Performance of a Rectangular Downdraft Open-top Kiln for a Dual Burner

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Abstract. *Bricks are well known materials used to support many constructions. The kiln is very simple and common equipment used to product the brick with firing technique taught from generation to generation. This work aims to evaluate the temperature distribution in the firing room and the specific energy consumption (SEC) of the proposed rectangular downdraft open-top kiln for a dual burner. The proposed kiln had dimension of 4 m x 8 m x 2.5 m (width x length x height); consisting of a dual burner with the wall thickness of 0.54 m. There were 50,997 pieces of bricks with the weight of 56,678 kg which were tested for proposed firing processes using the firewood as a fuel. The results showed that there were 74 hr of firing processes required; consisting of 18 hr for the preheating, 30 hr for the firing, and 26 hr for the cooling. The temperature distribution in the designed firing room was 597-721 °C for the side-walls where the top wall was 812 °C. The SEC was 2.52 MJ/kg fired brick.*

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1. Introduction

Bricks are the popular construction materials for thousands of years. They are also the most common building materials in Thailand due to large availability of clay as raw materials, the simple technology of production and cheaper than simplified materials at the same construction sectors as light-weight clay fired bricks and concrete blocks. The typical steps involved in brick making process are clay preparation, molding, drying of green bricks and firing. Thailand has produced 2,100 million clay bricks per year by 951 factories in 2003 [1]. Recently consumable goods are expensive affected by the inventory materials of brick factories. The kilns and technology adequately changed the efficiency management at process production and saving energy. Biomass, mainly firewood and rice husk are the main energy sources for brick firing [2]. Although Thailand is the rice top 5 world exporter of producing rice about 26.019 million tons per year, leaving rice husk of approximately 5.024 million tons [3] but the rice husk has been used in various sectors especially in biomass power plants. Rice husk is very expensive as 2,000 bath per ton compared with firewood of 900 bath per ton. The enterprise of brick is changing technology kiln from rice husk to firewood materials and the kiln type needs to be adapted too. Brick kiln technologies are used varieties of kilns for firing bricks. These can be classified in several ways, based on, the production process (intermittent and continuous kilns); on the direction of air flow (up-draft, down-draft and cross-draft kilns); or on the method of production of draft (natural draft and induced/forced draft kilns). In intermittent kilns, bricks are fired and cooled in batches. The kiln must be emptied and refilled; a new fire has to be started for each batch of bricks. Most of the heat contained in the hot flue gases, fired bricks, and the kiln structure is thus lost. In a continuous kiln, the fire is always burning and bricks are being warmed, fired, and cooled simultaneously in different parts of the kiln. Fired bricks are continuously removed and green bricks are continuously added. Consequently, the rate of output is approximately constant. Due to the incorporation of heat recovery features, continuous kilns are more energy efficient than intermittent kilns. Although, continuous kiln types can be stated to be the most important factor in energy savings, there is a trade-off between the energy consumption and the investment costs shown in Table 1.

Kiln type	Capacity '000 bricks		SEC	Investment cost
	per firing	per day	(MJ/kg)	'000 US$
Clamp kiln	5-1,000		2.0-8.0	--
Scove kiln	5-100		2.0-8.0	--
Scotch kiln	5-40		2.0-8.0	< 5
Downdraft kiln	10-40		2.0-6.0	< 20
Hoffman kiln		2- 24	1.5-2.8	> 80
Vertical Chineses kiln		4 - 30	0.8-0.9	> 4
Bull's Trench kiln		10- 48	1.5-2.8	> 7
High Draught kiln		20- 40	1.2-1.8	> 15
Tunnel kiln		50-150	1.2-2.5	> 1,000

Table 1 Capacity, energy consumption and investment cost of different types of kilns [4]

Classification for the types of brick kilns was previously reported [5,6]. Based on the direction of air flow with respect to the brick setting in the kiln, brick kilns can be classified as up draft kilns such as Clamps and vertical shaft brick kiln (VSBK), downdraft kilns and cross draft kilns such as Hoffman kilns, fixed chimney Bull's trench kiln and tunnel kilns. Energy efficiency is thus of great importance to brick manufacturers and their business operations [7]. The specific energy consumption (SEC) and specific coal consumption values of Clamp and other batch kilns (Asia) 2.0–4.5 MJ/kg of fired brick and 32–71 tons/100,000 bricks [8]. The open-top updraft kiln in firewood consumption has been reported that bricks fired in this type of kiln consume 4-5 MJ/kg of fired brick [9]. In intermittent kilns, bricks are fired in batches with maximum of SEC 3.85–5.35 MJ/kg of fired brick whereas for the downdraft one kiln 2.37 MJ/kg of fired brick [10].

In a down-draft kiln, air is first heated up by fire. The hot air is then made to enter the kiln from front and is brought down through the brick setting with the help of draft created by a stack. Typical, downdraft kilns in Latin America possess rectangular shape with a dome at the top and several openings at the side for inlet air and fuel [10]. The combustion starts at the front, rear and lateral zones of the kiln (12 burners), at the beginning of the burning process, the gases produced by the combustion move towards the roof of the dome, then the heat goes down through the bricks and finally through the small aperture at the floor. The fuel gases leave the kiln through an underground duct and move to the chimney. The draft is forced by a fan. This downdraft model kiln type can reduce energy consumption but it has some disadvantages. The dome on the top of the kiln causes fuel gas lost to the air. It is difficult to build with high cost and high risk to collapse. The dome has impeded air exchange to bricks in cooling process and has it a long process time. The distribution of fuel gases of 12 burners might be complex to manage the controller during burning process. Moreover, the brick loading inside the kiln through only front door in preparation process and bring it out after cooling down is a time-consuming and inconvenient process.

This research investigated an adopted rectangular downdraft open-top kiln model to simplify, none dome on the top and reduce cost. Moreover, the performance of this kiln was investigated.

2. Materials and Method

The rectangular downdraft open-top kilns in firewood are adapted from downdraft with a dome to improve performances and managements. This model is widely used in the areas of brick enterprise of Thailand. The dimensions of the kiln are width of 4 m, length of 8 m, and height of 2.5 m corresponding volume of 80 m^3 (Fig. 1). The walls of the kiln are 0.54 m thick and consist of filled bricks. There is no insulation material on the walls. The kiln can on contain clay brick about 50,000-80,000 pieces depending size or type of bricks loading. The main parts of rectangular downdraft open-top kilns in firewood consisted of 1) dual burner, 2) a high pressure blower, 3) kiln wall, 4) area of loading green brick, 5) the door, and 6) chimneys. The brief brick firing process in the Fig.1 kiln model is to as follows.

- The green brick is loaded in No.4 through the doors (no. 5), arrange the bricks from bottom to top, rows and space each row to hot gas flow. The bricks on top of kiln are closely and lower than top wall border about 0.10 m to prevent hot air loss. Then, sand is filled on the top brick after pre-heat bricks to insulate hot air loss too. The No. 5 is temporal door, simple to close and open when loading bricks and took it out.

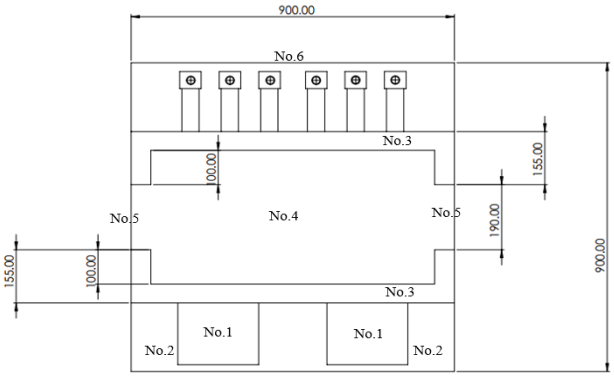

Fig. 1 Rectangular downdraft open-top kilns in firewood, Top view

- Burner (no. 1) consumes firewood, continuously slow filling at warm green brick to de-moisture content and prevent crack bricks. This takes about 18 h. Then, the high pressure blower is running, flow air through ducts in burner to complete combustion and hot gas air through kiln firing room (no. 4). The gases produced move towards the top of brick and sand insulator, then the heat goes down through the bricks and finally through the small aperture at the floor. The fuel gases leave the kiln through an underground duct and move to the chimney.

- Firewood is continuously filled in burner and operate blower until complete to firing bricks, experience observation fire flame through channel burner. If fire flame distribution to the back wall, stop the blower and close the burner to tempering bricks. Inside temperature brick kiln is close surrounding, it is finished firing process.

2.1 Experimental Procedure

The experimental procedure is as follows:

- The green brick types are 50,997 pieces; one type of 8-hole size dimension with wide, length, and thickness of 12.26x20.47x6.56 cm, respectively as quantity of 3,932 pieces. Another type of 4-hole size dimension with wide, length, and thickness of 6.42x15.13x6.37 cm, respectively as quantity of 47,045 pieces. The samples size brick were weight and moisture content.

- The green brick is full loading in firing room kiln.
- Fifteen K-type thermocouple probes with the temperature range of 0 to 1,300 °C were set up inside the kiln at burners (2 positions), the front wall (3 positons) and back wall (3 positions), two side door (4 positions), top brick (2 positions) and at a chimney position.
- The fuel was continuously sum firewood that collected from local area logger, recorded the weight before filled in the burners and sampling to moisture content.
- The temperature was manual recorded with data logger at every 3 h.
- The firing brick processes are as followed: pre-heat to warm and de-moist content take 24 h and an un-operate blower; drying process filled full fuels and operate blower are taken 24 h; the brick attracted high heat at high temperature longtime, the material stress, tempering brick take 24 h to slow decreased temperature. A total firing brick process of 72 h was finished, then carry out the sand on the top and open the doors were prepared collect brick productions.

2.2 Data Analysis

Temperature distributions in the rectangular downdraft open-top kiln was a main an important to quality of brick products. Several temperature recordings were shown graph and each temperature at the position. Firewood consumed to heating and the green brick loading can be energy consumption. According to [5], Specific energy consumption (SEC) is defined as the energy in MJ consumed for producing 1 kg of green brick. SEC is usually used as a parameter to compare energy performance of brick kilns. The SEC of the kiln is given by:

$$\text{SEC} = \frac{H_{in}}{M_{fbr}} \quad (1)$$

where M_{fbr} is mass of green bricks produced during one firing cycle/batch which is average mass of green brick x number of bricks fired in one firing cycle/batch. H_{in} is total energy input to the kiln for the duration of one firing cycle/batch which is energy input from external fuels fed in the kiln plus energy input from internal fuels added during moldings in the bricks plus energy input from the organic matter present in the brick soil. Moreover, product quality is evaluated as per the local market perception, good, inferior (under-fired & over burnt) and losses (breakages) [10].

3. Results and Discussion

3.1 Temperature Distribution in the Downdraft Kiln

Brick firing processes could be seen in deeper details in [5], the overall firing process can be categorized in three steps as preheat or warming, firing and cooling. K-type thermocouple probes were recorded at inner wall kiln and dual burners. Dual burner combustion firewood fuel was natural air flow to firing room. First step, sum fresh firewood fuel of moisture content about 60 %w.b. was slowly filled in combustion room every 3 h that consumed fuels of 660 kg, corresponding temperature reach 300 °C as Fig. 2. Also, preheat temperature was removed moisture of taking 18 h. Temperature at walls linear increased reach to 130 °C as Fig. 3. It is closely that gas hot air flow well distribution through brick in firing room. Then, blower is running and firewood fill full fuel every 1.5 h to accelerate firing zone, temperature at burners is rapidly increased maximum range 970-1026 °C at firing time. Firewood fuel consumed of 16,820 kg in 30 h at firing time.

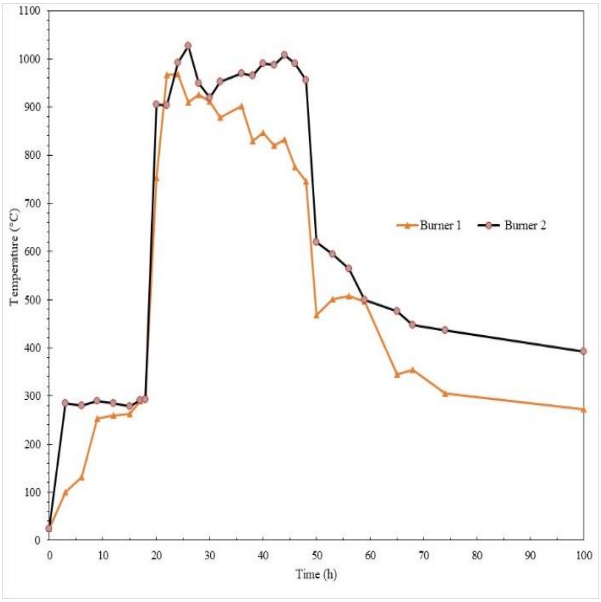

Fig. 2 Temperature profiles in dual burner

Hot gas fuel to accelerate distribution to firing room throughout brick move towards the top wall, that it is highest temperature of 812 °C, then the heat goes down through the bricks and finally through the small aperture at the floor. The fuel gases leave the kiln through an underground duct and move to the chimney. Whereas, pre-firing and firing time of 30 h, heat gas was distributed to walls as front, back, left and right side narrow range of 597-721 °C. The temperature of firing room was closely that effected quality of brick product as quantity of ripe brick, regular color and physical properties. Then, cooling zone, the burners were not filled the firewood, and close inlet air of burner, blower and chimney to prevent hot gas flow out. The temperature was slowly down until at time of 74 h, open the kiln that mean heat exchange with fresh air of burner inlet and chimney. The temperature is quite slowly down, it showed that this down draft open-top kiln conserved energy. The temperature can be rapidly down by given sand out the top and open the doors. This is adequate improvement the down draft kiln.

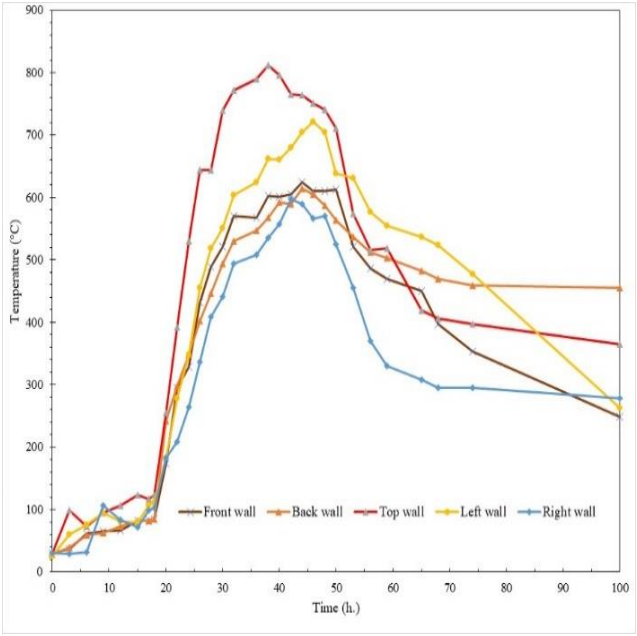

Fig. 3 Temperature profiles in firing process at the drying room wall

Moreover, firing range time of peak temperature distribution at main parts of downdraft open-top kiln were shown Fig. 4. The firing room of kiln was large, dual burner was regularly distributed temperature. A temperature burner of 1026 ˚C and anther one of 969 ˚C were nearly valuation. Temperature at right wall door, front wall and back wall was 597˚C, 624.6 ˚C and 613.6 ˚C, respectively. Whereas, temperature at left wall door of 721 ˚C was higher than others due to leak out of hot gas. Right and left were doors of kiln and were temporary wall. It can leak from clay binder because it is new rebuilt a firing batch. Temperature at top wall was 812 ˚C . It was natural hot air flow at the top and dispersed surrounding, moved down through bricks and exhaust tube of 328 ˚C.

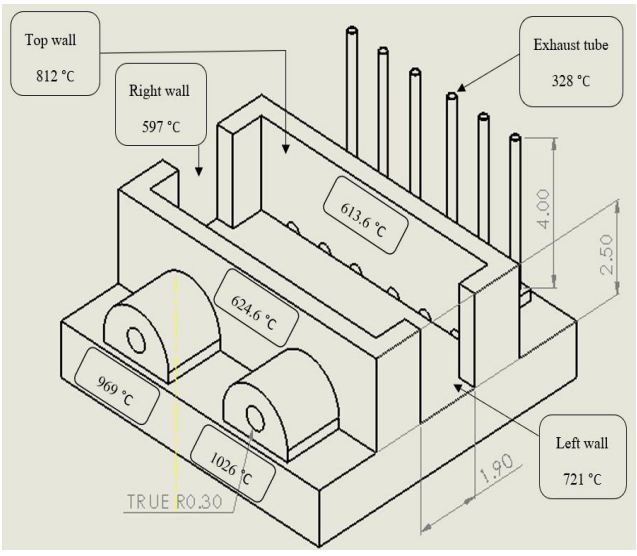

Fig. 4 Peak temperature distribution at main parts of downdraft kiln

3.2 Energy Consumption of the Downdraft Open-top Kiln

Data on fired clay brick in rectangular downdraft open-top kiln was shown in Table 2. A type of bricks is 4 hole and 8 hole which is summarize 50,997 pieces and 56,678 kg. Firewood was collected from local logger as *Dipterocarpus intricatus Dyer* and gross calorific value of 20.42 MJ/kg [11]. Firewood fuel of 17,480 kg was combustion to hot gas for the brick firing corresponding to total energy input 142,777 MJ. Specific energy consumption (SEC) is followed as equation 1 [5] of 2.52 MJ/kg fired brick. The energy required depends heavily of type of clay and the efficiency of the kiln. Hence, the specific energy consumption cannot be used as a single parameter to compare the kiln technologies across geographies. One should take extra care while commenting upon the technology performance using specific energy consumption data [5].

Whereas, as seen in [10] the SEC downdraft is 2.37 MJ/kg of fired brick, an intermittent kiln, bricks are fired in batches usual SEC maximum during 3.85–5.35 MJ/kg of fired brick and value of 4-5 MJ/kg of fired brick [9]. Kiln type, mechanisation rate in production, drying method, and fuel type are factors in different SEC values [13].

Indicator	Result	Unit
Downdraft dimension	5.0x9.0x2.5	m
a 4-hole brick weigh	1	kg
a 8-hole brick weigh	2.45	kg
Moisture content of green brick	7.85	%
A total weigh fired brick	56,678	kg
A total weigh firewood	17,480	kg
Moisture content of firewood	60	%
GCV of fuel at the moisture level at the kiln site	20.42	MJ/kg
Total energy input	142,777	MJ
Specific heat consumption	2.52	MJ/kg fired brick

Table 2 Data on fired clay brick in rectangular downdraft open-top kiln

The SEC of this research of 2.52 MJ/kg of fired brick is nearly value of [10], [13]. This indicates the potential for energy efficiency gains in brick production more than intermittent kiln, updraft kiln. However, the same type of kiln but this result may be the operation practice and leakages in the kiln, the fuel preparation process, the fuel feeding practice, uninsulated kiln walls, and the drying process. Furthermore, the research will be improved with insulated kiln walls and quality products.

4. Conclusions

This study highlights that most of the energy into brick production is consumed during the firing process in the rectangular downdraft open-top kiln. This model adapted from rectangular downdraft with a dome at the top

as improvement parts to appropriate local area, simple construction, and low cost investment. The results showed that the temperature distribution in firing room was similar to those of various walls (front, back, side and top). The potential energy efficiency gains in brick production is an indicated the SEC. The comparison the SEC this study with other research reveals agreement value of downdraft kilns. This study may serve as factories in the development of a local energy inventory of fired brick.

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