this purpose, field measurement of CO_2 concentration in stack flue gases of two brick factories in Phu Tho province – one of the largest brick production areas in the North of Vietnam were conducted. The results of data analysis have shown that the tunnel kiln has higher CO_2 emission factors compared to those of VSBK. The lower specific energy consumption and lower heat losses are the major causes for lower CO_2 emission factors of VSBK.

Keywords: Brick production sector, CO_2 emission factors, Tunnel kiln, VSBK, Vietnam.

Contribution/ Originality

This study is one of very few studies which have investigated the CO_2 emission factors for kiln technologies used in brick production sector in Vietnam.

1. INTRODUCTION

In Vietnam, the total CO_2 emission caused by the combustion of fossil fuels was about 114.1 million tons in 2009, in which the contribution of sectors was the following: production industry and construction (35.1%), power production (28%), transportation (25.4%), and other sectors (11.5%). The production industry and construction sector with high demand of fossil fuels (mainly coal and oil) has been the largest source of CO_2 emission. The amounts of CO_2 emission caused by

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the combustion of coal and oil have been continuously increased during the period of 1979-2009 in Vietnam [1] as shown in Fig. 1.

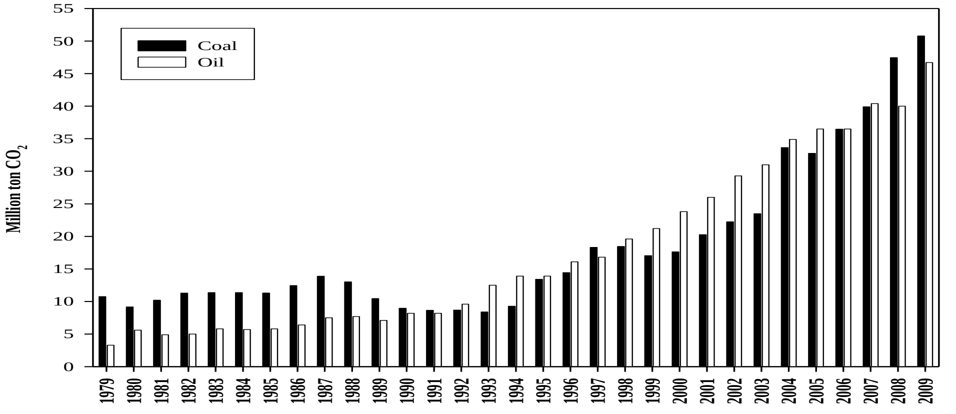

Fig-1. Amounts of CO_2 emission due to combustion of coal and oil during the period of 1979-2009 in Vietnam

On the other hand, during the last 20 years, the rapid economic development and urbanization in Vietnam has led to the significant increase in the construction activities. To meet the increasing demand of construction materials, brick production sector has strongly developed. The production of brick has continuously increased during the period of 2000-2010 [2] as shown in Fig. 2. In addition, the production of brick has been predicted to be much higher in 2015 and 2020, compared to those during the period of 2000-2010 (Fig. 2).

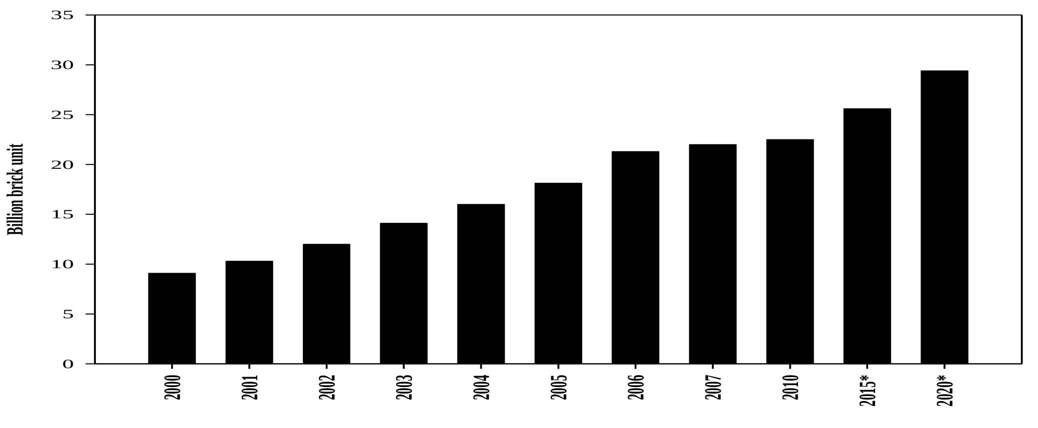

Fig-2. Production of brick during the period of 2000-2010 in Vietnam (*predicted data for 2015 and 2020 is used for comparison)

Currently, the two major brick kiln technologies used in brick production sector in Vietnam are the tunnel kiln and vertical shaft brick kiln (VSBK).

- **Tunnel Kiln**

Tunnel kiln (Fig. 3) has the origin from Germany and has been introduced into Vietnam since 1976. The capacity of this kiln is 7-40 million units/year thus is most suitable for medium- and large-scale production. This kiln technology is currently accounting for the largest share of brick production in Vietnam, about 60-65 %, due to a number of advantages such as advanced technology, large-scale and continuous production, large capacity, highly mechanized, heat recovery from firing, diversified products, reduced material consumption (about 15-40 %), reduced fuel consumption (about 20-35 %), and less environmental pollution problems compared to those of traditional kiln. The investment for installation and use of tunnel kiln in brick production has been encouraged by the Government of Vietnam towards the gradual elimination of traditional kiln which causing adverse environmental pollution problems.

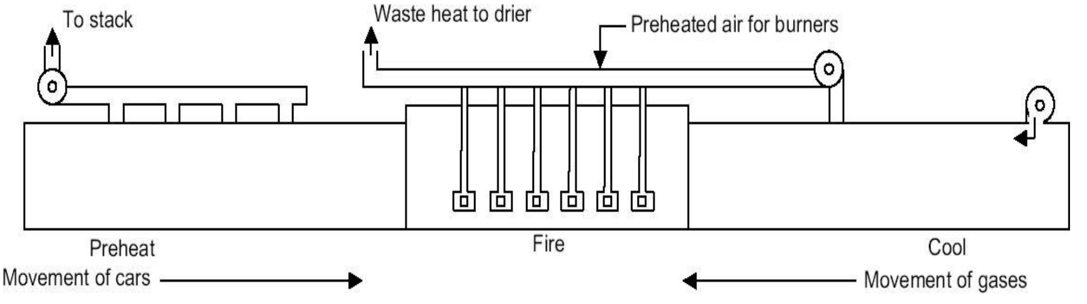

Fig-3. Schematic diagram of a tunnel kiln

In a tunnel kiln, a continuous moving ware kiln, the clay products/bricks to be fired are passed on cars through a long horizontal tunnel. The length of tunnel can vary from 60 m to 150 m. Three distinct zones appear in an operating tunnel kiln: brick firing zone at the central part of the tunnel where the fuel is fed and combustion is happening; brick preheating zone (before the firing zone) where the green bricks are being pre-heated by the hot flue gases coming from the firing zone; and brick cooling zone (ahead of the firing zone) where fired bricks are cooled by the cold air flowing into the kiln. Generally green bricks are produced by mixing powdered fuel with clay. Green bricks are then moved in the tunnel or chamber dryers on cars for drying. Heat from the hot flue gases coming out of the kiln is utilized for the drying of bricks. The cars loaded with dried green bricks are pushed in the kiln. The cars are moved inside the kiln intermittently at fixed time intervals. The duration of the firing cycle can range from 30 to 72 hours. Fuel (granulated/pulverised coal) is fed into the firing zone of the kiln through feed holes provided in the kiln roof. The firing zone usually extends up to 8 cars. The temperature in the firing zone is maintained from 900 to 1050 ^{o}C. There is counter current heat transfer between the bricks and the air. Cold air enters the kiln from the car exit end and gets heated while cooling the fired bricks. After combustion, the hot flue gases travel towards the car entrance end losing a part of the heat to the green bricks entering the kiln and then go to stack. Hot air/gases are extracted from the tunnel kiln at several points along the length of the kiln and are supplied to the drying tunnel/chamber. In some of the kilns, there is also provision of a hot air generator to supplement the requirement of hot air for drying.

- **VSBK**

The VSBK (Fig. 4) has the origin from China and has been introduced into Vietnam since 2001. VSBK is most suitable for medium- and small-scale production. During the last years, the application of VSBK has led to the gradual replacement of traditional kilns which causing adverse environmental pollution problems in Vietnam. The other advantage of the VSBK technology is the reasonable investment cost which most suitable to medium and small enterprises. For example, the investment cost for VSBK is just about 20% of that for modern tunnel kiln.

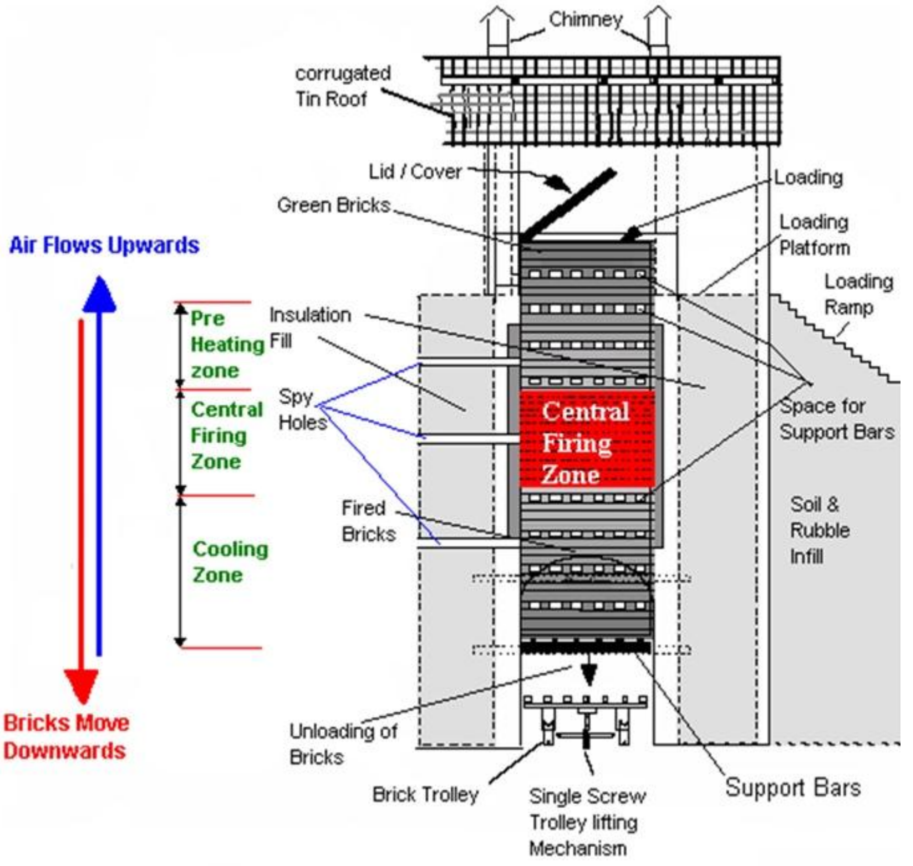

Fig-4. Schematic diagram of a VSBK

The VSBK technology is an energy-efficient updraft kiln comprising of a vertical shaft from which bricks are loaded at the top and removed at ground level in a continuous process (Fig. 4). An unloading tunnel runs through the centre of each kiln allowing for access to both sides of the shaft. Internal body fuel is mixed into the bricks with a measured amount of external coal spread evenly between the layers of stacked bricks to control the firing temperature. The position of the fire in each shaft in relation to the updraft is determined by the rate the bricks are removed and loaded into the shaft. This reuses the rising heat, making it very fuel-efficient. The firing shaft is very well insulated on all four sides, so that heat loss is minimized. Once the kiln reaches the specified temperature, the heat from the coal ignites the internal coal of the bricks so that very little heat is lost through exhaust gases or the kiln itself. These exhaust gasses are used for the gradual preheating of the unfired bricks on top, thus reducing energy consumption compared to the traditional kilns. The VSBK works on the basis of a 'counter current principle'. When the lid is closed, the shaft and exhaust becomes an integral chimney system. The firing process of preheat, firing (vitrification) and cooling takes place within the shaft, as the bricks move down the shaft. Energy efficiency is derived through the verticality of the shaft and structural thermal efficiency. The firing process is completed within a 24-hour period, a considerably short firing cycle, which tolerates very few mistakes.

The strong development of brick production sector during the recent years might result in the significant increase in CO_2 emission amount from this sector due to the increased use of fossil fuels, mostly coal. However, currently there is no estimation of the CO_2 emission amount from brick production in Vietnam due to the lack of CO_2 emission factors for kiln technologies used in this sector. This makes difficult for attributing the contribution of CO_2 emission from brick production sector to the total CO_2 emission of industry sector and evaluating the impact of brick production sector to climate change in Vietnam. For addressing this issue, this research aims at preliminarily estimating and comparing the CO_2 emission factors of two major kiln technologies which are tunnel and VSBK based on the CO_2 concentration data measured in stack flue gases of two brick factories in Phu Tho province – one of the largest brick production areas in the North of Vietnam.

2. METHODS

2.1. Measurement of CO_2 Concentration and Stack Gas Velocity

2.1.1. Measurement of CO_2 Concentration

CO_2 concentration in stack flue gases of brick factories were measured using the GCEM 40 Series Gas Analyser manufactured by CODEL International Ltd., UK following the USEPA Method 3A [3]. The GCEM 40 Series Gas Analyser uses a field proven in-situ 316 stainless steel probe designed for the harshest stack conditions to measure directly in the flue stream. Designed for use primarily on combustion processes, the GCEM40 40 Series Gas Analyser could be used to measure CO_2 using an infra-red spectroscopy to ensure that there is no cross sensitivity from other contaminants in the gas stream. Fully automated zero and span calibrations are performed using clean dry compressed air and protocol gas mixtures to provide long-term accuracy along with minimal maintenance requirements. Pneumatics mounted directly on the measurement probe allow both zero and span gas to be injected into the measurement chamber either manually, automatically or remotely. The analyser is fitted with a probe mounted temperature sensor. The GCEM 40 Series Gas Analyser can provide the real-time measurement data.

2.1.2. Measurement of Stack Gas Velocity

Stack gas velocity is measured using the type S Pitot tube following the USEPA methods including Method 1 [4] and Method 2 [5]. Prior to each measurement, the type S Pitot tube is calibrated using standard Pitot tube.

2.1.3. Selection of Measurement Site

The measurement site for CO_2 concentration and stack gas velocity is selected following USEPA methods including Method 1 [4] and Method 2 [5]. According to these methods, the measurement site should be located at least eight stack diameters downstream and two diameters upstream from any flow disturbance such as a bend, expansion, or contraction in the stack, of from a visible flame. If necessary, an alternative location may be selected, at a position at least two stack diameters downstream and a half diameter upstream from any flow disturbance.

In this research, measurements of CO_2 concentration in stack flue gases of brick factories using tunnel kiln and VSBK technologies in Phu Tho province, North of Vietnam were carried out during the periods of 4-10 Sep 2014 and 20-26 Sep 2014, respectively (Fig. 5 and Fig. 6). The production capacities of these tunnel kiln and VSBK are 30 million per year (equivalent to 8660 kg brick per hour) and 6 million bricks per year (equivalent to 1732 kg brick per hour), respectively.

The fuel used by both kilns is the local coal powder named "*4a Hon Gai*" with the carbon content by percentage of weight is 72% and the gross calorific value ~ 6500 kcal/kg. These kilns have been operated within the last 5 years.

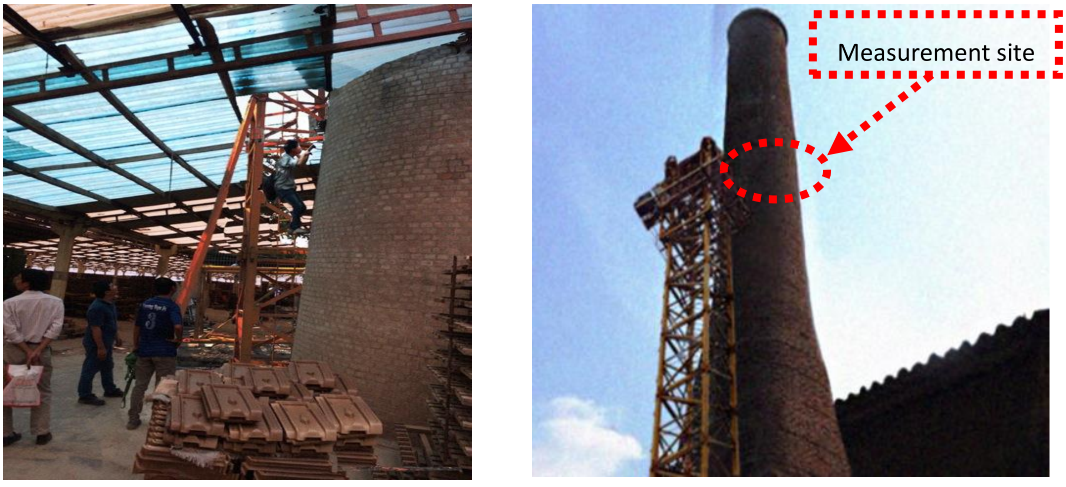

Fig-5. Measurement of CO_2 concentration in stack flue gases of brick factory using tunnel kiln technology

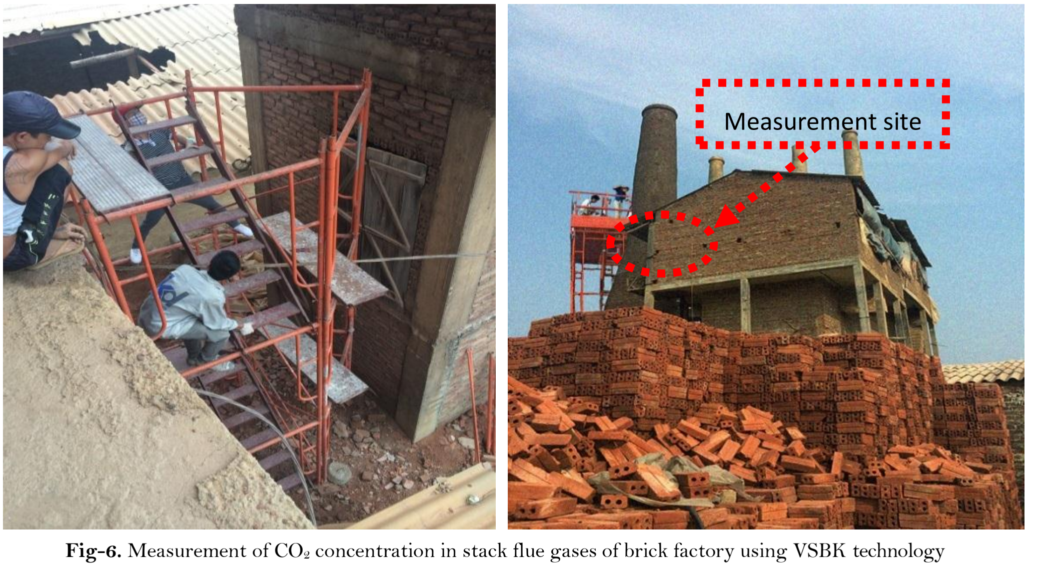

Fig-6. Measurement of CO_2 concentration in stack flue gases of brick factory using VSBK technology

2.2. Estimation of Stack Flue Gas Flow Rate

Stack flue gas flow rate is estimated as follows:

$F = v.A.3600$

Where:

- F: Flow rate of stack flue gas (m^3/hour)
- v: Stack flue gas velocity (m/s)
- A: Cross-section area of stack at the measurement point (m^2)

2.3. Estimation of CO_2 Emission Factors

The CO_2 emission factors for kiln technologies is estimated as follows:

$EF = C_{CO2}.F/W_b.1000$

Where:

- EF: CO_2 emission factor (g CO_2/kg of fired brick)
- C_{CO2}: Concentration of CO_2 in stack flue gas (mg/m^3)
- F: Flow rate of stack flue gas (m^3/hour)
- W_b: Brick production capacity (kg of fired brick/hour)

3. RESULTS AND DISCUSSION

The CO_2 hourly mean concentrations measured in stack flue gases of brick factories using tunnel kiln and VSBK technologies in Phu Tho province during the periods of 4-10 Sep 2014 and 20-26 Sep 2014 are shown in Fig. 7 and Fig. 8, respectively.

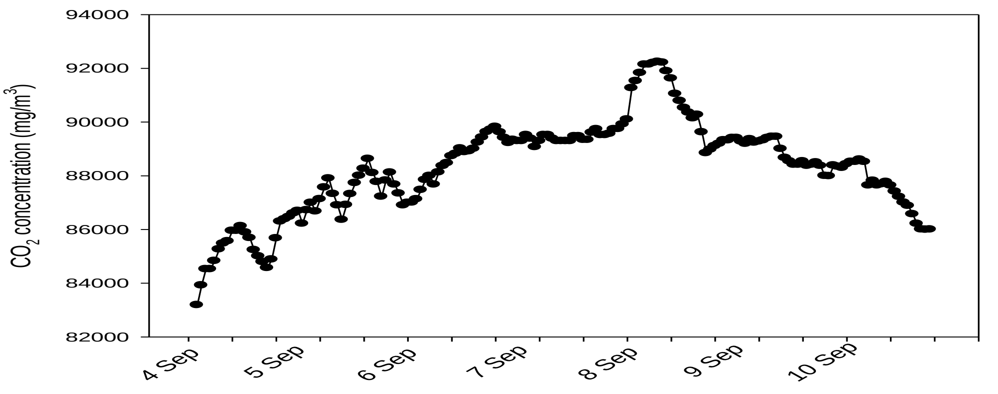

Fig-7. CO_2 hourly mean concentrations measured in stack flue gases of brick factory using tunnel kiln technology during the period of 4-10 Sep

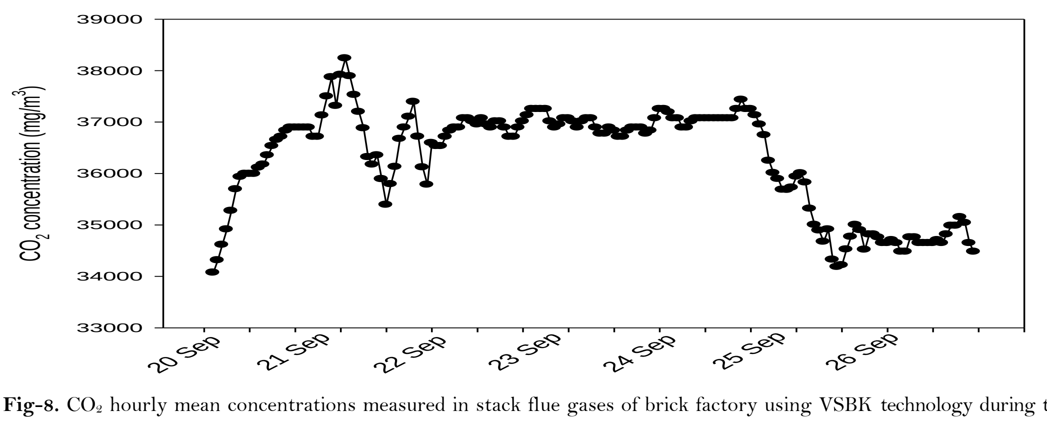

Fig-8. CO_2 hourly mean concentrations measured in stack flue gases of brick factory using VSBK technology during the period of 20-26 Sep

The flow rate of stack flue gas is calculated using the measured stack flue gas velocity and the recorded cross-section area of stack at the measurement point and presented in Table 1. Using the measurement data for CO_2 concentrations in stack flue gases of brick factories, the CO_2 emission factors of two brick kiln technologies which are tunnel kiln and VSBK are estimated and summarized in Table 1. It is seen that the averaged CO_2 emission factor of 174.87 g CO_2/kg of fired brick estimated for tunnel kiln is about 2.2 times higher than that estimated for VSBK. The less consumption of fuel of VSBK is the major reason for its lower CO_2 emission factor compared to tunnel kiln. According to Giovanetti and Volsteedt [6], the specific energy consumptions of VSBK and tunnel kiln are 0.84-1.1 and 1.65-2.1 MJ/kg of fired brick, respectively. Because of proper combustion of fuel, efficient heat transfer and minimal heat losses, VSBK is one of the most energy efficient brick kiln technologies. A very efficient counter flow heat transfer arrangement between air and bricks, uniform fuel distribution and sufficient insulation around the kiln attribute to the energy efficiency of a VSBK. The main sources of heat loss in a VSBK are only the hot flue gases and fired bricks coming out of the kiln. Whereas, since energy consumed by a tunnel kiln also includes the energy utilized for drying bricks in the tunnel dryer, its specific energy consumption is higher than that of VSBK. In addition to the hot flue gases and fired bricks at the kiln exit, the heat loss in tunnel kiln is also caused by heat contained in the kiln cars.

Table-1. CO_2 emission factors estimated for two brick kiln technologies

Kiln technology	Measurement date	CO_2 concentration ± Std. (mg/m^3)	Stack flue gas velocity (m/s)	Cross-section area of stack at the measurement point (m^2)	Flow rate of stack flue gas (m^3/hour)	Brick production capacity (kg of fired brick/hour)	CO_2 emission factor (g CO_2/kg of fired brick)
Tunnel	4 Sep 2014	85393	3.52	1.33	16811	8660	165.77
	5 Sep 2014	87397	3.60	1.33	17193	8660	173.52
	6 Sep 2014	88603	3.58	1.33	17098	8660	174.93
	7 Sep 2014	89417	3.55	1.33	16955	8660	175.06
	8 Sep 2014	90735	3.61	1.33	17241	8660	180.64
	9 Sep 2014	88941	3.65	1.33	17432	8660	179.03
	10 Sep 2014	87543	3.63	1.33	17337	8660	175.25
	Whole period	***88290***	***3.59***	***1.33***	***17152***	***8660***	***174.87***
VSBK	20 Sep 2014	36084	2.70	0.38	3739	1732	77.89
	21 Sep 2014	36841	2.75	0.38	3808	1732	81.00
	22 Sep 2014	36912	2.79	0.38	3863	1732	82.34
	23 Sep 2014	36934	2.71	0.38	3753	1732	80.02
	24 Sep 2014	37104	2.80	0.38	3877	1732	83.06
	25 Sep 2014	35330	2.65	0.38	3670	1732	74.85
	26 Sep 2014	34730	2.78	0.38	3850	1732	77.19
	Whole period	***36276***	***2.74***	***0.38***	***3794***	***1732***	***79.47***

In Fig. 8, the CO_2 emission factors estimated for tunnel kiln and VSBK in this study are compared with those reported for tunnel kiln and VSBK in the other countries which also using coal as the fuel. It is found that the averaged CO_2 emission factor of tunnel kiln estimated for this study is about 11.4% and 14.2% higher than those reported for India [7] and USA [8], respectively. However, with respect to VSBK, the CO_2 emission factor estimated in this study is lower about 27.8% than that in India [7]. The differences in CO_2 emission factors estimated for the same type of kiln technology and fuel between this study and the other studies might be attributed to the differences in used duration of kiln technologies, composition of fuel, energy consumption patterns, energy saving practices, etc. in Vietnam and the other countries.

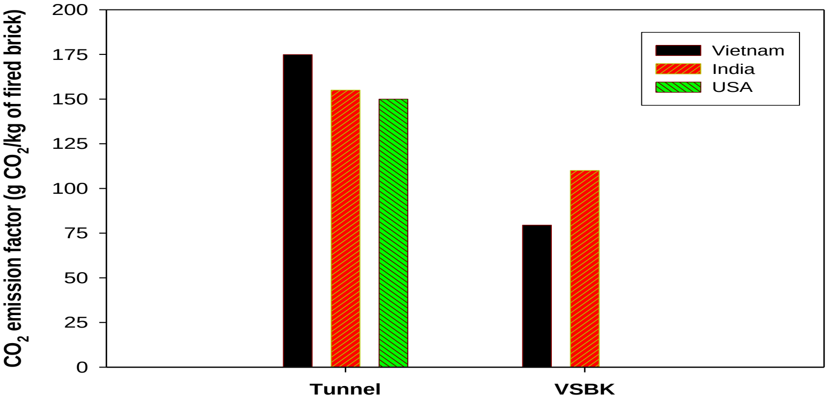

Fig-8. Comparison for CO_2 emission factors estimated between this study and the other studies

4. CONCLUSION AND RECOMMENDATIONS

This research carried out the measurement of CO_2 concentration in stack flue gases of two brick factories in Phu Tho province – one of the largest brick production areas in the North of Vietnam for preliminarily estimating the CO_2 emission factors of two major kiln technologies which are tunnel and VSBK. The study results have shown that the higher CO_2 emission factors were found with tunnel kiln. The higher specific energy consumption and heat losses of tunnel kiln are the major causes for its higher CO_2 emission factors compared to those of VSBK.

The CO_2 emission factors of tunnel and VSBK in this research were estimated basing on the field measurement data for only two factories. There could be some uncertainties due to a number of factors. Thus in order to suggest the more accurate CO_2 emission factors for these kiln technologies, it is necessary to conduct more field measurements for a larger number of factories corresponding to each kind of kiln technology.

5. ACKNOWLEDGEMENTS

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REFERENCES

[1] International Energy Agency, "CO2 emissions from fuel combustion highlights. IEA statistics," 2011.

[2] Vietnam Construction Material Association, "Overview on the development of Vietnam construction material industry (In Vietnamese)," 2008.

[3] USEPA, "Method 3A - Determination of oxygen and carbon dioxide concentrations in emissions from stationary sources (Instrumental Analyzer Procedure). Part 60 -- Standards of performance for new stationary sources, Appendix A to Part 60," 1991.

[4] USEPA, "Method 1 - sample and velocity traverses for stationary sources method. Part 60 -- Standards of performance for new stationary sources, Appendix A to Part 60," 1991.

[5] USEPA, "Method 2 - determination of stack gas velocity and volumetric flow rate (Type S Pitot Tube), Part 60 -- Standards of performance for new stationary sources, Appendix A to Part 60," 1991.

[6] Giovanetti and Volsteedt, "Vertical shaft brick kiln (VSBK) - An effective South-South technology transfer for climate change mitigation in the clay brick sector," presented at the Paper for the 16th IUAPPA World Clean Air Congress, 2013.

[7] Asian Institute of Technology, "Small and medium scale industries in Asia: Energy and environment. Brick and ceramic sectors. ISBN 974-8209-03-2," 2003.

[8] USEPA, "Emission factor documentation for AP-42 section 11.3. Brick and structural clay product manufacturing," Final Report, 1997.