Estimating Emission Factors of Fifteen Categories of Meats from Thai-Style Barbeque Activities

Saranya Manatsakarn and Nares Chuersuwan

Abstract— This study aims to determine air emission factors from meats grilling activity commonly found in Thailand. The major air pollutants included CO, NOx, SO2, particulate matter (PM10) and two greenhouse gases (CO2 and CH4). Measurements were conducted in a chamber to collect air emission in stack. Eucalyptus charcoal was solely used as the fuel during the grilling of meats. Gases pollutants were analyzed real-time while PM and CH4 were collected and subsequently analyzed in the laboratory. CH4 concentrations were quantified by a Gas Chromatograph while PM concentrations were quantified by gravimetric methods. Each of meat grilling was replicated nine times for the total of 15 types of meats (n = 135 tests). The average emission factors of all meats ranged from 756.49-3,343.91 g/kg of meat for CO, 0.42-3.58 g/kg of meat for NOx, 0.009-0.042 g/kg of meat for PM10, 10,587.62-47,236.79 g/kg of meat for CO2 and 30.39-171.12 g/kg of meat for CH4. SO2 was not detected. Results from this study was intended to provide insight for emission estimates from food stalls found across the country. These emission factors can be used to generate more realistic emission inventories and therefore improve the results of estimate emissions of meat grilling in Thailand.

Keywords— meat grilling, major air pollutants, greenhouse gas, emission factors.

I. Introduction

Meat grilling is commonly found along the urban street food stalls in Thailand. Charcoal meat grilling is a source of anthropogenic greenhouse gas and major air pollutant released into the atmosphere. Cooking emissions are influenced by the fuel used and the food being cooked [1]. During incomplete combustion of charcoal meat grilling emits particulate matters, carbon dioxide (CO2), carbon monoxide (CO), nitrogen oxides (NOx), volatile organic compounds (VOCs), aldehyde, polycyclic aromatic hydrocarbons (PAH), and total hydrocarbons (THC) [2-5]. During charcoal burning air pollutants can be absorbed in food and degrade air quality in the surrounding environment [6]. Regarding these pollutants, their adverse effects on human health are a great of concern, increasing hazard of the nearby people exposed to pollutants with potential health risks [6]. The pollutant emissions from the combustion such as, PM, NOx and CO have contributed substantially to the regional environment pollution problem [7-8] and meat grilling has the potential to produce net global warming especially CO2, the main driving force for the past global climate change [9-11]. However, the emission factors from meat grilling activities in Thailand are not available.

To evaluate the emissions from meat grilling by charcoal, emission factors are normally used to estimate the emissions. These estimations relate to the quantity of pollutants released into the atmosphere by such activities. The emission factor (EF) represents the quantity of a compound emitted per quantity of fuel consumed (g/kg), per kilogram of meat (g/kg meat) or per unit energy. In this context, the objective of this study is to determine emission factors of gases and particulate matters emitted from grilling activities in Thailand.

II. Methodology

All meats were purchased locally from markets in the area, including pork, chicken, fish, squid, shrimp, Thai sausage, Thai sour pork and meatball. Charcoal derived from eucalyptus woods was used exclusively as the solely fuel. Charcoal was also purchased from local production. This study selected meats that were commonly sale or consumed locally. The grilling tests and results were based on wet weight basis.

Combustion testing equipment has been designed and installed in a laboratory at Suranaree University of Technology. The equipment is in the form of an inverted funnel with a cylinder bottom, 1.20 m. in diameter and 0.80 m. in high. From the top of the cylinder, the tower decreases to 0.28 m. in a length of 0.50 m., and is topped with a stack 1.70 m. in height. Surface area of the stack is

Saranya Manatsakarn
Program in Environmental Pollution and Safety, School of Environmental Health
Nares Chuersuwan
Suranaree University of Technology, Nakhon Ratchasima, Thailand

https://doi.org/10.17758/EAP.U0317208

0.03 m2. The lowest position of the testing equipment is the aluminum rectangular box, used to collect the ash obtained from combustion. The size of aluminum rectangular box is 0.50 m. x 0.50 m. Meats were grilled on a aluminum mesh screen, 0.40 m. x 0.47 m. The schematic sketch of the combustion testing equipment is shown in Fig. 1, along with locations of sampling points. A gas sampling point was at 0.50 m. below the top funnel. Temperatures and velocity of airflow was measured at the same location. Particulate matters were collected in-stack using the ANDERSEN eight-stage impactor (Graseby Andersen, USA). All measurements of CO, CO2, SO2, and NOx, were performed by a Testo 350 (Testo AG, Germany), while CH4 were measured by a GC-FID (Agilent Inc., USA).

The probe was inserted into the sampling port after the charcoal was lit. In-stack measurement with the gas analyzer, Testo 350, was connected to a computer to record real-time concentrations of CO, CO2, SO2, and NOx. The Testo easyEmission® software was used as the interface.

Grab sample was used for collecting methane gas in-stack. The samples were sampling every 3 minutes using a polypropylene syringe and were transferred into separated gas sampling bags (Tedlar® bag), about 200 ml in each bag. Methane was quantified by a GC- FID (Agilent 7890A, USA). The GC was calibrated daily with a standard CH4 gas (certified 19.5 ppm, Air Liquid, Thailand). All gas sample bags were analyzed within 24 h in laboratory. All gas sampling bag used in each experiment were flushed adequately with compressed clean air for at least three times and evacuated before use.

All samples were tested for moisture content according to Association of Official Analytical Chemists method [12]. The background concentrations of test gases were also measured routinely for 5 minutes at the beginning of each test

Prior to each grilling test, meats, charcoal, and aluminum foil were pre-weighted with an analytical balance and recorded all weights. Aluminum pan was placed under to collect remaining ash. Charcoal weighted about 700 g for each test and placed in the bottom of an aluminum mesh screen. Another electronic balance, Mettler Toledo (MS32001L), was placed under the combustion equipment and connected to a computer to record mass changes. The LabX™ software was used as the interface to continuously monitor the mass. Emissions were recorded until the combustion was finished. Gas velocity in stack (m/s), temperature (°C), sampling time (min), and weight loss (g) were also continuously measured and recorded. All the grilling activities were ventilated naturally. Ash was left at room temperature to cool down before weighted and recorded the remaining mass.

A. Computing Method

Emission factor of gaseous was estimated according to [13].

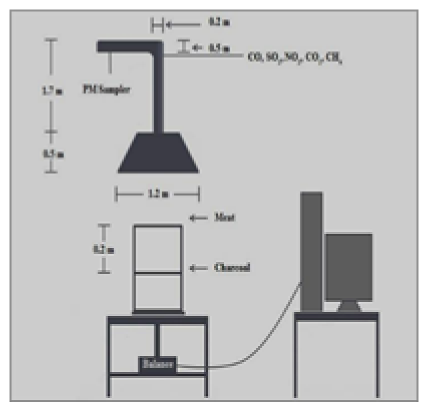
$$E_i = \frac{10^{-3}}{m_{fd}} \int_{t_0}^{t_f} A_s\, u\, C_i \,\frac{w_i}{22.4} \quad (1)$$

where: Ei is the emission factor of gas i (g/kg), mfd is the mass of burned material (g), t0 is the initial time of burn (s), tf is the final time of burn (s), As is the surface area of the stack (m2), u is the velocity of gas in the stack (m/s), Ci is the concentrations of measured gas (ppm), and w_i is the molecular weight of measured gas (g/g-mol).

The emission factor for particulate matter was determined by direct method as follows:

$$EF_{PM} = \frac{M_i}{M_{meat}} \quad (2)$$

where: EFPM is the emission factor of particulate matter (mg/kg or g/kg), Mi is the mass of emitted particles on a filter (mg or g), and Mmeat is the weight of meat (g or kg).



(a)

(b)

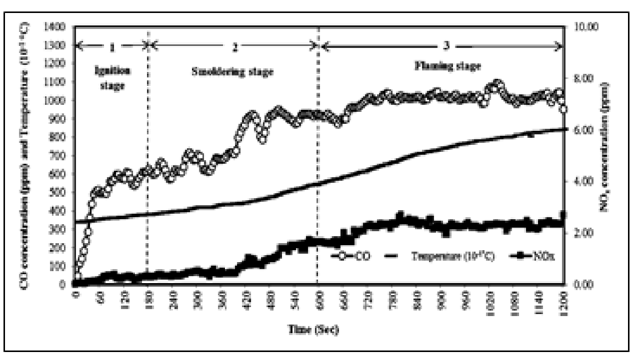
Fig. 1: **(a)** Illustrative drawing of combustion testing equipment and **(b)** Combustion testing equipment, the chimney and aluminum mesh screen and aluminum rectangular box for collecting ash on top of the balance

III. Results and Discussion

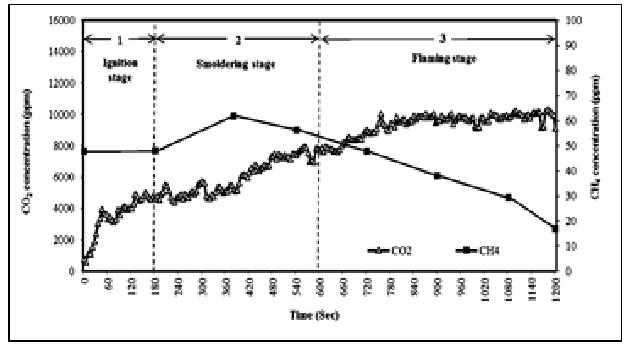
Each grilling took about 15-20 minutes. Gas emissions during ignition stage increased rapidly. A large quantity of PM, CO, NOx, and CO2 were generated during smoldering stage and further increased during the flaming stage (Fig. 2). In contrast, CH4 concentrations were slowly increase during ignition stage and higher in smoldering stage. CH4 concentrations were slowly decrease in flaming stage and were lowest at the end of the grilling activity.

Real-time measurement data indicated that incomplete combustion from charcoal meat grilling led to high emissions, especially CO whilst led to low concentrations of NOx and PM emissions. This suggested that the fat content of meats and temperature during meat grilling was one of the key factors in releasing high CO and NOx emissions. SO2 was not detected in all samples. When meat fat dripped onto the flamed charcoal, rapid increased and high concentrations of CO and NOx were observed. Meats with high fat contents showed high potential of releasing more CO and NOx into the atmosphere during charcoal grilling. These meats included pork, chicken, chicken wing, Thai sour pork, and catfish.

Carbon monoxide had the highest estimated emission factors in the range of 756.5-3,343.9 g/kg of meat, followed by NOx 0.4-3.6 g/kg of meat. PM10 was in the range of 0.009-0.042 g/kg of meat, based on wet weight basis (Table 1). In terms of greenhouse gases, estimated emission factors of CO2 was 10,587.6-47,236.8 g/kg of meat while CH4 was in the range of 30.4-171.1 g/kg of meat. In an U.S. EPA, 1999 report, the emission factors of grilled chicken with fired-charbroiler were 157.9, 4.2, and 9.4 g/kg of meat for CO, NOx, and PM10, respectively [3]. The CO emission factor from this study was higher than the values reported in the literature while NOx and PM10 emission factors were lower.



(a)



(b)

Fig. 2: Example of the typical patterns of emissions from chicken grilling activities **(a)** Time series of CO and NO_x concentrations **(b)** Time series of CO_2 and CH_4 concentrations

Meat type	Emission factors (g/kg of meat)				
	CO	NO_x	PM_{10}	CO_2	CH_4
Pork	898.48±169.56	1.86±1.21	0.013±0.002	14,253.85±2,664.81	40.05±12.78
Chicken	995.98±107.10	2.20±1.50	0.012±0.002	13,635.19±2,336.30	30.39±10.19
Chicken wing	1,318.96±328.01	3.58±0.85	0.023±0.003	16,697.06±2,922.87	33.59±7.77
Chicken liver	1,020.08±213.34	0.95±0.66	0.009±0.001	13,591.04±2,720.59	41.67±15.63
Catfish	3,343.91±193.25	1.99±1.38	0.041±0.003	45,000.44±9,602.49	171.12±35.09
Ruby fish	2,992.29±648.20	1.11±0.88	0.020±0.004	38,001.45±9,350.28	131.94±15.64
Tilapia	2,566.39±747.02	1.14±0.59	0.026±0.013	32,364.09±6,881.15	98.06±43.31
Shrimp	2,702.94±410.51	1.23±1.28	0.042±0.012	34,013.70±3,984.17	135.76±39.58
Squid	756.49±104.50	0.71±0.50	0.011±0.005	10,587.62±2,380.06	33.52±11.71
Thai sausage	3,221.21±1,078.82	1.08±0.63	0.041±0.009	47,236.79±12,428.16	167.67±43.00
Thai sour pork	3,033.58±702.65	2.33±1.43	0.031±0.008	36,644.31±7,667.46	147.27±29.30
Meatball	2,046.96±256.73	1.16±0.46	0.017±0.004	25,182.34±3,789.48	104.52±20.92
Pork ball	2,594.88±346.79	1.06±0.96	0.027±0.003	26,524.08±5,109.03	122.29±44.82
Fish ball	2,062.22±776.24	0.85±0.44	0.017±0.003	29,345.75±5,582.94	81.81±17.04
Chicken ball	2,205.76±1,167.99	0.42±0.42	0.023±0.006	24,201.65±10,351.04	137.69±73.43

IV. Conclusion

Among fifteen meats, grilling catfish showed the highest emission factor of CO and CH4 (3,343.91 and 171.12 g/kg of meat, respectively) while grilling the chicken wing had the highest emission factor of NOx, 3.58 g/kg of meat. Grilling shrimp showed the highest emission factor of PM10, 0.042 g/kg of meat, and Thai sausage had the highest emission factor of CO2 47,236.79 g/kg of meat. Developing emission factors to suite local conditions is a step toward the refinement of emission inventory in Thailand. Measurements of particulate matter, especially PM10 showed discrepancy with literature that needs more scrutiny. However, grilling method and type of fuel were differed and possibly contributed to large deviations. All of meat grilling activities was unable to detected SO2 since sulfur is negligible in both fuel and meats used in the experiments. Future measurements may exclude SO2 from the similar experiments.

ACKNOWLEDGMENT

The authors would like to thank the Suranaree University of Technology, Nakhon Ratchasima, Thailand for financial support of the study and School of Environmental Health for laboratory works and equipment.

REFERENCES

[1] S. Haryono, T. Susumu, and C. Renqiu, "Indoor PM2.5 characteristics and CO concentration related to water-based and oil-based cooking emissions using a gas stove," Aerosol and Air Quality Research, pp. 401–411, 2011. https://doi.org/10.4209/aaqr.2011.02.0016

[2] B. Sung, YS. Kim, and R Perry, "Indoor air quality in homes, offices and restaurants in Korean urban areas-indoor/ outdoor relationship," Atmospheric Environment, pp. 529-544, 1997. https://doi.org/10.1016/S1352-2310(96)00215-4

[3] United States Environmental Protection Agency (U.S. EPA), United States Environmental Protection Agency, Emissions from Street Vendor Cooking Devices (Charcoal Grilling), EPA-600/R99-048, Washington, D.C. 1999.

[4] M. Nordica, O. Damon, S. Dean, B. Tami, and R. Christoph, "A laboratory comparison of the global warming impact of five major types of biomass cooking stoves," Energy for Sustainable Development, pp. 56-65, 2008.

[5] K. Ehsanul, K. Ki-Hyum, and HO. Yoon, "Trace metal contents in barbeque (BBQ) charcoal products," Journal of Hazardous Materials, pp. 1418-1424, 2011. https://doi.org/10.1016/j.jhazmat.2010.10.064

[6] SK. Pandey, KH. Kim, CH. Kang, MC. Jung, and H. Yoon, "BBQ Charcoal as an important source of mercury emission," journal of Hazardous Materials, pp. 536-538, 2009. https://doi.org/10.1016/j.jhazmat.2008.05.050

[7] FK. Duan, YQ. Lu, and DI. YA, "Influence of straw burning on the air quality in Beijing," Environmental Monitoring in China, pp. 8-11, 2001. https://doi.org/10.1007/s11430-008-0021-8

[8] Q. Lan, RS. Chapman, DM. Schreinemachers, LW. Tian, and XZ. He, "Household stove improvement and risk of lung cancer in Xuanwei, China," Journal of the National Cancer Institute, pp. 826-835, 2002 https://doi.org/10.1093/jnci/94.11.826

[9] J. Zhang, KR. Smith, Y. Ma, S YE, F Jiang, W Qi, P Liu, M. Khalil, R. Rasmussen, and S. Thorneloe, "Greenhouse gases and other pollutants from household stoves in China: A database for emission factors," Atmospheric Environment, pp. 4537-4549, 2000. https://doi.org/10.1016/S1352-2310(99)00450-1

[10] Inter governmental Panel on Climate Change (IPCC), Third assessment report climate change, The scientific basis, UK Cambridge University Press, 2001

[11] M. Andreae, and P Merlet, "Emission of trace gases and aerosol from biomass burning," Global Biogeochemical Cycles, pp. 955-956, 2001. https://doi.org/10.1029/2000GB001382

[12] Association of Official Analytical Chemists (AOAC), Determination of moisture content. In Official methods of analysis (17th ed.), Gaithersburg, Maryland, 2002.

[13] B. Jenkins, A. Jones, S. Turn, and R. Williams, "Emission factors for polycyclic aromatic hydrocarbons from biomass burning," Environmental Sciences and Technology, pp. 2462–2469, 1996. https://doi.org/10.1021/es950699m