EVALUATION OF FLUE GAS TREATMENT EFFICIENCY FROM HONEYCOMB COAL - BURNING PROCESS IN HOUSEHOLDS AT XUAN DINH WARD, BAC TU LIEM DISTRICT, HANOI

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Abstract

The air quality in Hanoi is getting worse and worse due to the increase in population, private vehicles, industrial zones and emission sources from residential areas. One of the sources of air pollution comes coal burning, which emits many kinds of substances, such as carbon dioxide (CO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and sulfur dioxide (SO_2). The use of this energy source is controversial since it generates hidden indoor air pollution which adversely impacts human health. Therefore, reducing the concentration or treating air pollutants from coal burning has great significance in improving air quality and human health. The research investigated the honeycomb coal burning situation in Xuan Dinh ward, Bac Tu Liem district, Hanoi. The results of interviewing 23 households with honeycomb coal - burning activities showed that 56 % of households use 2 - 4 kg of coal/day for business and domestic purposes. The concentrations of SO_2, CO and NO_x in the input smoke were quite high, at 532.89 ± 37.21; 2452.33 ± 45.73 and 28 ± 3.04 mg/m^3, respectively. The coal - fired honeycomb exhaust gas treatment model using V_2O_5/TiO_2 anatase photocatalysts showed high efficiency in the reduction of CO (95 %), SO_2 (97 %) and NO_x (89 %).

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1. Introduction

Coal is used for energy production in many countries [1, 2, 3]. Coal is used in commercial electricity, urban areas and various industries [4, 5, 6]. Approximately 2.8 - 3 billion people use coal for heating and cooking in their households [7]. In Poland, about 12 million tons of coal were used in household incinerators for heating purposes in 2018 [8]. In developing countries, many households burn wood and/or coal for heating and cooking [9]. In addition to providing energy benefits, coal combustion releases a significant amount of emissions generated during combustion into the atmosphere which

have negative impacts on the environment and human health [10]. Coal combustion emissions include mainly CO, CO_2, NO_x, SO_2 and PM [11,12].

Currently, air pollution from individual household incinerators emitted during coal burning is not recorded. Coal burning for heating and cooking resulted in hazardous levels of indoor air pollutants in households in Xuanwei and Fuyuan. Rural counties in southwestern China have the highest rates of lung cancer among never-smokers in the country [13]. In addition, altered levels of several circulating immune/inflammatory markers were found to be associated with an increased risk of future lung cancer [14]. In Vietnam, fuel sources such as honeycomb coal, firewood, agricultural solid waste and liquefied petroleum gas (LPG) are the main sources of energy used for daily cooking. However, the use of these fuel sources also causes many indoor environmental pollution problems, affecting human health [15].

Hanoi is the second largest city in Vietnam with a population of about 8 million people [16]. Studies reported that some major cities of Vietnam (e.g., Hanoi) were among the top 10 air - polluted countries in Asia [17]. According to the study of Hopke et al., (2008), traffic emissions were the main cause of air pollution in Hanoi and the concentration of black carbon - a form of soot generated from traffic emissions - was very high [18]. In addition, industrial emissions and emissions from households' kitchens were also sources of air pollution. In Hanoi, there are still many households, especially many restaurants, that still use coal to serve livelihood activities. In 2020, the number of coal stoves in Hanoi is about 19,3342 [19]. Coal burning is not only considered a popular cooking tool in poor households but is also "favored" by small restaurants. Street vendors, tea, or fast - food shops often use coal. The restaurant's coal stoves are located along the small alleys, smoke and toxic gases flow along, flying to the households on the upper floors, causing a significant impact on the urban beauty and directly affecting the lives of the people around. Xuan Dinh ward is located in Bac Tu Liem district, Hanoi, with an area of about 3.52 km², a total population of 39,993 people, with a density of 11,361 people/km². This is a relatively narrow, crowded area, with a lot of coal - burning activities. The burning of coal for business purposes or personal life has been causing many negative impacts on air quality, directly affecting the health of users.

Traditional air pollution treatment techniques include adsorption, separation and the use of chemical disinfectants, but all of them share the same flaw: pollutants simply move from one location to another without being fully eliminated, or there is the potential for the formation of byproducts that are toxic to human health. Photocatalysts can function at room temperature when exposed to sunlight. As a result, photocatalytic materials are a promising element in technology for air purification and reducing the number of contaminants in the environment of water. Numerous articles on photocatalytic materials with considerable application potential have been published throughout the world [20]. The recent discovery of the photocatalytic pollution treatment technology using nano - TiO_2 material is regarded as a ground - breaking advancement. When titanium dioxide is exposed to ultraviolet (UV) radiation, excited states of electron and hole pairs are

produced. These pairs can then interact with oxygen and water vapor in the atmosphere to form superoxide ions (O_2) and hydroxyl radicals ($OH^\cdot$). Chemical compounds can be destroyed by the extremely potent agents O_2 and $OH^\cdot$ to produce CO_2 and H_2O [21]. Additionally, research revealed that vanadium - denatured TiO_2 materials could function quite effectively in the visible light region [20].

This study, therefore, conducted a survey of honeycomb coal - burning activities in Xuan Dinh ward, Bac Tu Liem district, Hanoi. The study also evaluated the composition of coal - fired emissions (NO_x, SO_x, CO_2 and CO) and proposed technology to apply photocatalysts to treat coal - fired emissions for households.

2. Methods

Household interview method

Conduct field trips to assess the honeycomb coal - burning situation in the study area through survey questionnaires. The total number of studied households with honeycomb coal - burning activities in Xuan Dinh ward, Bac Tu Liem district, Hanoi was 23. The survey period was from November to December 2019.

Drawing design method

The drawing of coal - fired exhaust gas treatment model was drawn with Autocad software - 2010 version.
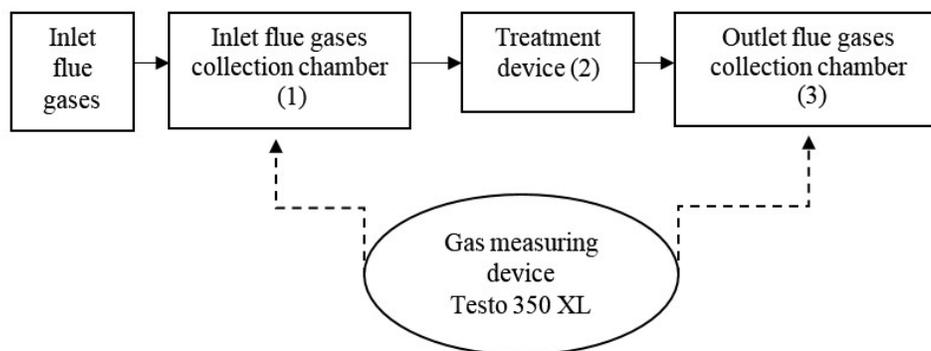
Measuring flue gas method

Figure 1: Honeycomb coal - fired emission measurement diagram

First, the exhaust gas was sucked into the inlet flue gas collection chamber. Then, the flue gas was passed through a processing device containing the V_2O_5 / TiO_2 Anatase photocatalyst with visible light. The treated flue gas was collected by the outlet flue gas collection chamber. Inlet and outlet gas measurement results (NO_x, SO_x, CO_2 and CO) were based on analysis results from the Testo 350 XL. The Testo probe was placed perpendicular to the airflow in the inlet and outlet chambers.

The honeycomb coal - fired flue gas treatment efficiency was calculated by the following formula:

$$H = (C_0 - C_t)/C_0 * 100$$

C_0: *Inlet flue gas concentration (mg/m^3)*

C_t: *Outlet flue gas concentration (mg/m^3)*

H: Flue gas treatment efficiency (%).

Statistical method: Statistics based on Excel software - 2013 version. The measured data was entered into the software for statistics and processing.

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3. Results

3.1. Evaluation of the situation of honeycomb coal - burning in households in Xuan Dinh ward, Bac Tu Liem district, Hanoi

The subjects using honeycomb coal were mainly small businesses and households. Households used coal for trading, business as well as family activities (Figure 2a).
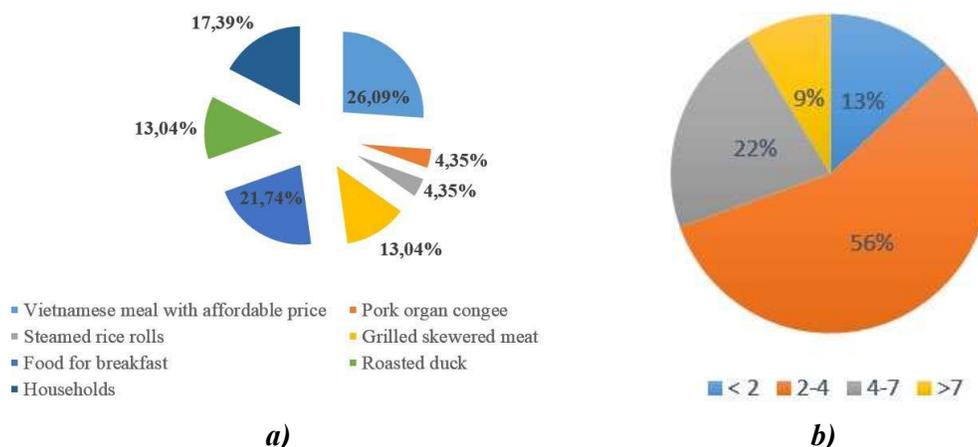

Figure 2: Purpose of using honeycomb coal - burning (a) and honeycomb coal - burning percentage based on coal volume (kg/day) (b)

The daily volume of coal used by households was about 1 - 8 kg (Figure 2b). Households burning more than 7 kg of coal/day accounted for a low percentage, only 9 %. Most of the households used 2 - 4 kg of coal/day (56 %). According to statistics on indoor air pollution from the World Health Organization for the year 2020, around 3 billion people worldwide still use charcoal, wood stoves,... for cooking and heating. In 2020, household air pollution caused 3.2 million deaths, including approximately 237,000 deaths of children under the age of five. Exposure to household air pollution increases the risk of developing non - communicable diseases, such as lung cancer, chronic obstructive pulmonary disease, stroke and ischemic heart disease. The biggest health burden from the use of polluting fuels in households is placed on women and children because they are often in charge of household work (e.g., cooking and collecting firewood) [7]. It is essential to use treatment technologies to reduce household air pollution and protect health.

3.2. Components of inlet honeycomb coal - fired flue gas

In order to evaluate the composition of coal - fired exhaust gas, 1 kg of honeycomb coal was put into the stove. The blower continuously supplied air. Honeycomb coal can be burned. The coal - burning flue gas was collected into a chamber and analyzed for content. The composition of exhaust gas after burning honeycomb coal is presented in Table 1.

The concentration of SO_2, CO, NO_x in the emission was quite high at 532.89 $\pm$ 37.21; 2452.33 $\pm$ 45.73 and 28 $\pm$ 3,04 mg/m^3, respectively. The exhaust gas composition after burning coal contained a large amount of CO_2 with a concentration of 4.39 $\pm$ 0.08 %. Doan et al., (2016) reported that the CO_2 and CO concentration in the honeycomb coal - fired flue gas was about 4,64 % and 2000 mg/m^3 [20].

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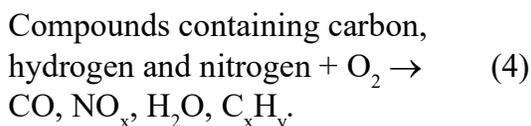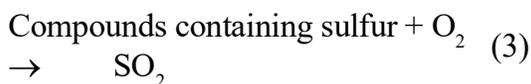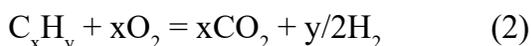*Table 1. Components of inlet honeycomb coal - fired flue gas (n = 9)*

No.	Parameters	Unit	C (mg/m³)	QCVN 19:2009 Column B (mg/m³)	Comment
1	SO_2	mg/m³	532.89 ± 37.21	500	Need to be treated
2	CO	mg/m³	2452.33 ± 45.73	1000	Need to be treated
3	NO_2	mg/m³	2 ± 0.29	-	-
4	NO	mg/m³	26 ± 0.31	-	-
5	NO_x	mg/m³	28 ± 3.04	850	-
6	CO_2	%	4.39 ± 0.08	-	-

Although the air was supplied continuously, there was still the presence of CO in the coal - fired exhaust. This can be explained that the gas retention time in the burner was not high enough for the oxygen in the air to contact the carbon and completely convert C_xH_y to CO_2. The generation of emissions during coal - burning can occur due to complete or incomplete reactions, forming the corresponding gases. The basic reactions that take place are as follows [22]:

Incomplete carbon burning reaction:

$$2C_xH_y + xO_2 = 2xCO + yH_2 \qquad (1)$$

Incomplete carbon burning reaction:

$$C_xH_y + xO_2 = xCO_2 + y/2H_2 \qquad (2)$$

Compounds containing sulfur + O_2 → SO_2 $\qquad (3)$

Compounds containing carbon, hydrogen and nitrogen + O_2 → CO, NO_x, H_2O, C_xH_y. $\qquad (4)$

Gaseous substances whose concentrations are significantly impacted by outdoor levels, such as carbon monoxide (CO), nitrogen oxides (NO_x) and sulfur dioxide (SO_2). However, indoor levels can be raised by combustion devices, tobacco smoke and incense burning. After using an unvented gas burner to cook, some Canadian homes' CO levels have been reported to be as high as 115 mg/m³. At low levels (120 - 520 ppmv), CO has minimal side effects that are frequently mistaken for a cold. These signs include a headache, lightheadedness, confusion, nausea and fatigue. Due to its unpleasant effects on the respiratory system, NO_2 is a concern in indoor air. Indoor NO_2 concentrations normally range from 30 to 40 ppbv, with occurrences as high as 100 ppbv. Indoor concentrations of SO_2 range from 0.5 to 32 lg/m³. The side effects of SO_2 exposure include coughing, throat and eye irritation and difficulty breathing [23]. In general, honeycomb coal - burning emissions both pollute the environment and affect human health. In this study, the CO and SO_2 concentrations both exceeded QCVN 19:2009. Thus, the CO and SO_2 concentrations in the emission were quite high and they should be treated before releasing into the environment.

3.3. Proposing a technology for treating honeycomb coal - fired emissions for households

The data above showed that the treatment of coal - fired emissions is really necessary to protect human health, air quality, thereby improving the quality of human life. However, in order to apply treatment technologies to households, treatment equipment must be inexpensive, compact, suitable for the working space, quality assurance, safe and sustainable,... In this research,

based on survey results on the coal - burning situation and estimated emissions from coal - burning, the photocatalytic method for treating coal - fired emissions for households has shown its suitability.
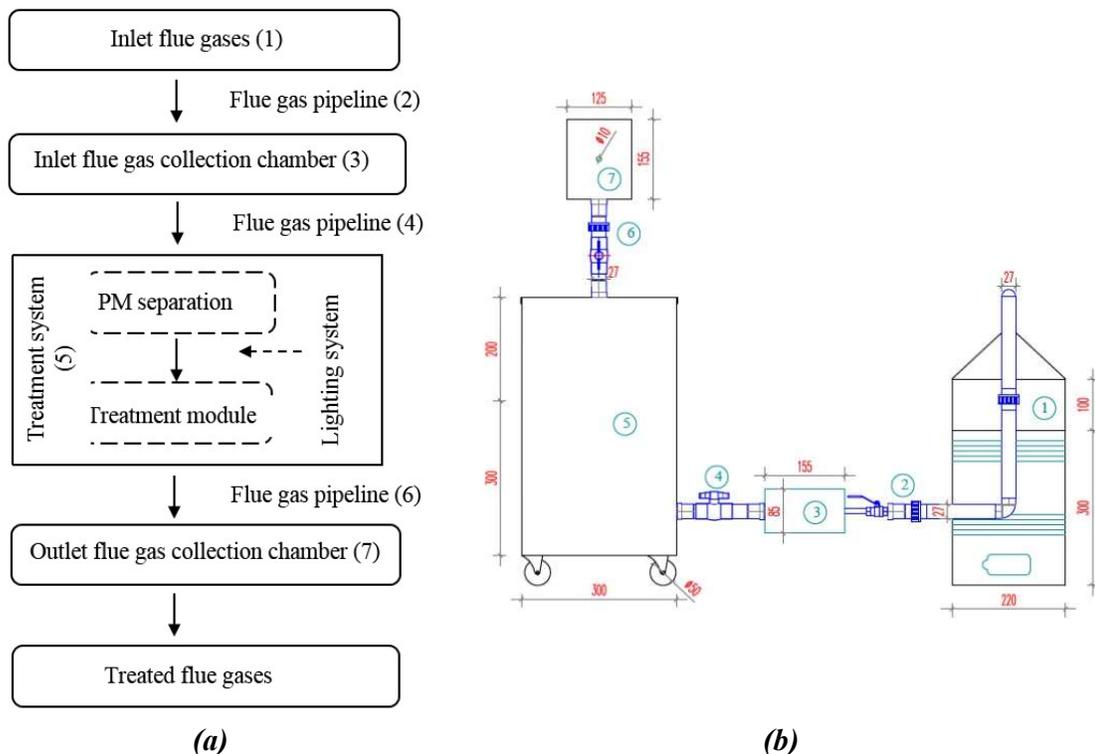

Figure 3: Technological diagram (a) and elevation (b) for honeycomb coal - burning emission treatment in households

The operating principle of the treatment device will be as follows: Initially, coal - fired emissions are collected into the inlet air collection chamber by an exhaust fan. The exhaust gas then enters the treatment system with a reaction chamber containing a layer of dust filter cotton for the purpose of retaining dust particles on this cotton layer. The exhaust gas then continues to pass through the V_2O_5/TiO_2 anatase photocatalyst layer. Here, the exhaust gas will be treated when it comes into contact with the catalyst material at room temperature and under lighting conditions. Finally, the treated gas continues to go to the outlet air collection chamber and out to the environment by the exhaust fan. The treatment model uses a flow regulator to control the inlet and outlet flow of the exhaust gas.

3.4. Testing the effectiveness of a model using V_2O_5/TiO_2 anatase photocatalyst in treating smoke from a honeycomb coal - fired furnace at a semi - pilot scale

We performed the test on treating the exhaust gas produced by burning coal (Figure 3b). The module had a diameter of 0.7 cm, contained 1 g of photocatalytic material and was designed by a crystal module. The exhaust gas was collected in a gas collector following the treatment stage. In order to calculate the treatment efficiency, the concentration of the gas components was determined.

Table 2. Evaluation of the efficiency of honeycomb coal - fired flue gas treatment (n = 9)

Parameters	Unit	Inlet of gases	Outlet of gases	Efficiency of reduction (%)
CO	mg/m^3	2452.33 ± 45.73	105.77 ±26.05	95.69 ± 1.06
SO$_2$	mg/m^3	532.89 ± 37.21	12.33 ±2.87	97.67 ± 0.62
NO$_x$	mg/m^3	28 ± 3.04	2.89 ±1.26	89.52± 4.72
CO$_2$ (%)	%	4.39 ± 0.08	4.41 ± 0,03	-

The findings demonstrated that the exhaust gas produced by burning coal was effectively treated: The converted CO was greater than 95 %, the converted SO$_2$ was 97 % and the converted NOx was 89 %, compared to the composition of the input exhaust gas (Table 2). The concentration of CO$_2$ that was collected was quite high, rising from 4.39 % to more than 4.41 %. The efficiency of NO$_x$ and CO gas removal in this study was higher when using Fe/N/Co-TiO$_2$ materials with the degradation rates of NO$_x$ and CO under visible light were 71.43 % and 23.79 %, respectively [24]. Initial research contributes to solving the problem of air pollution from honeycomb coal - burning emissions. In addition, photocatalysts are also quite cheap compared to precious metals in gas treatment, which households can buy and use, both to solve the problem of indoor air pollution and to improve their health.

4. Conclusion

The findings of this study showed that the daily volume of coal used by households was about 1 - 8 kg. In which, households burning more than 7 kg of coal/day accounted for a low percentage, only 9 %. The highest was 56 %, for households using 2 - 4 kg of coal/day. Analytical results showed that the concentration of SO$_2$, CO, NO$_x$ in the inlet flue gas was quite high at 532.89 ± 37.21; 2452.33 ± 45.73 and 28 ± 3,04 mg/m^3, respectively. The exhaust gas composition after firing coal contains a large amount of CO$_2$ with a concentration of 4.39 ± 0.08 %. To reduce the impacts of honeycomb coal - fired flue gases on the health of people and the environment, we proposed the model for coal - fired emission treatment with V$_2$O$_5$/TiO$_2$ anatase photocatalyst, which can be applied in households and give high removal of CO (95 %), SO$_2$ (97 %) and NO$_x$ (89 %).

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