DEVELOPING LOCAL AIR EMISSION FACTORS FOR GRILLING ACTIVITIES OF STREET FOOD STALLS

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต

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DEVELOPING LOCAL AIR EMISSION FACTORS FOR GRILLING ACTIVITIES OF STREET FOOD STALLS

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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ศรัญญา มนัสการ : การพัฒนาค่าปัจจัยการปล่อยมลพิษในระดับพื้นที่จากกิจกรรมการปิ้งย่างของการขายริมถนน (DEVELOPING LOCAL AIR EMISSION FACTORS FOR GRILLING ACTIVITIES OF STREET FOOD STALLS) อาจารย์ที่ปรึกษา : รองศาสตราจารย์ ดร.นเรศ เชื้อสุวรรณ, 203 หน้า.

การศึกษานี้มีวัตถุประสงค์เพื่อพัฒนาค่าปัจจัยการปล่อยมลพิษจากกิจกรรมการปิ้งย่างอาหาร 15 ชนิดที่สามารถพบเห็นได้ทั่วไปในประเทศไทย โดยวัดความเข้มข้นของแก๊สมลพิษหลัก คือ แก๊สคาร์บอนมอนอกไซด์ แก๊สออกไซด์ของไนโตรเจน แก๊สซัลเฟอร์ไดออกไซด์ รวมถึงแก๊สเรือนกระจก 2 ชนิด คือ แก๊สคาร์บอนไดออกไซด์ แก๊สมีเทน และฝุ่นขนาดเล็กกว่า 10 ไมครอน ภายใต้ชุดทดสอบการเผาไหม้ โดยใช้เครื่องวิเคราะห์แก๊สแบบต่อเนื่อง ยกเว้นแก๊สมีเทนวิเคราะห์โดยใช้เครื่องแก๊สโครมาโทกราฟี ตัวตรวจวัดชนิดเฟลมไอออไนเซชันและฝุ่นขนาดเล็กกว่า 10 ไมครอน วิเคราะห์โดยใช้วิธีการวัดตามระบบกราวิเมตริก ในการศึกษาครั้งนี้ใช้เพียงถ่านไม้ยูคาลิปตัสเป็นเชื้อเพลิงซึ่งเป็นที่นิยมในกิจกรรมการปิ้งย่าง ผลการศึกษาบนฐานต่อน้ำหนักแห้งพบว่าค่าปัจจัยการปล่อยแก๊สคาร์บอนมอนอกไซด์จากกิจกรรมการปิ้งย่างอาหารอยู่ในช่วง 411.36±125.41 ถึง 3,682.62±335.91 กรัมต่อกิโลกรัมของเชื้อเพลิงที่ถูกเผาไหม้ 3,390.49±639.84 ถึง 10,732.75±2,324.95 กรัมต่อกิโลกรัมของเนื้อที่สูญเสีย 369.12±118.24 ถึง 2,707.67±235.08 กรัมต่อกิโลกรัมของเชื้อเพลิงที่ถูกเผาไหม้และเนื้อที่สูญเสีย ตามลำดับ ค่าปัจจัยการปล่อยแก๊สออกไซด์ของไนโตรเจนจากกิจกรรมการปิ้งย่างอาหารอยู่ในช่วง 0.11±0.12 ถึง 2.55±1.85 กรัมต่อกิโลกรัมของเชื้อเพลิงที่ถูกเผาไหม้ 0.87±0.88 ถึง 9.67±2.31 กรัมต่อกิโลกรัมของเนื้อที่สูญเสีย 0.09±0.11 ถึง 1.95±1.39 กรัมต่อกิโลกรัมของเชื้อเพลิงที่ถูกเผาไหม้และเนื้อที่สูญเสีย ตามลำดับ ค่าปัจจัยการปล่อยฝุ่นขนาดเล็กกว่า 10 ไมครอนจากกิจกรรมการปิ้งย่างอาหารอยู่ในช่วง 0.005±0.011 ถึง 0.060±0.017 กรัมต่อกิโลกรัมของเชื้อเพลิงที่ถูกเผาไหม้ 0.027±0.003 ถึง 0.166±0.048 กรัมต่อกิโลกรัมของเนื้อที่สูญเสีย 0.004±0.001 ถึง 0.044±0.012 กรัมต่อกิโลกรัมของเชื้อเพลิงที่ถูกเผาไหม้และเนื้อที่สูญเสีย ตามลำดับ ค่าปัจจัยการปล่อยแก๊สเรือนกระจก 2 ชนิด พบว่าค่าปัจจัยการปล่อยแก๊สคาร์บอนไดออกไซด์จากกิจกรรมการปิ้งย่างอาหารอยู่ในช่วง 4,657.14±1,437.47 ถึง 46,871.34±6,525.10 กรัมต่อกิโลกรัมของเชื้อเพลิงที่ถูกเผาไหม้ 45,151.60±7,903.92 ถึง 136,303.61±33,537.60 กรัมต่อกิโลกรัมของเนื้อที่สูญเสีย 4,226.13±1,278.80 ถึง 35,878.81± 5,886.92 กรัมต่อกิโลกรัมของเชื้อเพลิงที่ถูกเผาไหม้และเนื้อที่สูญเสีย ตามลำดับ และค่าปัจจัยการปล่อยแก๊สมีเทนจากกิจกรรมการปิ้งย่างอาหารอยู่ในช่วง 22.80±1.83 ถึง 184.49±65.24 กรัมต่อกิโลกรัมของเชื้อเพลิงที่ถูกเผาไหม้ 90.82±21.02 ถึง 507.54±168.11 กรัมต่อกิโลกรัมของ

เนื้อที่สูญเสีย 17.20±2.72 ถึง 134.84±46.21 กรัมต่อกิโลกรัมของเชื้อเพลิงที่ถูกเผาไหม้และเนื้อที่สูญเสีย ตามลำดับ ในการศึกษานี้ไม่สามารถตรวจพบแก๊สซัลเฟอร์ไดออกไซด์ เมื่อเปรียบเทียบค่าปัจจัยการปล่อยมลพิษที่ได้จากการศึกษานี้กับค่าปัจจัยการปล่อยมลพิษจากฐานข้อมูลของต่างประเทศ พบว่าบนฐานต่อน้ำหนักแห้งของเนื้อ ค่าปัจจัยการปล่อยแก๊สคาร์บอนมอนอกไซด์และแก๊สออกไซด์ของไนโตรเจนจากการย่างไก่ที่ได้จากการศึกษานี้มีค่าสูงกว่า ส่วนค่าปัจจัยการปล่อยฝุ่นขนาดเล็กกว่า 10 ไมครอนมีค่าต่ำกว่าค่าปัจจัยการปล่อยมลพิษจากฐานข้อมูลของต่างประเทศ และผลการเปรียบเทียบค่าปัจจัยการปล่อยมลพิษบนฐานต่อน้ำหนักเปียกของเนื้อพบว่าค่าปัจจัยการปล่อยแก๊สคาร์บอนมอนอกไซด์จากการย่างไก่ที่ได้จากการศึกษานี้มีค่าสูงกว่า ส่วนค่าปัจจัยการปล่อยแก๊สออกไซด์ของไนโตรเจนและฝุ่นขนาดเล็กกว่า 10 ไมครอนมีค่าต่ำกว่าค่าปัจจัยการปล่อยมลพิษจากฐานข้อมูลของต่างประเทศ ค่าปัจจัยการปล่อยมลพิษที่ได้จากการศึกษานี้สามารถนำไปใช้ในการจัดทำบัญชีการระบายสารมลพิษทางอากาศที่ใกล้ความจริงมากขึ้นและสามารถใช้ข้อมูลนี้ประมาณการปลดปล่อยแก๊สมลพิษจากกิจกรรมการปิ้งย่างของการขายริมถนนของประเทศไทยได้

สาขาวิชามลพิษสิ่งแวดล้อมและความปลอดภัย ลายมือชื่อนักศึกษา Saranya Manatsakarn

ปีการศึกษา 2559 ลายมือชื่ออาจารย์ที่ปรึกษา Nan Oli

SARANYA MANATSAKARN : DEVELOPING LOCAL AIR EMISSION FACTORS FOR GRILLING ACTIVITIES OF STREET FOOD STALLS. THESIS ADVISOR : ASSOC. PROF. NARES CHUERSUWAN, Ph.D. 203 PP.

MEAT GRILLING/MAJOR AIR POLLUTANTS/GREENHOUSE GAS/EMISSION FACTORS

This study aims to determine air emission factors of fifteen categories of meats from grilling activity commonly found in the street food stalls in Thailand. The major air pollutants included CO, NO_x, SO_2, particulate matter (PM_{10}) and two greenhouse gases (CO_2 and CH_4). Measurements were conducted in a chamber and sampled from a stack. The eucalyptus charcoal was solely used as the fuel during the grilling of meats. Gases pollutants were measured real-time while PM and CH_4 were collected and subsequently analyzed in the laboratory. CH_4 concentrations were quantified by a Gas Chromatograph while PM concentrations were quantified by the gravimetric method. The average emission factors of CO based on dry weight basis of fuel and meat for all meats, ranged from 411.36±125.41 to 3,682.62±335.91 g/kg of fuel, 3,390.49±639.84 to 10,732.75±2,324.95 g/kg of meat, and 369.12±118.24 to 2,707.67±235.08 g/kg of material, respectively, followed by NO_x, 0.11±0.12 to 2.55±1.85 g/kg of fuel, 0.87±0.88 to 9.67±2.31 g/kg of meat, and 0.09±0.11 to 1.95±1.39 g/kg of material, respectively. PM_{10} was in the range of 0.005±0.011 to 0.060±0.017 g/kg of fuel, 0.027±0.003 to 0.166±0.048 g/kg of meat, and 0.004±0.001 to 0.044±0.012 g/kg of material, respectively. In terms of greenhouse gases, estimated emission factors of CO_2 was in the range of 4,657.14±1,437.47 to 46,871.34±6,525.10

g/kg of fuel, 45,151.60±7,903.92 to 136,303.61±33,537.60 g/kg of meat, and 4,226.13±1,278.80 to 35,878.81±5,886.92 g/kg of material, respectively, while CH_4 was in the range of 22.80±1.83 to 184.49±65.24 g/kg of fuel, 90.82±21.02 to 507.54±168.11 g/kg of meat, and 17.20±2.72 to 134.84±46.21 g/kg of material respectively. SO_2 was not detected. Emission factors of CO and NO_x from grilled chicken were higher than the literatures while PM_{10} emission factor was lower based on dry weight basis of meat. The CO emission factor from this study was higher than the literatures on wet weight basis of meat while NO_x and PM_{10} emission factors were lower. Results from this study provide insight for emission estimates from meat grilling. These emission factors can be used to generate more realistic emission inventories and therefore improve the results of estimate emissions of meat grilling with charcoal in Thailand.

School of Environmental pollution and safety — Student's Signature Saranya Manatsakarn.

Academic Year 2016 — Advisor's Signature ________

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Saranya Manatsakarn

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LIST OF ABBREVIATIONS

AOAC	Association of Official Analytical Chemists
ASTM	American Society for Testing and Materials
atm	Standard atmosphere pressure unit
CEMS	Continuous Emission Monitoring Systems
CH_4	Methane
C_2H_2	Acetylene
C_2H_6	Ethane
Cl_2	Chlorine
CO	Carbon monoxide
CO_2	Carbon dioxide
D_a	Diameter
DNPH	2,4-Dinitrophenylhydrazine
EC	Elemental carbon
EF	Emission factor
ER	Emission ratio
FID	Flame Ionization Detector
g	Gram
GC-FID	Gas Chromatography – Flame Ionization Detector
H_2	Hydrogen
HAPs	Hazardous air pollutants

LIST OF ABBREVIATIONS (Continued)

HC	Hydrocarbon
He	Helium
HEPA	High efficiency particulate air
H_2S	Hydrogen sulfide
kg	Kilogram
LPG	Liquefied petroleum gas
m^3	Cubic meter
mg	Milligram
MJ	Megajoule
MPa	Megapascal
NH_3	Ammonia
NMHCs	Non-methane hydrocarbons
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxide
O_2	Oxygen
O_3	Ozone
OC	Organic carbon
PAC	Polycyclic aromatic compounds
PAHs	Polycyclic aromatic hydrocarbons
PEMS	Predictive Emissions Monitoring Systems

LIST OF ABBREVIATIONS (Continued)

PM	Particulate Matter
$PM_{2.5}$	Particulate matter with an aerodynamic diameter less than or equal to a nominal 2.5 micrometers
PM_{10}	Particulate matter with an aerodynamic diameter less than or equal to a nominal 10 micrometers
ppm	Parts per million
PUF	Polyurethane foam
RH	Relative humidity
SEWPaC	Department of Sustainability, Environment, Water, Population and Communities
SO_2	Sulfur dioxide
SO_x	Sulfur oxide
SUT	Suranaree University of Technology
SVOCs	Semivolatile organic compounds
THC	Total hydrocarbons
TSP	Total suspended particles
U.S. EPA	United States Environmental Protection Agency
VOCs	Volatile organic compounds
WHO	World Health Organization
μm	Micrometer

CHAPTER I

INTRODUCTION

1.1 Rationale/Problem statement

Street food stalls as an occupation has existed for hundreds of years. The street food stalls can be counted as an integral component of urban economy around the world, distributing affordable goods and services. They are convenient for consumers with accessible retail options (Bromley, 2000). The street food stalls are very common along the urban streets in Thailand. Charcoal is the main fuel for food preparation and cooking. Meat grilling is very popular among the food stalls but charcoal meat grilling is a source of anthropogenic greenhouse gas and major air pollutant released into the atmosphere. During incomplete combustion of charcoal meat grilling emits particulate matters (PM), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), volatile organic compounds (VOCs), aldehyde, polycyclic aromatic hydrocarbons (PAHs), and total hydrocarbons (THC) (Sung et al., 1997; U.S. EPA, 1999; Nordica, 2008; Ehsanul et al., 2011). During charcoal burning air pollutants can be absorbed in food and degrade air quality in the surrounding environment. Regarding these pollutants, their adverse effects on human health are of great concern, particularly in large cities where number of street food stalls is high and increasing hazard of the nearby people exposed to pollutants with potential health risks (Pandey, 2009). The pollutant emissions from the combustion such as, PM, NO_x and CO have contributed substantially to the regional environment pollution problem (Duan et al., 2001; Lan et al., 2002) and meat grilling has the potential to produce net global warming especially CO_2, the main driving force for the past global climate change (Zhang et al., 2000; Andreae et al., 2001; IPCC, 2001). However, the evaluation of these emissions is still scarce due to a lack of assessment of the emission sources.

To evaluate the emissions from street food stalls, measurement is required or use related emission factors. This estimation relates to the quantity of pollutants released into the atmosphere by such activities. Emission factors can represent as mass of emitted pollutant divided by a units of energy or mass of fuel used (as g/MJ or g/kg) (Thomas, 2008). Estimation of emissions are important for developing emission control strategies, determining applicability of permitting and control programs, ascertaining the effects of sources and appropriate mitigation strategies, and a number of other related applications by an array of users, including governmental agency, consultant, and industry (U.S. EPA, 1996). It is important that emission factors should be available for most significant sources of air pollution and that they produce reliable emission estimates. In Thailand, however, emission factors of pollutants especially particulate matters and gaseous pollutants derived from combustion sources are rare and mostly unavailable.

This study aims to develop emission factors for gases and particulate matters emitted from grilling activities of street food stalls commonly found in Thailand. The study based on grilling experiments in the combustion testing equipment at Suranaree University of Technology (SUT) to measure the emissions. A mass balance was proposed as a basis of the measurements.

1.2 Research objectives

1.2.1 To quantify gases and particulate matters emitted from grilling activities of street food stalls.

1.2.2 To develop specific emission factors for gases and particulate matters emitted from grilling activities of street food stalls.

1.2.3 To evaluate the differences of local emission factors with other international default values.

1.3 Scope of research work

1.3.1 Fifteen types of meat were included in this study: pork, chicken, chicken wing, chicken liver, catfish, ruby fish, tilapia, squid, shrimp, Thai sausage, Thai sour pork, meatball, pork ball, fish ball, and chicken ball.

1.3.2 Major air pollutants considered in this study included CO, NO_x, SO_2, particulate matter (PM_{10}) and two greenhouse gases (CO_2 and CH_4).

1.3.3 Used the combustion testing equipment at School of Environmental Health, SUT in the experiment.

1.4 Research framework

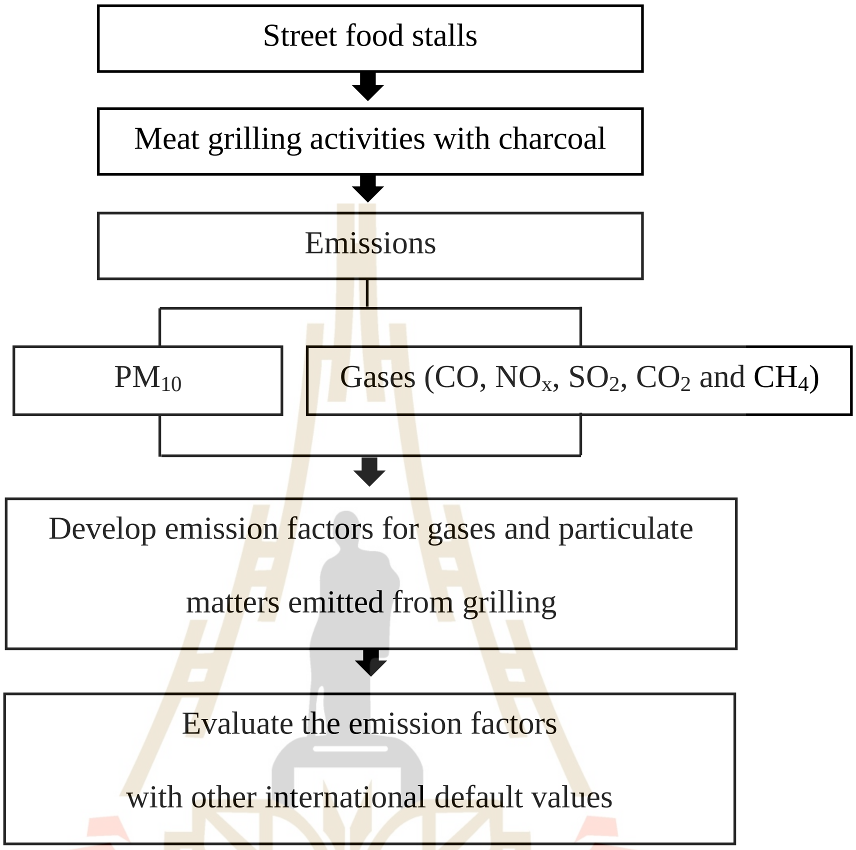


Figure 1.1 Research framework**.**

1.5 Expected results

1.5.1 Emissions of CO, NO_x, SO_2, CO_2, CH_4, and particulate matters (PM_{10}) emitted from grilling activities.

1.5.2 Locally develop emission factors of gases (CO, NO_x, SO_2, CO_2 and CH_4) and particulate matters (PM_{10}) from grilling activities typically found from street food stalls in Thailand.

1.5.3 Appropriate emission factors from meat grilling suitable for emission inventory development for Thailand.

CHAPTER II

LITERATURE REVIEWS

2.1 Emission Factor

2.1.1 Definition of emission factor

An emission factor is usually defined as the representation value that relates quantity of a pollutant released from the activity to the atmosphere. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e. g., kilograms of particulate emitted per megagram of charcoal burned). Such factors facilitate estimation of emissions from various sources of air pollution. Data quality of emission factor are simply averages of all available data that acceptable, and are generally assumed to be representative of long-term averages for all facilities in the source category (i. e., a population average) (U.S. EPA, 1997).

There are many factors related to emission factor including process conditions and the presence or absence of emission control equipment. Estimation of air emissions should be used for specific source category of emission factor under consideration.

In general, the emission factors are usually multiplied by quantity of production, flow rate, or other measures to yield the release of air emissions. A facility can calculate emission factors of its own use based on measurement or rely on published emission factor data. Emissions factors are used mostly for air emissions, although the World Health Organization (WHO) has published emission factors for surface water discharge and land disposal for certain processes in Rapid Inventory Techniques in Environmental Pollution (SEWPaC, 1999).

Emission factors are developed based on direct monitoring (CEMS/PEMS) or measurement (source testing) results. Facility-specific established emission factors (mass of emission per unit time, mass of emission per input material flow, or mass of emission per unit output production) are applicable to the measurement processes or similar equipment/processes or comparable to the operating conditions. Generic emission factors are commonly used when site-specific source monitoring data are unavailable (Western Cape Government, 2005).

The basic equation used in an emission factor calculation is the followings (SEWPaC, 1999).

$$E_X = BQ \times EF_X \times \frac{100 - CE_X}{100} \tag{2.1}$$

where: E_X = Emission of contaminant x, kg

BQ = Activity rate or base quantity (BQ), BQ unit

EF_X = Uncontrolled emission factors of contaminant x, kg/BQ unit

CE_X = Overall emission control efficiency of contaminant x, %

or

$$E_X = BQ \times CEF_X \tag{2.2}$$

where: E_X = Emission of contaminant x, kg

BQ = Activity rate or base quantity (BQ), BQ unit

CEF_X = Controlled emission factors of contaminant x, kg/BQ unit

2.1.2 Advantages

Valid emission factors for each source of pollution are the key to the emission inventory. Estimating air emissions from many individual sources can be estimated by testing a small fraction of those sources. Generation of default emission factors for non-measurable substances by applying specific knowledge of the process characteristics sometimes can be used (Vladimir and Mirko, 2012).

2.1.3 Limitations

- The suitable emission factor should be specific to each source. In some case, they are not suitable for establishing actual emissions from individual facilities at a single point in time.

- In general, emission factors do not address the design and operational differences of emitting sources. In some cases, influence of various process parameters related emission factors cause insufficient to take into account, such as temperature, pollutant concentration etc.

- Emission factors do not reflect start-up, shut down or other modes of operation that could significantly contribute to air emissions because emission factors are often developed for “normal or typical” operating conditions.

- Detailed knowledge for a process should be realized in the use of some emission factors. It is important to consider the ‘appropriateness’ and ‘relevance’ of an emissions factor before applying it (Vladimir and Mirko, 2012).

2.2 Emission factors of small combustion devices and emission factors of grilling activities

2.2.1 Emission factors of small combustion devices

Although small combustion and large scale combustion (e.g., forest and Savannah burning of biomass, industrial combustion of fossil fuels) are different, small combustion is not well characterized but may have a significant impact on emission inventories (Levine, 1996). A number of studies have been conducted to measure the emissions from residential wood combustion, church candle burning, kerosene and oil lamps, wood fireplaces, and meat cooking processes (Hildemann et al., 1991a; Schare and Smith, 1995; Fine et al., 1999; Oanh et al., 1999; Fan and Zhang, 2001). Some of the results from these measurements are summarized in Table 2.1

Table 2.1 Particulate emission factors for various small-scale combustion devices.

Combustion device	**Fuel**	**Emission factor (mean or single measurement (range))**		**Reference**
		g/kg fuel[a]	**mg/MJ delivered**	
Cookstove, Southeast Asia	Wood	0.051[b]	-	Oanh et al. (1999)
Cookstove, Southeast Asia	Coal briquette	0.007[b]	-	Oanh et al. (1999)
Cookstove, Southeast Asia	Charcoal	0.036[b]	-	Oanh et al. (1999)

Table 2.1 Particulate emission factors for various small-scale combustion devices (Continued).

Combustion device	Fuel	Emission factor (mean or single measurement (range))		Reference
		g/kg fuel[a]	mg/MJ delivered	
Cookstove, India	Fuelwood	1.9–2.8	-	Joshi et al. (1989)
Cookstove, India	Crop residue	2.4–9.4	-	Joshi et al. (1989)
Cookstove, India	Dung cake	49.9–5.9	-	Joshi et al. (1989)
Cookstove, China	Wood	3.82 (1.51–8.73)	1490 (1090–2250)	Zhang et al. (2000)
Cookstove, China	Crop residue	0.83 (0.089–2.21)	3930 (1025–8480)	Zhang et al. (2000)
Cookstove, China	Coal	0.829 (0.039–3.86)	433 (49–2240)	Zhang et al. (2000)
Cookstove, China	Kerosene	0.134 (0.046–0.283)	6.4 (4.1–8.7)	Zhang et al. (2000)
Cookstove, China	Gases	0.261 (nd–1.62)	9.2 (nd–24.9)	Zhang et al. (2000)
Cookstove, India	LPG	0.514	20.9	Smith et al. (2000)

Table 2.1 Particulate emission factors for various small-scale combustion devices (Continued).

Combustion device	Fuel	Emission factor (mean or single measurement (range))		Reference
		g/kg fuel[a]	mg/MJ delivered	
Cookstove, India	Kerosene	0.609 (0.516–0.701)	29.3 (23.9–34.6)	Smith et al. (2000)
Cookstove, India	Root fuel	1.11 (1.040–1.176)	702 (333–1301)	Smith et al. (2000)
Cookstove, India	Wood	2.52 (0.941–3.97)	671 (347–982)	Smith et al. (2000)
Cookstove, India	Crop residue	2.32 (0.631-4.251)	671 (139–1659)	Smith et al. (2000)
Cookstove, India	Dung cake	1.61 (0.55–2.21)	1332 (570–1999)	Smith et al. (2000)
Cookstove, India	Charcoal	2.38	528	Smith et al. (2000)
Cookstove, India	Char briquette	2.86	1094	Smith et al. (2000)
Charcoal kiln, Thailand	Wood	0.588 (0.22–1.17)	1970 (690–4190)[c]	Smith et al. (2000)
Residential stove, USA	Wood	3–28	-	Burnet et al. (1986)

Table 2.1 Particulate emission factors for various small-scale combustion devices (Continued).

Combustion device	Fuel	Emission factor (mean or single measurement (range)) g/kg fuel[a]	Emission factor (mean or single measurement (range)) mg/MJ delivered	Reference
Pellet wood stove, USA	Wood	2.54	-	U.S. EPA (1996)
Residential stove, USA	Wood	6.64–11.8	-	U.S. EPA (1996)
Fireplace, USA	Softwood	13	-	Hildemann et al. (1991a)
Fireplace, USA	Hardwood	5.28	-	Hildemann et al. (1991a)
Fireplace, USA	Synthetic log	12	-	Hildemann et al. (1991a)
Charbroiling of regular meet, USA	-	40 g/kg meat	-	Hildemann et al. (1991a)

Table 2.1 Particulate emission factors for various small-scale combustion devices (Continued).

Combustion device	**Fuel**	**Emission factor (mean or single measurement (range))**		**Reference**
		g/kg fuel[a]	**mg/MJ delivered**	
Charbroiling of extra-lean meet, USA	-	7.1 g/kg meat	-	Hildemann et al. (1991a)
Frying regular meet, USA	-	1.1 g/kg meat	-	Hildemann et al. (1991a)
Frying extra-lean meet, USA	-	1.4 g/kg meat	-	Hildemann et al. (1991a)

Source: Zhang and Morawska, (2002).

[a] Other used units are specified in the table.

[b] The values reported from this study are substantially lower than other reported values for similar stoves. The hood method used in the study to determine emission factors is not reliable because the constant flow condition was not met.

[c] mg of particulate matter/kg charcoal produced

2.2.2 Emission factors of grilling activities

U.S. EPA (1999) quantified the emissions due to charcoal grilling of meat by street vendors in Mexicali, Mexico. Both of beef and chicken including marinated and non-marinated meat grilling using charcoal were tested. The emissions of interest included PM, VOCs, SVOCs, aldehydes, CO, CO_2, NO_x, THC, and SO_2. This report noted that charcoal did not contribute significantly to total PM, VOCs or SVOCs emission levels. Marinated meat had higher VOCs and total PM emissions than non-marinated meat. Emission rates between beef and chicken (whole chicken with skin) were not significant differences. Emissions of CO and NO derived from charcoal fire rather than the cooking of meat. Hydrocarbons presented in the charcoal were released during the initial of burning. THC emission was only confined during the first half an hour of charcoal light off. Emission rates for SO_2 were not reported due to problems with the analyzer. Test results are summarized in Tables 2.2 and 2.3, the emission factors are expressed in grams per kilogram of meat (g/kg).

Emission tests supporting rule development in the South Coast Air Quality Management District (SCAQMD) were conducted by the University of California, Riverside Bourns College of Engineering - Center for Environmental Research and Technology (CE-CERT) (Norbeck, 1997). These tests focused on PM and VOCs (see Tables 2.2 and 2.3). McDonald et al. (2003) used additional test data from CE-CERT to develop emission estimates for the Colorado Front Range Study. These data included emission factors for CO and some hazardous air pollutants (HAPs) (mainly PAHs; see Tables 2.2 and 2.3, respectively).

Table 2.2 Summary of commercial cooking test results: criteria pollutants (g/kg).

Equipment Type (fuel)	Meat/Food	Emission Factor[1] (g/kg meat)						Notes
		PM	PM_{10}	$PM_{2.5}$	CO	NO_x	VOCs	
Under fired-Charbroiler (charcoal)	Beef	8.1	7.5	7.1	163.5	2.4	4.7	Source: U.S. EPA, 1999. Beef was flank steak. Chicken was thigh meat. CO and NO_x emissions appear to be mainly from charcoal burning. VOCs was measured as THC. Some of the VOCs was attributed to the burning of charcoal (most of which burns off after the first 30 minutes of light-off).
	Beef (marinated)	9.5	9.2	8.7	167.6	3.6	5.8	
	Chicken (marinated)	9.8	9.4	9.1	157.9	4.2	4.5	

Table 2.2 Summary of commercial cooking test results: criteria pollutants (g/kg) (Continued).

Equipment Type (fuel)	Meat/Food	Emission Factor[1] (g/kg meat)						Notes
		PM	PM_{10}	$PM_{2.5}$	CO	NO_x	VOCs	
Under-fired Charbroiler (natural gas)	Hamburger (25% fat)	32.7	32.7	31.9	13.72	n/a	3.94	Source: Norbeck, 1997. VOCs measured a reactive organic gases (ROG). CO taken from McDonald et al., 2003.
	Steak	17.2	17.2	16.8	4.97	n/a	0.86	Source: Norbeck, 1997. CO taken from McDonald et al., 2003.
	Chicken (whole)	10.5	10.5	9.9	4.84	n/a	1.82	Source: Norbeck, 1997. CO taken from McDonald et al., 2003.
	Seafood	3.3	3.3	3.2	n/a	n/a	0.38	Source: Norbeck, 1997. Seafood - Atlantic salmon.

Table 2.2 Summary of commercial cooking test results: criteria pollutants (g/kg) (Continued).

Equipment Type (fuel)	Meat/Food	Emission Factor[1] (g/kg meat)						Notes
		PM	PM_{10}	$PM_{2.5}$	CO	NO_x	VOC_s	
Deep fat fryer (natural gas)	Shoestring potatoes	n/d	n/a	n/a	n/a	n/a	0.21	Source: Norbeck, 1997. EF is in g/kg potatoes
	Breaded chicken	n/d	n/a	n/a	n/a	n/a	0.12	Source: Norbeck, 1997.
	Breaded fish	n/d	n/a	n/a	n/a	n/a	0.14	Source: Norbeck, 1997.
Griddle (electric)	Hamburger (24% fat)	5.0	5.0	3.8	0.38	n/a	0.07	Source: Norbeck, 1997. CO taken from McDonald et al., 2003.
	Chicken (boneless breast)	n/d	n/a	n/a	0.45	n/a	0.4	Source: Norbeck, 1997. CO taken from McDonald et al., 2003.
	Seafood	n/d	n/a	n/a	n/a	n/a	0.11	Source: Norbeck, 1997.
Conveyorized Charbroiler (natural gas)	Hamburger (21% fat)	7.4	7.4	7.3	8.29	n/a	2.27	Source: Norbeck, 1997. CO taken from McDonald et al., 2003.

Table 2.2 Summary of commercial cooking test results: criteria pollutants (g/kg) (Continued).

Equipment Type (fuel)	Meat/Food	Emission Factor[1] (g/kg meat)						Notes
		PM	PM_{10}	$PM_{2.5}$	CO	NO_x	VOCs	
Double-sided (clamshell) Griddle (electric)	Hamburger (24% fat)	0.85	0.85	0.72	n/a	n/a	0.01	Source: Norbeck, 1997.

Source: (Pechan, 2003)

[1]n/d - not detected; n/a - not analyzed. For PM, all testing was performed using dilution sampling techniques. Hence, both filterable and condensable fractions are represented.

Table 2.3 Summary of commercial cooking test results: hazardous air pollutants (g/kg).

Equipment Type (fuel)	Meat	Emission Factor[1] (g/kg meat)												Notes
		Ben	**Tol**	**EBen**	**o-xyl**	**m,p-xyl**	**Sty**	**Form**	**Acet**	**Prop**	**EdCl**	**MeCl**	**Phen**	
Under fired-Charbroiler (charcoal)	Beef	0.392	0.154	0.026	0.023	0.023	0.151	0.337	0.251	0.068	0.017	0.012	0.016	Source: U.S. EPA, 1999. Beef was flank steak. Chicken was thigh meat. Where 2 test runs were performed, the listed value is the average (non-detects were not averaged into the emission factor due to lack of data on detection limits). Fat content: beef = 7%; chicken = 18%; marinated beef = 19%.
	Beef (marinated)	0.502	0.184	0.038	0.030	0.025	0.218	0.526	0.329	0.084	0.015	0.010	0.021	
	Chicken (marinated)	0.504	0.200	0.040	0.033	0.028	0.190	0.393	0.282	0.076	0.014	0.012	0.023	

Source: (Pechan, 2003)

[1]Ben = benzene; Tol = toluene; Eben = ethyl benzene; Sty = styrene; Form = formaldehyde; Acet = acetaldehyde; Prop = propionaldehyde; EdCl = ethylene dichloride; MeCl = methylene chloride; Phen = phenol.

Table 2.3 Summary of commercial cooking test results: hazardous air pollutants (g/kg) (Continued).

Equipment Type (fuel)	Meat	Emission Factor[1] (g/kg meat)												Notes
		AcPh	o-Cre	p-Cre	Nap	BaP	Ace	Flu	Phn	Fla	Pyr	dnBP	4nPh	
Under fired-Charbroiler (charcoal)	Beef	1.83 E-03	9.18 E-04	1.77 E-03	2.15 E-02	n/a	0.00	n/d	2.14 E-03	6.51 E-04	6.51 E-04	1.03 E-03	n/d	Source: U.S. EPA, 1999. Beef was flank steak. Chicken was thigh meat. Where 2 test runs were performed, the listed value is the average (non-detects were not averaged into the emission factor due to lack of data). Fat content: beef = 7%; chicken = 18%; marinated beef = 19%. Charcoal contributed to emissions for about half of these HAPs.
	Beef (marinated)	2.73 E-03	1.28 E-03	2.16 E-03	2.54 E-02	n/a	1.42 E-03	6.81 E-04	3.17 E-03	5.39 E-04	7.04 E-04	n/d	n/d	
	Chicken (marinated)	2.43 E-03	1.68 E-03	3.43 E-03	2.29 E-02	n/a	1.57 E-03	8.25 E-04	3.56 E-03	7.14 E-04	5.00 E-04	1.92 E-03	6.60 E-03	
Conveyorized Charbroiler (natural gas)	Hamburger	n/a	n/a	n/a	2.30 E-02	1.70 E-04	4.89 E-03	1.09 E-03	4.88 E-03	8.80 E-04	1.15 E-03	n/a	n/a	Source: McDonald et al., 2003.
Under-fired Charbroiler (natural gas)	Hamburger	n/a	n/a	n/a	1.90 E-02	1.50 E-04	4.24 E-03	1.26 E-03	4.88 E-03	1.40 E-03	1.90 E-03	n/a	n/a	
	Steak	n/a	n/a	n/a	1.50 E-02	7.00 E-05	4.28 E-03	1.17 E-03	5.31 E-03	1.28 E-03	1.56 E-03	n/a	n/a	
	Chicken	n/a	n/a	n/a	8.75 E-03	1.00 E-04	2.06 E-03	7.20 E-04	3.46 E-03	1.28 E-03	1.80 E-03	n/a	n/a	

Table 2.3 Summary of commercial cooking test results: hazardous air pollutants (g/kg) (Continued).

Equipment Type (fuel)	Meat	Emission Factor[1] (g/kg meat)												Notes
		AcPh	o-Cre	p-Cre	Nap	BaP	Ace	Flu	Phn	Fla	Pyr	dnBP	4nPh	
Griddle (electric)	Hamburger	n/a	n/a	n/a	6.10 E-03	2.00 E-05	1.60 E-04	2.10 E-04	2.07 E-03	8.60 E-04	1.15 E-03	n/a	n/a	Source: McDonald et al., 2003.
	Chicken	n/a	n/a	n/a	1.00 E-03	1.00 E-05	1.30 E-04	1.80 E-04	1.87 E-03	6.20 E-04	6.20 E-04	n/a	n/a	

Source: (Pechan, 2003)

[1]n/d = not detected; AcPh = acetophenone; o-Cre = ortho-cresol; p-Cre = para-cresol; Nap = naphthalene; BaP = benzo[a]pyrene; Ace = acenaphthylene; Flu = fluorene; Phn = phenanthrene; Fla = fluoranthene; Pyr = pyrene; dnBP = di-n-butyl phthalate; 4nPh = 4-nitrophenol.

Table 2.3 Summary of commercial cooking test results: hazardous air pollutants (g/kg) (Continued).

Equipment Type (fuel)	Meat	Emission Factor[1] (g/kg meat)											Notes
		BbFl	BkFl	BaA	Chr	dBa,hA	InP	Acn	An	BghiP	PAHt	BiP	
Conveyorized Charbroiler (natural gas)	Hamburger	n/a	n/a	2.20 E-04	n/a	n/a	1.00 E-04	2.80 E-04	9.10 E-04	1.60 E-04	0.05	2.43 E-03	Source: McDonald et al., 2003. Most PAH species were analyzed; however some were

Table 2.3 Summary of commercial cooking test results: hazardous air pollutants (g/kg) (Continued).

Equipment Type (fuel)	Meat	Emission Factor[1] (g/kg meat)											Notes
		BbFl	BkFl	BaA	Chr	dBa,hA	InP	Acn	An	BghiP	PAHt	BiP	
Under-fired Charbroiler (natural gas)	Hamburger	n/a	n/a	2.20 E-04	n/a	n/a	9.00 E-05	1.50 E-04	9.40 E-04	1.70 E-04	0.05	1.72 E-03	grouped with other species (e.g., benzob+j+k] fluoranthene). Hence, species specific emission factors were not available.
	Steak	n/a	n/a	1.10 E-04	n/a	n/a	5.00 E-05	1.50 E-04	1.03 E-03	9.00 E-05	0.04	1.54 E-03	
	Chicken	n/a	n/a	3.40 E-04	n/a	n/a	6.00 E-05	1.00 E-04	8.80 E-04	9.00 E-05	0.03	9.10 E-04	
Griddle (electric)	Hamburger	n/a	n/a	7.00 E-05	n/a	n/a	n/d	2.00 E-05	1.70 E-04	n/d	7.96 E-03	6.00 E-05	
	Chicken	n/a	n/a	1.20 E-04	n/a	n/a	n/d	5.00 E-05	4.40 E-04	n/d	9.51 E-03	1.30 E-04	

Source: (Pechan, 2003)

[1]n/d = not detected; n/a = not analyzed; BbFl = benzo[b]fluoranthene; BkFl = benzo[k]fluoranthene; BaA = benz[a]anthracene; Chr = chrysene; dBa,hA = dibenzo[a,h]anthracene; InP = indeno[1,2,3-c,d]pyrene; Acn = acenaphthene; An = anthracene; BghiP = Benzo[g,h,i,]perylene; PAHt = total PAH; BiP = Biphenyl.

2.3 Emission measurements for small combustion

In general, there are three major types of methods for the determination of emission factors and emission rates of small combustion devices included chamber method, hood method, and carbon balance method (Mitra et al., 2002).

2.3.1 Chamber method

Chamber method was developed to measure emissions under controlled conditions. Chamber method has been designed to ensure well defined and reproducible burning conditions as well as the possibility of sampling the easily exhausts (Gelosa et al., 2007). Chamber created well-mixing of air flow by means of fans to avoid stratification of the gases or smoke (Tremeer, 1996). Simulation laboratory using a chamber approach, small amounts of material are burned in as representative manner as possible. A detailed of the mass of burning material, combustion air and dilution air flow rates, relevant temperatures, and the concentrations of the pollutants of interest were recorded during the simulated burning therefore, mass balance model is the basic principle for the chamber test. During a chamber test, the combustion takes place in a chamber (or a simulated kitchen) in which the air is assumed to be well mixed, the initial (background) concentration of the measured pollutant is assumed to be zero, and the ventilation rate of the chamber is assumed to be constant. Under these conditions, the pollutant concentration (C) in the chamber at time t is the function of the elapsed time (t) of the combustion as follows (Mitra et al., 2002):

$$C(t) = \frac{R}{Vk}(1 - e^{-kt}) \quad (2.3)$$

where: R = Burn rate (g/h),

V = Chamber volume (m^3),

k = Ventilation rate.

The emission rate can be determined from the linear regression slope of the plot of C(t) versus $(1 – e^{-kt})$. Apparently, this approach requires continuous monitoring of C(t). The emission factor then can be derived from the emission rate R and the burn rate (Joshi et al., 1989; Schare and Smith, 1995; Fine et al.,1999).

Lee and Wang (2006) employed chamber method to investigate the air pollutants from mosquito coils and candles burning and Wang et al., (2006) employed chamber method to investigate fine particles from incense burning. The controlled experiments were conducted in 18.26 m^3 stainless steel environmental test chamber. The chamber was purged by blower air, which was passed through a clean air system with activated charcoal particle filters and high efficiency particulate air (HEPA) filters. Mixing fans were installed at the ceiling of the chamber to ensure adequate air mixing. The temperature of inlet air was controlled by using conditioning coils. Relative humidity (RH) was controlled by adding deionized water to the air system. Figure 2.1 shows the schematic diagram of the test chamber set-up.

Derudi et al. (2012) employed chamber method to investigate the pollutant emissions from burning candles. The test chamber consisted of three parts: the room was a cylinder (diameter 0.6 m, height 0.4 m) covered by a conical cap (height 0.6 m) and a stack (internal diameter 0.07 m and height 1.5 m). The chamber had two portholes to observe the candles behavior during the tests. Radiation protection from the chamber walls to the candle leading to uncontrolled rise of the candle temperature by using internal walls of chamber was black. The bottom of test chamber had air sparger to supply air to the chamber environment with minimum turbulence and very low velocity. An air sparger was constituted by a perforated coil covered by a bed of small glass spheres. The test chamber was created providing well-mixed conditions between candle fumes with the incoming air and smooth air flow around the candle and a large vortex above it. At the inlet of stack was long and far enough from the stack inlet to avoid entrance effects of air sample concentration (Fig 2.2).

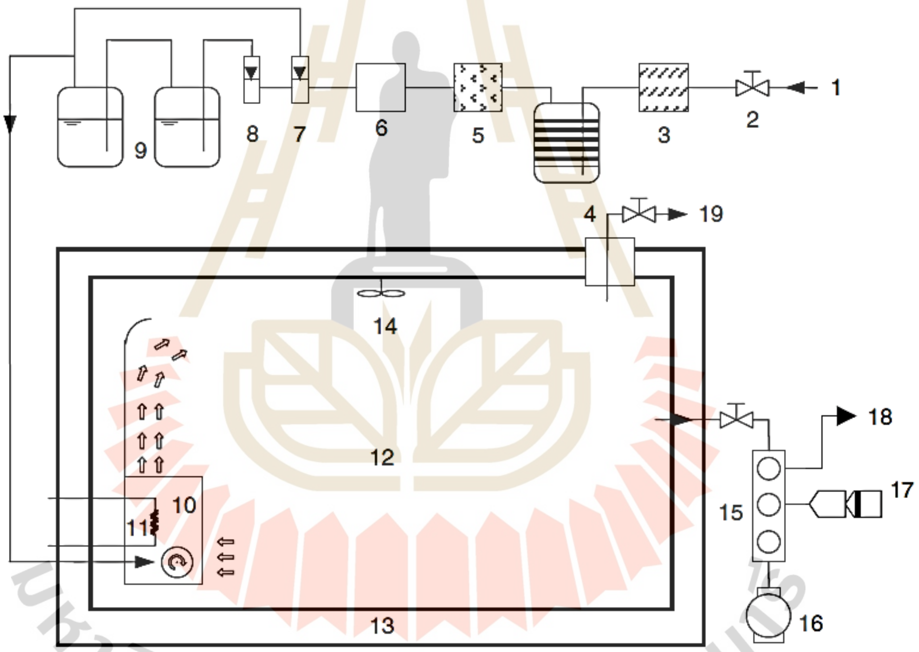


Figure 2.1 Schematic diagram of the test chamber set-up to investigate the air pollutants from mosquito coils, candles burning, and fine particles from incense burning (Lee and Wang, 2006 and Wang et al., 2006).

(1) Inlet, (2) valve, (3) blower, (4) active charcoal filters, (5) HEPA filters, (6) mass flow controllers, (7) flow controller dry air, (8) flow controller wet air, (9)

humidifier, (10) rotating cylinder, (11) heating unit, (12) large environmental test chamber, (13) insulation, (14) mixing fan, (15) sampling manifold, (16) canister, (17) ozone scrubber & DNPH cartridge, (18) A Teflon tubing connecting to gas analyzers, (19) outlet.

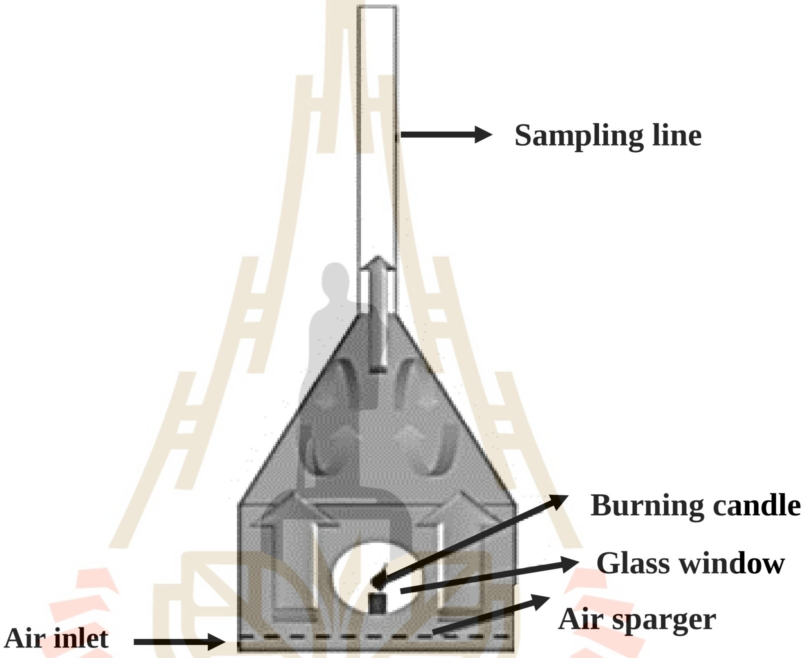


Figure 2.2 Sketch of the test chamber to investigate the pollutants emissions from burning candles (Derudi et al., 2012)**.**

2.3.2 Hood method

The basic concept of hood method is to construct a hood above the tested device to capture all the emissions. This method requires a constant and steady exhaust flow rate during the entire burning test. The emission rate and emission factor can be determined for small combustion (Mitra et al., 2002). Under experimental conditions, the hood method may not be possible to capture all emissions due to some of the products from combustion can escape around the sides of the hood. However, the hood method can be used with confidence provided that the extraction rate is high enough to capture all the smoke and without affecting the combustion characteristics of the tested device (Tremeer, 1996). Figures 2.3, 2.4 and 2.5 show the hood method design.

Darley et al. (1977, 1979) have been developed burning tower for determining the nature and amounts of emission from agricultural waste burning. The tower is in the form of an inverted funnel, 16 feet in diameter at the base, decreasing to 29.5 inches (0.75 m) in a length of 20 feet (6.1 m), and topped with a stack 8 feet (2.4 m) in length. The tower is erected above a table, 8 feet (2.4 m) in diameter, which is positioned on a scale with a maximum capacity of 125 pounds (56.7 kg). The sample site for gases, particulate, and for recording temperatures and airflow is in the stack about 2 feet (0.61 m) below the top (Fig 2.3)

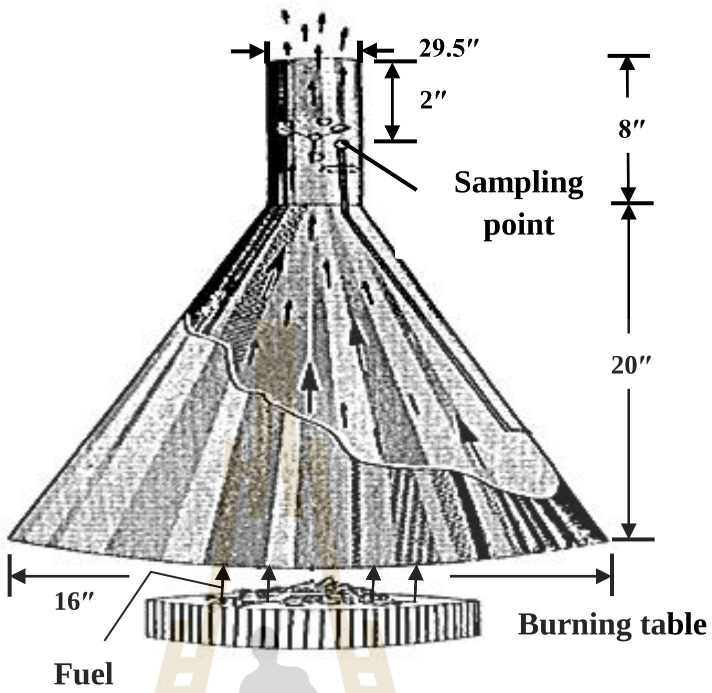


Figure 2.3 Sketch of burning tower to determine the emission from agricultural waste burning (Darley et al., 1977, 1979).

Bhattacharya et al. (2002) employed hood method to estimating the emission factors of cook stoves. The hood method is used for testing emission from biomass-fired stoves. The stove was placed under an extraction hood. Flue gas was sucked by using a suction blower (Fig. 2.4).

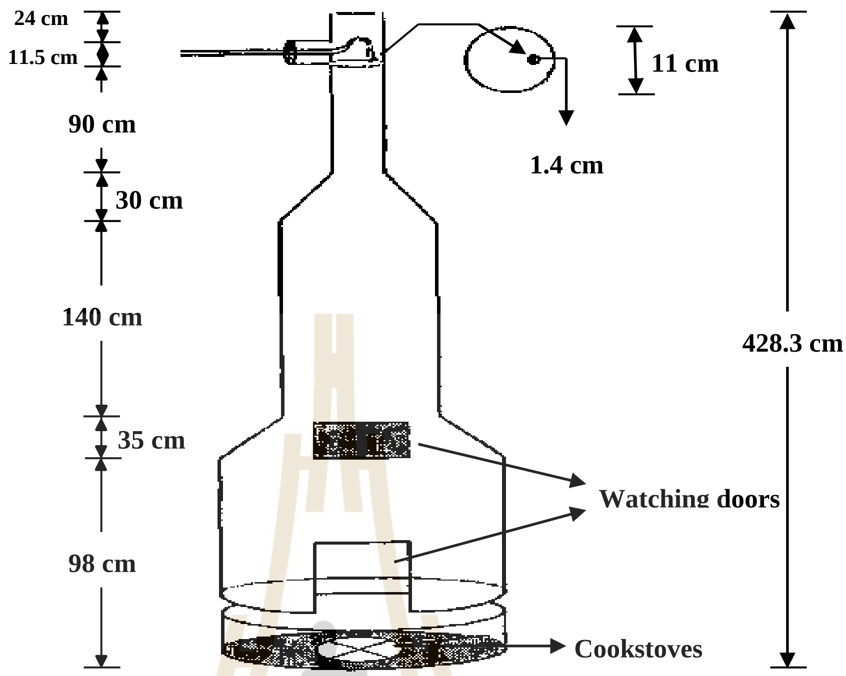


Figure 2.4 Hood method design to estimate the emission factors of cook stoves (Bhattacharya et al., 2002).

Guoliang et al. (2008) have been designed burning tower to simulate the conditions that peasants in rural China use, such as crop residues for cooking in traditional brick stoves. Figure 2.5 shows the burning tower used for investigating emission factors of particulate matter and gaseous pollutants from crop residue burning. The tower is in the form of an inverted funnel with a cylindrical bottom, 1.2 m in diameter and 0.4 m high. From the top of the cylinder, the tower decreases to 0.2 m in a length of 1.0 m, and is topped with a stack 1.2 m in height. There is a combustion table (0.4 m × 0.4 m) in the form of net, which is made up of a steel bar with each angle having supports 0.1 m in height. The sample site for gases, PM, and for recording temperatures and velocity of airflow is in the stack about 0.2 to 0.35 m below the top.

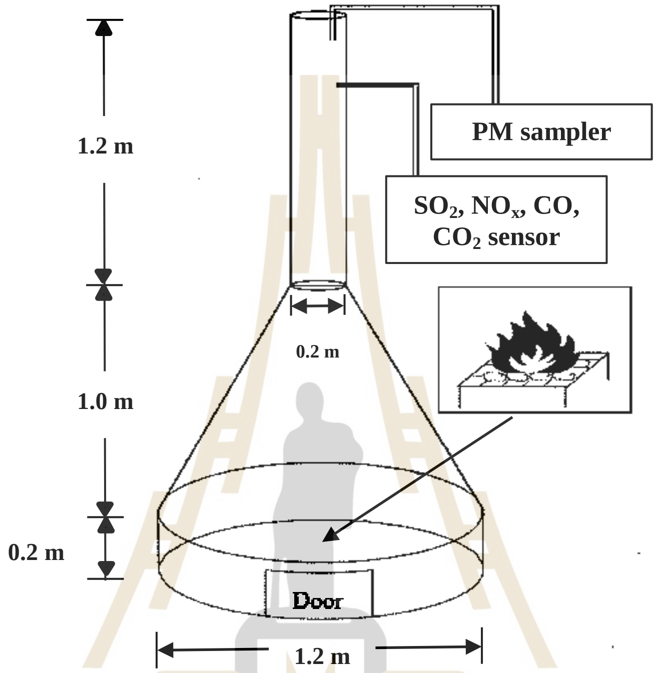


Figure 2.5 Burning tower used for investigating emission factors from crop residue burning (Guoliang et al., 2008).

2.3.3 Carbon balance approach under simulated or real-world conditions

Measurements of cook stove emissions and charcoal kiln emissions under real-world conditions have been successfully used in the carbon balance approach (Zhang et al., 2000; Pennise et al., 2001). Equation of carbon mass balance for the combustion, i.e., total carbon mass burned equals total mass of carbon emitted both in gases and in aerosols. The measurement of carbon concentrations in each is required. It also requires the measurement of carbon input of the combustion, i.e., carbon mass in the fuel consumed and carbon mass in the ash and unburned residues (if any). From carbon mass balance equation, mass-based emission factors for each measured species can be derived, as shown in detail by Zhang et al. (2000). Performance of tested devices can be minimized when measuring emission in the field. Determination of emission factors for some massive combustion devices such as large brick or mud stoves and non-ducted charcoal making kilns are difficult to be tested in the laboratory, therefore the carbon balance approach can be applied. The combustion may not be a steady state process, so the sampling methodology is typically used the average emission factors defined a burn cycle (i.e, the power output or burn rate varies at different stages of the combustion). During sample collection, the tested unvented combustion devices are normally placed under a hood. The position of sampling points can be relatively flexible in the flue gas stream, because it can be reasonably assumed that all airborne pollutants experience the same dilution factor at any sampling position in the flue gas. The sampling probe is inserted in the hood exhaust duct. Filters employed to collect particulate matter (PM) should be heat-treated quartz fiber filters which are required by subsequent analysis of carbon content of PM. Carbon content of PM can be analyzed using thermal–optical techniques (Huntzicker et al., 1986; Birch and Cary, 1996).

This method is used for evaluating emission factors during field experiments. However, this method can be applied in combustion chamber experiment. Emission factor based on carbon balance method requires knowing the carbon content of the fuel to calculate emission factors. In this method, all the burned carbon is assumed to be emitted into the atmosphere as carbonaceous particles and carbonaceous gases such as CO_2, CO, CH_4 and NMHCs, which is described in the following equation,

$$C_f - C_a = C_{CO_2} + C_{CO} + C_{CH_4} + C_{NMHCs} + C_{PM} \tag{2.4}$$

where: C_f, C_a = The carbon mass in the fuel and ash, respectively,

$C_{CO_2}, C_{CO}, C_{CH_4}, C_{NMHCs}, C_{PM}$ = The carbon mass in CO_2, CO, CH_4, NMHCs and particles, respectively.

Li et al. (2007) studies emission factors of organic carbon (OC) and elemental carbon (EC) in $PM_{2.5}$ and calculated as carbon mass in the particles. The emission factors are determined by the following equation.

$$EF_x = \Delta X / \left(\Delta\sum[CO_2],[CO],[CH_4],[C_{VOCs}],[C_{aerosol}],...\right) \times [C_{biomass}] \tag{2.5}$$

where: ΔX = The difference between concentrations in the background and in smoke conditions,

$\left(\Delta\sum[CO_2],[CO],[CH_4],[C_{VOCs}],[C_{aerosol}],...\right)$ = The species concentration expressed as the amount of carbon.

EF_x is commonly referred to ($\Delta\sum[CO_2]$, [CO]) as these two species represent generally 95-99% of the carbon-containing emissions. When EF_x corresponds to the ratio of the production of species X to the production of CO (or CO_2), it is called emission ratio (ER) (Andreae and Merlet, 2001).

If a steady-state flow-through chamber is well mixed, uniform conditions and concentrations are expected throughout the chamber and will equal those in the exit stream (Cooper and Alley, 1994). The emission factors are thus determined as follows:

$$EF_x\left(g/kg\right) = \frac{\Delta C_x \times Q_{chamber} \times t_{run}}{1000\frac{mg}{g} \times m_{burned}} \quad (2.6)$$

where: EF_x = The emission factor in (g) of pollutant x (kg^{-1}) fuel burned,

ΔC_x = The exit concentration of pollutant x in excess of the background (mg/m^3),

$Q_{chamber}$ = The flow rate of dilution air into the burn chamber (m^3/min),

t_{run} = The sampling time (min),

m_{burned} = The dry mass consumed during the burn (kg).

Alternative method for calculation of emission factors, hereafter referred to as emission factor (carbon), is based on the conservation of carbon in the biomass, and does not require pre- and post-burn weighing of biomass (ASI, 2003; Andreae and Merlet, 2001). The emission factor (carbon) method is used for evaluating emission factors during field experiments. The following equation can be applied (Hurst et al., 1994; Ward et al., 1992; ASI, 2003; Andreae and Merlet, 2001)

$$EF_x\left(g/kg\right) = \frac{\Delta C_x \times \left(1000\frac{g}{kg}\right) \times C_{fraction}}{\left(\Delta CO_2 - C + \Delta CO - C + \Delta THC - C + \Delta PM_{2.5} - C\right)} \quad (2.7)$$

where: EF_x = The emission factor in (g) of pollutant x (kg^{-1}) fuel burned,

ΔC_x = The exit concentration of pollutant x in excess of the background (mg/m^3),

$C_{fraction}$ = The mass fraction of carbon in dry matter.

($\Delta CO_2 - C + \Delta CO - C + \Delta THC - C + \Delta PM_{2.5} - C$) = All carbon in the biomass consumed by the fire is released into the atmosphere during combustion, and can be accounted for by measuring concentrations of CO_2, CO, THC and $PM_{2.5}$ in the plume. Time-averaged concentrations of these pollutants are considered to be representative of the entire plume over the whole sampling period if the sampling period extends over the total burning time. A carbon mass balance closure is used (Eq. (2.8)) to validate this assumption.

$$\text{Biomass C accounted for; \%} = \frac{(\Delta CO_2 - C + \Delta CO - C + \Delta THC - C + \Delta PM_{2.5} - C)}{m_{burned} \times C_{fraction} \times 0.01} \times Q_{chamber} \times t_{run} \quad (2.8)$$

where: Biomass C accounted = Carbon in the biomass (%),

$Q_{chamber}$ = The flow rate of dilution air into the burn chamber (m^3/min),

t_{run} = The sampling time (min),

m_{burned} = The dry mass consumed during the burn (kg),

$C_{fraction}$ = The mass fraction of carbon in dry matter.

($\Delta CO_2 - C + \Delta CO - C + \Delta THC - C + \Delta PM_{2.5} - C$) = All carbon in the biomass consumed by the fire is released into the atmosphere during combustion, and can be accounted for by measuring concentrations of CO_2, CO, THC and $PM_{2.5}$ in the plume.

The carbon content of the biomass fuel is inversely proportional to the moisture content and the non-carbon ash content (Dhammapala et al., 2006). The similar method of carbon mass balance (Ward et al., 1996) calculated particulate emission factors by all of the carbon combusted in a fire that emitted in to the measurable portions of a smoke plume in five forms of carbon: CO_2, CO, CH_4, non-methane hydrocarbons, and particulate carbon (Eq. 2.9).

$$EF_x = \frac{[C]_n}{[C]_{CO_2} + [C]_{CO} + [C]_{CH_4} + [C]_{NMHC} + [C]_{PC}} \qquad (2.9)$$

where: EF_x = The emission factor of a species x,

$[C]_n$ = Total carbon concentration emitted in the plume,

$[C]_{CO_2} + [C]_{CO} + [C]_{CH_4} + [C]_{NMHC} + [C]_{PC}$ = Five forms of carbon: CO_2, CO, CH_4, non-methane hydrocarbons, and particulate carbon in the plume.

2.4 Calculation of emission factor

2.4.1 Emission factor of particulate matter

In the case that a steady-state flow through chamber is well mixed, uniform conditions and concentrations are expected throughout the chamber, including in the exit stream. The emission factors are determined by direct method as follows:

$$EF_{PM} = \frac{M_i}{M_{fuel}} \qquad (2.10)$$

where: EF_{PM} = Emission factor of particulate matter (mg/kg or g/kg),

M_i = Mass of emitted particles on a filter (mg or g),

M_{fuel} = Mass of fuel consumed (g or kg)

Another feature of emission factor could be expressed in terms of mass of pollutant per energy input, which can be found by dividing the different weights of filter by the fuel-heating value, to obtain emission factor per energy unit (mg/MJ). Alternatively, emission factor of particulate matter can be estimated from stack parameters and sampling rates in the following equation described by Jenkins et al., (1996).

$$E_{i,j} = \frac{1}{m_{fd}} \int_{t_0}^{t_f} A_s \bar{u} \frac{m_{k,t}}{v_o} \eta \frac{T_i}{T_s} \qquad (2.11)$$

where: $E_{i,j}$ = Emission factor of PM or aerosols (g/kg),

m_{fd} = Mass of burned material (g),

t_0 = Initial time of burn (s),

t_f = Final time of burn (s),

A_s = Surface area of the stack (m^2),

u = Velocity of gas in the stack (m/s),

$m_{k,i}$ = Sampling weight of species i (g/g-mol),

v_o = Air pump work flow rate (m^3/s),

η = Mass content of aerosol in PM (ppm),

T_i = Absolute ambient air temperature (C°),

T_s = Absolute stack gas temperature (C°).

2.4.2 Emission factor of gaseous

A mass balance model was used to determine the emission rates and emission factors for the tested combustion devices (Schare and Smith, 1995). The pollutant emitted from the test chamber or the room was assumed mixing uniformly and the background concentration of the pollutant was zero. The concentrations of the pollutant in the chamber could be described as Eq. 2.3.

Alternatively, emission factor of gaseous can be estimated according to Jenkins et al., (1996).

$$E_i = \frac{10^{-3}}{m_{fd}} \int_{t_o}^{t_f} A_s u C_i \frac{w_i}{22.4} dt \qquad (2.12)$$

where: E_i = Emission factor of gas i (g/kg),

m_{fd} = Mass of burned material (g),

t_0 = Initial time of burn (s),

t_f = Final time of burn (s),

A_s = Surface area of the stack (m^2),

u = Velocity of gas in the stack (m/s),

C_i = Concentrations of measured gas i (ppm),

w_i = Molecular weight of measured gas i (g/g-mol).

2.5 Particulate matters and gaseous emitted from charcoal grilling device

Meat grilling with charcoal in street food stalls is commonly found along the streets in Thailand. Such activities are mostly uncontrolled and led to incomplete combustion resulting in a release of gases, PM and greenhouse gases into the atmosphere. When burnt charcoal emitted a mixture of NO_x and VOCs, the key ingredients in smog, is released. Charcoal burning also emits HC and PM, which can aggravate chronic heart and lung problems (Joe, 2009). Emissions concerning the street food stalls devices are PM_{10}, $PM_{2.5}$, SVOCs, PAHs, VOCs, aldehydes, CO, NO_x SO_x, CO_2 and THC (U.S. EPA, 1999). Their adverse effects on human health are a great concern, particularly in large cities where the number of street food stalls is high.

2.5.1 Particulate Matters (PM_{10} and $PM_{2.5}$)

PMs are the term for solid or liquid particles found in the air. Some particles are large or dark enough to be seen as soot or smoke. While some particles are too small and unable to see with the naked eye but can be detected only with an electron microscope. Particles originate from a variety of mobile and stationary sources (diesel trucks, woodstoves, power plants, etc.) (U.S. EPA, 1995). Charcoal also emits PM into the atmosphere contributing to increase pollution and higher concentrations of ground-level ozone.

2.5.2 Carbon Dioxide (CO_2)

CO_2 is the primary greenhouse gas emitted naturally and through human activities. Human activities are altering the carbon cycle, both by adding more CO_2 to the atmosphere and by influencing the ability of natural sinks, like forests, to remove

CO_2 from the atmosphere. While CO_2 emissions come from a variety of natural sources, human-related emissions are responsible for the increase that has occurred in the atmosphere since the industrial revolution (National Research Council, 2010). CO_2 is a gas emitted when a barbeque is operated, burning of fossil fuels, and forest combustion.

2.5.3 Carbon Monoxide (CO)

CO is a colorless, odorless, poisonous gas formed when carbon in fuels is not burned completely (U.S. EPA, 1995). CO is generated by charcoal grilling. Charcoal also emits CO and PM, which can aggravate chronic heart and lung problems and damage the liver, kidney and nervous system.

2.5.4 Nitrogen Oxides (NO_x)

NO_x are produced in combustion processes, partly from nitrogen compounds in the fuel, but mostly by direct combination of atmospheric oxygen and nitrogen in flames (Hall et al., 2006). Charcoal grills and lighter fluid also contribute more to ground-level ozone, which NO_x are produced in hot weather conditions. NO_x are generated from burning charcoal. It is a key ingredient in smog and released into the atmosphere.

2.5.5 Volatile Organic Compounds (VOCs)

Charcoal grilling emits VOCs through evaporation. VOCs are the key ingredient in smog released. These VOCs contribute to the formation of ground-level ozone when they mix with other air pollutants in the presence of sunlight. Ground-level ozone can cause health problems in people with lung and heart diseases, active children, and adults who work or exercise outdoors. Charcoal grilling may also leave a residue of toxic chemicals on the grilled food (Pima Country Government Arizona, 2012).

2.5.6 Polycyclic aromatic hydrocarbons (PAHs)

During incomplete combustion of organic materials, a large number of chemical compounds are formed which will contribute to air pollution. Amongst the formed compounds are polycyclic aromatic compounds (PAC) including, as a subgroup, PAHs which include only carbon and hydrogen in their molecular structure. Important sources of PAHs which contribute to urban air pollution are gasoline and diesel fuelled automobiles (Westerholm et al, 1991; 1992), domestic oil heating (Bardh and Ahling, 1983) and wood burning (Daisey et al, 1989). Rogge et al., (1991) identified emission factors of 10 PAHs obtained in smoke emitted from charbroiling of meat using a natural gas flame.

2.5.7 Total Hydrocarbons (THC)

The term "total hydrocarbons" (THC) refers to a broad family of chemicals that contain carbon and hydrogen atoms. Methane (CH_4), a non-reactive hydrocarbon, is the most common hydrocarbon in the earth's atmosphere. Specific reactive hydrocarbons or non-methane hydrocarbons (NMHC) can react with oxides of nitrogen in the presence of sunlight to form ozone. Health effects may result at varying concentrations depending on the hydrocarbon.

Sources of hydrocarbons include vegetation, vehicle emissions, gasoline marketing and storage tanks, petroleum and chemical industries, dry cleaning, fireplaces, natural gas combustion and aircraft traffic. Hydrocarbons are also emitted by fugitive sources such as evaporation of solvents, or leaking valves, flanges, pumps and compressors at industrial facilities. Incinerator and flare stacks can also be sources of hydrocarbons (Clean Air Strategic Alliance, 2006). The THC was emitted within the initial 30 minutes of lighting the charcoal. After the initial 30 minutes of burning, all of hydrocarbon contained in the charcoal burned off, and only carbon in the charcoal remained to sustain the fire. This may explain why the cooking of meat has very little effect on the total emission of THC (U.S. EPA, 1999).

2.6 Equipment used for measurement of particulate matters and gaseous pollutant

2.6.1 Measurement of particulate matters (PM)

Cascade impactor is one of the instruments for PM measurement. The cascade impactor contain separated stages, which are designed to selectively collect multiple size fractions simultaneously on a substrate. Anderson eight stage cascade impactor for sample separate particle fractionation from 10.0 to 0.4 micrometer (μm) aerodynamic diameters. Each impactor stage contains multiple precision drilled orifices. When air is drawn through the sampler, multiple jets of air in each stage direct any airborne particles toward the surface of the collection plate for that stage. The size of the jets is constant for each stage, but is smaller in each succeeding stage. Larger particles are collected in the initial stages and smaller particles in the final stages. The range of particle sizes collected on each stage depends on the jet velocity of the stage and the cut-off of the previous stage. Any particle not collected on the first stage follows the air stream around the edge of the plate to the next stage, where it is either impacted or passed on to the succeeding stage, and so on until the jet velocity is sufficient for impaction. The weight of PM for each stage was determined by comparing the initial tare weights of the impactor substrates with posttest values.

The common designs of the particle sizing sampler evolved from the following human respiratory tract. The sampling device is used as a substitute for the respiratory tract which classifying airborne particles by using aerodynamic system. The sampling instrument should collected and classify the particles according to the aerodynamic dimension. Lung penetration by airborne particles can be predicted from the dust collecting data. Deposition of the dust in the respiratory system depend on size, shape, and density and all the physical properties of the particles that constitute the aerodynamic dimensions as can be seen in Table 2.4 (New Star NV Manual, 2004).

Table 2.4 Specifications-cut points for the eight stage non-viable impactor.

Stage number	Range of cut diameter (μm)
0	9-10 and above
1	9-5.8
2	5.8-4.7
3	4.7-3.3
4	3.3-2.1
5	2.1-1.1
6	1.1-0.65
7	0.65-0.43

Source: (New Star NV Manual, 2004)

Problems that can arise when using a cascade impactor include particle bounce and inter-stage losses. Particle bounce is mainly a problem associated with dry, solid particles and is less pronounced when sampling liquid or wet particles. When the particles hit a hard impaction plate they may bounce and be carried away with the gas flow and, hence, be collected at a subsequent impactor stage, thereby contributing to the apparent mass of a smaller particle size. Various techniques have been used to reduce the bouncing effect such as coating the impaction plate with a thin film of oil or grease or using some porous material such as a glass or quartz fiber filter (Chang et al., 1999) or polyurethane foam (PUF) (Breum, 2000) as substrate. The study for determination particulate matters from various small-scale combustion devices by using cascade impactor are summarized in Table 2.5

Table 2.5 Summary of determination particulate matters from various small-scale combustion devices using cascade impactor.

Emission source	Reference
Stack	Pilat et al. (1970)
Small-scale biomass combustion	Johansson (2002)
Biomass combustion	Nussbaumer et al. (2008)
Residential wood combustion in rural China	Guofeng et al. (2012)
Grilling process	Rangjob and Nathapindhu (2012)

2.6.2 Measurement of CO, NO_x, SO_2, and CO_2

Portable emission analyzer is one of the instruments for CO, NO_x, SO_2, and CO_2 measurement. This instrument consists of sensors capable of quantifying gas concentration. The design of gas probe is absorbed gas samples in channels. The assembled pump absorbs the gases from channel and transmits them to the sensors and analyzers mounted in instrument. The measurement results will be displayed in the monitor (Besire et al., 2010).

A gas sensor is a transducer that detects gas molecules and which produces an electrical signal with a magnitude proportional to the concentration of the gas. There are five types most suitable and widely used as gas detection include electrochemical sensors, catalytic combustible gas sensors, solid-state gas sensors, infrared gas sensors, and photoionization detectors (Jack, 2000). Electrochemical sensors are one of the most common types of sensors used in portable gas detectors. Substance-specific electrochemical sensors are available for many of the most common toxic gases including CO, NO_2, SO_2, H_2S, Cl_2, NH_3, O_3 and others. Electrochemical sensors are compact, require very little power, exhibit excellent linearity and repeatability, and generally have a long life span. Gas that enters the sensor undergoes an electrochemical reaction that causes a change in the electrical output of the sensor. The difference in the electrical output is proportional to the amount of gas present (Robert, 2005). For this reason, the electrochemical sensors are widely used in portable instruments that contain multiple sensors.

Measuring emissions from small scale combustion is usually used portable instruments such as Testo®. The Testo 350 is a portable analyzer and a self-contained emission analyzer system capable of measuring O_2, CO, NO, NO_2, SO_2, H_2S, and HC in combustion emission sources, while capturing data on pressure, temperature, and flow. Low NO_x and low CO resolutions are 0.1 part per million (ppm). Electrochemical sensor is the fundamental components of a portable gas analyzer. The output signal from electrochemical sensor shows concentrations of the targeted gases in the combustion stream. The study for determination air pollutants from various small-scale combustion devices by using Testo 350 are summarized in Table 2.6

Table 2.6 Summary of determination air pollutants from various small-scale combustion devices by using Testo 350.

Emission source	Air pollutants	Reference
Fuel combustion in industrial boilers	CO, CO_2, SO_2 and NO_2	Aykan (2006)
Co-combustion of coal with rice husks and bamboo	CO, O_2, NO, NO_2 and SO_2	Philip et al. (2007)
Power Plant	O_2, CO, CO_2, NO, NO_2, SO_2, NO_X and H_2	Besire et al. (2010)
Small combustion	NO_x	Stephen (2010)
Co-combustion of Thai lignite and agricultural residues	CO and O_2	Mantananont et al. (2011)
Port	NO_x	Melo and Murcia (2013)

2.6.3 Measurement of hydrocarbon (HC)

Gas Chromatography – Flame Ionization Detector for GC-FID is a very common analytical techniques and high sensitive, provide a wide linear range and efficient detection of organic compounds. A FID uses a hydrogen flame to ionization organic compounds in the sample stream. The FID responds to almost all organic compounds, including methane (CH_4), ethane (C_2H_6), acetylene (C_2H_2) etc. The sample gas is introduced into a hydrogen flame inside the FID. Any hydrocarbons in the sample will produce ions when they are burnt. The signal is produced primarily by the ions formed during the oxidation of carbon-hydrogen bonds, the strength of the response is directly related to the molar concentration of the organic compound and the number of carbon atoms per molecule. The current signal generated at the FID's collector electrode is carried through a shielded cable that runs to an electrometer and amplifier circuit. The electrometer circuit converts the current to a voltage that is amplified and then digitized by a voltage to frequency (V/F) converter (WBEA, 2013).

2.7 The importance for developing emission factors

Emission estimates are important for authority or industry to establish emission control strategies, determine the effects of sources and appropriate mitigation strategies. The fundamental tools for air quality management also rely on emission factors and emission inventories. Data from source-specific emission tests or continuous emission monitors provide the best representation of estimating the tested source's emissions. However, test data from individual sources are not always available and even then they may not reflect the variability of actual emissions over time. Thus, emission factors are frequently the best or only method available for estimating emissions, in spite of their limitations (U.S. EPA, 1996).

CHAPTER III

MATERIALS AND METHODS

This research involved the development of local emission factors for gases and particulate matters emitted from grilling activities of street food stalls in the laboratory-scale combustion testing equipment. Methodology to develop local emission factors emitted from grilling activities is summarized in Figure 3.1.

Experimental steps

Step 1: Preparing meat samples.

Meat grilling activities included in this study: pork, chicken, fish, squid, shrimp, Thai sausage, Thai sour pork and meatball.

↓

Step 2: Calorific determination of charcoal with bomb calorimeter.

↓

Step 3: Fuels tested.

↓

Step 4: Preparation of combustion simulations.

↓

Step 5: Measurement of CO, NO_x, SO_2 and CO_2 with Testo 350, CH_4 with GC-FID, and PM_{10} with ANDERSEN eight-stage impactor.

↓

Step 6: Evaluation of local emission factors for gases and particulate matters emitted from meat grilling activities.

Figure 3.1 Experimental steps.

3.1 Preparing meat samples

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 the local production. This study selected meats that were commonly sale or consumed locally. The grilling tests and results were based on wet weight and dry weight basis. Table 3.1 shows details on variety of meat, range of wet weight for meat, amount of fuel and measuring time for grilling activities. All samples were tested for moisture content according to AOAC (2000) method. All meats were non-marinaded.

Table 3.1 Types and amount material for grilling activities.

Meat	Initial wet weight (Range) (g/stick)	Amount of fuel (g)	Grill time (min)
Pork 	35-55	700	20
Chicken 	44-63	700	20

Table 3.1 Types and amount material for grilling activities (Continued).

Meat	Initial wet weight (Range) (g/stick)	Amount of fuel (g)	Grill time (min)
Chicken liver 	34-63	700	20
Chicken wing 	65-120	700	20
Catfish 	340-450	700	20
Tilapia 	430-540	700	20

Table 3.1 Types and amount material for grilling activities (Continued).

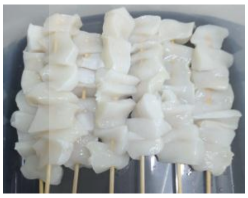
Meat	**Initial wet weight (Range) (g/stick)**	**Amount of fuel (g)**	**Grill time (min)**
Ruby fish 	450-720	700	20
Squid 	55-62	700	15
Shrimp 	23-37	700	15
Thai sausage 	31-52	700	20

Table 3.1 Types and amount material for grilling activities (Continued).

Meat	Initial wet weight (Range) (g/stick)	Amount of fuel (g)	Grill time (min)
Thai sour pork 	75-97	700	20
Meatball 	43-59	700	15
Pork ball 	32-61	700	15
Fish ball 	32-70	700	15

Table 3.1 Types and amount material for grilling activities (Continued).

Meat	Initial wet weight (Range) (g/stick)	Amount of fuel (g)	Grill time (min)
Chicken ball 	38-53	700	15

Procedure for moisture content determination

Figure 3.2 shows equipment used for humidity determination.

1. Dry the crucibles and lids in the oven at 105°C for 3 h and transfer to desiccator to cool. Weight the crucibles and lids and record.
2. Prepare meat and wooden stick.
3. Weight meat and wooden stick. Record the weight prior to put into the oven (W_1).
4. Place the crucibles with sample in the oven. Dry for 3 h at 105°C.
5. Transfer the crucibles with partially covered lids in the desiccator to cool. Reweight the crucibles repeat until successive weights do not differ by more than 1 mg. Record the dry weight (W_2).

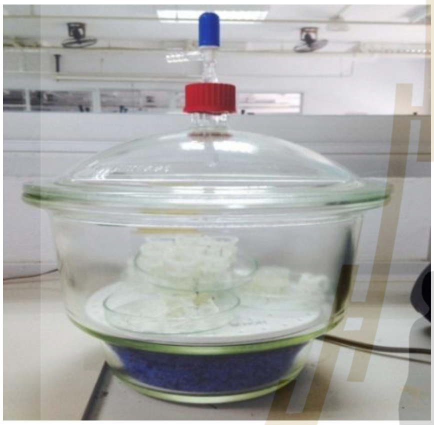
Calculate dry weight and percent moisture from the following formula.

$$\%\text{Dry weight} = \left(\frac{W_1 - W_2}{W_1}\right) \times 100 \tag{3.1}$$

where: W_1 = weight (g) of sample before drying

W_2 = weight (g) of sample after drying

$$\% \text{ Moisture} = 100 - \% \text{ Dry weight} \qquad (3.2)$$



(a). Desiccators

(b). Crucible with lid

(c). Aluminum pan

(d). Aluminum foil

(e). Oven (f). Balance

Figure 3.2 Equipment used for moisture content determination (a)-(f).

3.2 Calorific determination of charcoal with bomb calorimeter

Charcoal was tested for calorific value according to ASTM D 5865-02 (2004) method prior to use in the experiment. The calorific value of charcoal is determined by calculating the heat provided by the combustion of a specified quantity of the sample product in a bomb calorimeter, C5003, IKA, Germany (Figure 3.3). The system components consist of control panel, keyboard, display, electronics unit, measuring cell, temperature sensor, oxygen filling device, decomposition vessel, measuring cell cover and the calorimeter system consists of inner vessel, decomposition vessel, pure oxygen (P=30 bar), ignition wire cotton thread crucible, and fuel sample. All phases of the measurement procedure are controlled and monitored during the experiment.

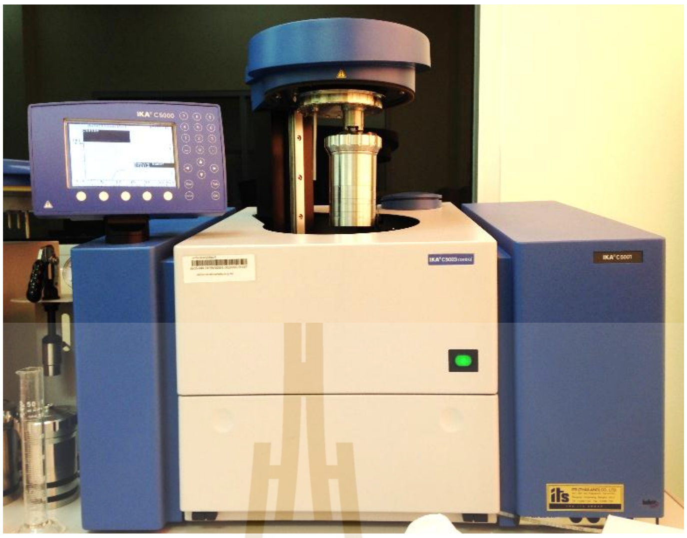


Figure 3.3 Bomb calorimeter.

Procedure for calorific determination

1. Sample weight is about 0.8-1.2 g.
2. Record the weight to the nearest 0.1 mg.
3. Put charcoal into sample holder.
4. Preparation of the bomb:

   4.1 Rinse the bomb with water to wet internal seals, surface areas of the bomb, and precondition the calorimeter according to the manufacturer's instructions. Add 1.0 mL of water to the bomb before assembly.

   4.2 Connect a measured fuse.

   4.3 Assemble the bomb. Admit oxygen to the bomb to a consistent pressure of between 2 and 3 MPa (20 and 30 atm). The same pressure is used for each heat capacity run. Control oxygen flow to the bomb so as not to blow material from the sample holder.
5. Preparation of calorimeter:

5.1 Fill the calorimeter vessel with water at a temperature not more than 2°C below room temperature and place the assembled bomb in the calorimeter. Check that no oxygen bubbles are leaking from the bomb. If there is evidence of leakage, remove and exhaust the bomb. Discard the sample.

5.2 With the calorimeter vessel positioned in the jacket start the stirrers.

6. Temperature Observations Automated Calorimeters:

6.1 The calorimeter vessel's temperature shall remain stable over a period of 30 s before firing. The stability shall be ±0.001°C/s or less for an isoperibol calorimeter.

7. Temperature Observations Manual Calorimeters:

7.1 For isoperibol calorimeters, when approaching the final stabilization temperature, record readings until three successive readings do not differ by more than 0.001°C per min.

7.2 Open the calorimeter and remove the bomb. Release the pressure at a uniform rate such that the operation will not be less than 1 min. Open the bomb and examine the bomb interior. Discard the test if unburned sample or sooty deposits are found.

7.3 The calorific value shown on the display (g/MJ). Record the results.

3.3 Determination of elemental composition in charcoal

Each of fuels has a unique composition and energy content described by its fuel specifications. Knowing the fuel specifications is essential for determining combustion parameters such as combustion efficiency, minimum air requirements, CO_2 concentration and emissions factors. The methodology for testing chemical content of charcoal including carbon (C), hydrogen (H), nitrogen (N), sulfur (S), and oxygen (O) is described here. The content of C, H, N, S, and O in the sample was measured by an elemental analyzer (Truspec Micro 628 Series, LECO, USA) (ASTM D 5373 – 02, 2004). Principle of this instrument is based on dynamic flash. Equipment used for C, H, N, S, and O content determination showed in Figure 3.4. The purpose of this investigation was to compare two types of charcoal for the chemical content, percentage of CO_2 maximum and percentage of O_2 from charcoal combustion determination that is specific data used for setting fuel specific coefficient for Testo 350 prior to the combustion experiment. The type of charcoal were derived from eucalyptus and jackfruit woods. Methodology to develop charcoal coefficient for this study is explained as follows.

(a). Charcoal powder (b). Balance

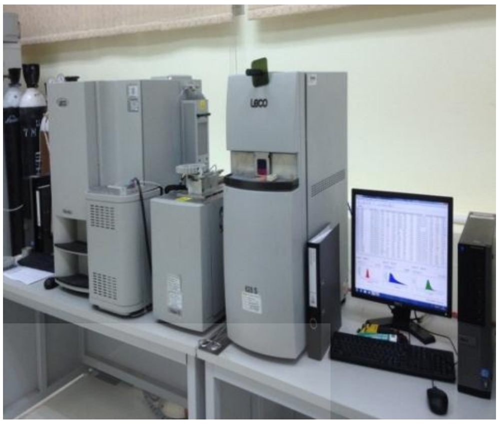
(c). Tin capsule

(d). Tin capsule

(e). Crucible

(f). Forceps

(g). Calibration sample



(h). C, H, N, S and O analyzer

Figure 3.4 Equipment used for C, H, N, S and O content determination (a)-(h).

Procedure for carbon hydrogen nitrogen sulfur and oxygen determination

1. Perform a system check before operation to determine if the instrument is operating properly.

   1.1 Let the instrument warm up and stabilize.

   1.2 From the diagnostics menu, click system check.

   1.3 Check the results of all system. The circle in front of the system name should be filled in green and in the results column all systems should indicate “Passed”.

2. Perform a leak check on both the oxygen and helium systems.
3. Choose method.
4. Login a blank. Put “Blank” in sample name channel and put mass weight in mass channel
5. Analyze a blank.
6. Perform blank calibration.

6.1 In the spreadsheet, select the analyzed blanks to set the initial blank calibration value area. These should be the same blanks used in the previous step.

6.2 From the configuration menu, click blank. The blank dialog box will appear with a new blank calibration value.

6.3 Click OK to enter the new blank calibration value.

7. Login a standard.

7.1 From the samples menu, click login. The sample login dialog box will appear.

7.2 Enter the sample name of the standard.

8. Analyze a standard.

9. Sample preparation

9.1 Place the micro capsule on the balance using forceps.

9.2 Press tare to tare the balance.

9.3 Add sample to the micro capsule being careful not to spill any on the balance pan.

9.4 Remove the micro capsule from the balance and crimp.

9.5 Place the crimped micro capsule on the balance and record the mass.

10. Analyze a sample

10.1 Sample analysis determines the element concentration in a sample.

11. The final result is displayed as weight percentage or in parts per million as determined by the operator.

Procedure for setting fuel specific coefficient on Testo 350

1. Analyze C, H, N, S and O content from charcoal by using TruSpecCHN determinator, CHN628 series (LECO Corp., USA).
2. Convert the percent of C, H, N, S and O to moles. Solving empirical formulas from known mass percentages is shown in Figure 3.5
3. Add moles of each element to balance chemical equation (3.3) for charcoal combustion.
4. Calculate the percentage of CO_2 maximum from balanced chemical equation (3.4).
5. Enter the value of percentage of CO_2 maximum and percentage of O_2 on Testo 350 for setting fuel specific coefficient prior to the experiment.
6. Measure O_2, CO, NO_x, SO_2, and CO_2 of two types charcoal combustion by using Testo 350.
7. Conduct the t-test to compares the actual difference between two means in relation of the emission test from two type of charcoal.
8. Choose one type of charcoal for this study to minimize variation.

The general flowchart for solving empirical formulas from known mass percentages is the followings.

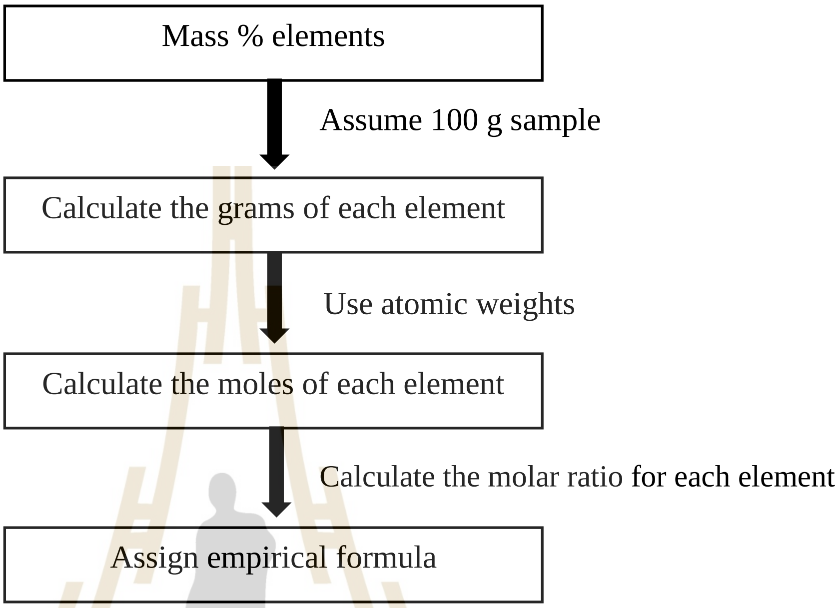


Figure 3.5 Flowchart for solving empirical formulas from known mass percentages.

A general equation for the combustion of a simple hydrocarbon in air (Eq. 3.3) according to TSI Incorporated, (2004).

$$C_xH_y + \frac{(4x+y)O_2}{4} \Rightarrow xCO_2 + \left(\frac{y}{2}\right)H_2O \qquad (3.3)$$

where: x and y are the number of atoms of carbon and hydrogen in the fuel.

Complete combustion of a simple hydrocarbon C_xH_y produces a fixed amount of carbon dioxide. If the theoretical air is used (i.e. excess air is zero) the concentration of CO_2 in the exhaust is at the maximum concentration. To calculate the percentage of CO_2 maximum assumes water condenses out leaving only CO_2 and N_2 (from the air) as gases in the exhaust stream by using the equation below for a simple hydrocarbon.

$$\%CO_2max = \frac{molesCO_2}{(molesCO_2 + molesN_2)} \times 100 \tag{3.4}$$

(TSI Incorporated, 2004).

$$molesCO_2 = xmoles \tag{3.5}$$

(TSI Incorporated, 2004).

$$molesN_2 = \frac{(4x + y) \times 3.76}{4} \tag{3.6}$$

(TSI Incorporated, 2004).

3.4 Preparation of combustion simulations

1. Combustion testing equipment: Combustion testing equipment has been designed and installed in a laboratory, located in the equipment building 8 at Suranaree University of Technology. The combustion testing equipment is in the form of an inverted funnel with a cylinder bottom, 1.2 m in diameter and 0.8 m in high. From the top of the cylinder, the tower decrease to 0.28 m in a length of 0.5 m, and is topped with a stack 1.7 m in height. Surface area of the stack is 0.03 m^2. The schematic sketches and actual figures of the combustion testing equipment are shown in Figures 3.6 and 3.7, along with locations of sampling ports. The sample site for gases, temperature, and velocity of airflow is in the stack about 0.50 m below the top. The lowest position of the combustion is the aluminum rectangular box, used to collect the ash obtained from combustion. Size of aluminum rectangular box is 0.50 m × 0.50 m and size of aluminum mesh screen is 0.40 m × 0.47 m (Figure 3.8). An aluminum mesh screen similar to the filter screen was used for grilling activities of street food stalls.

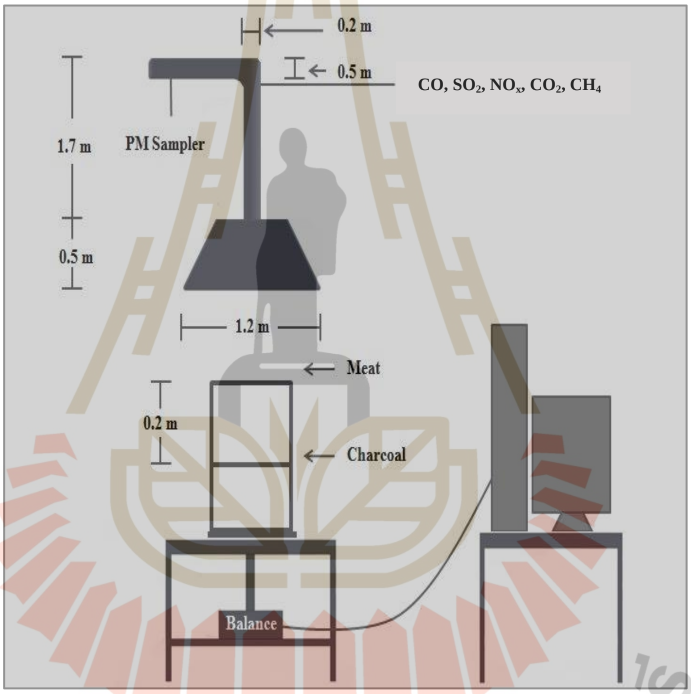


Figure 3.6 Schematic diagram of combustion testing equipment with locations of sampling ports.

Figure 3.7 Combustion testing equipment.

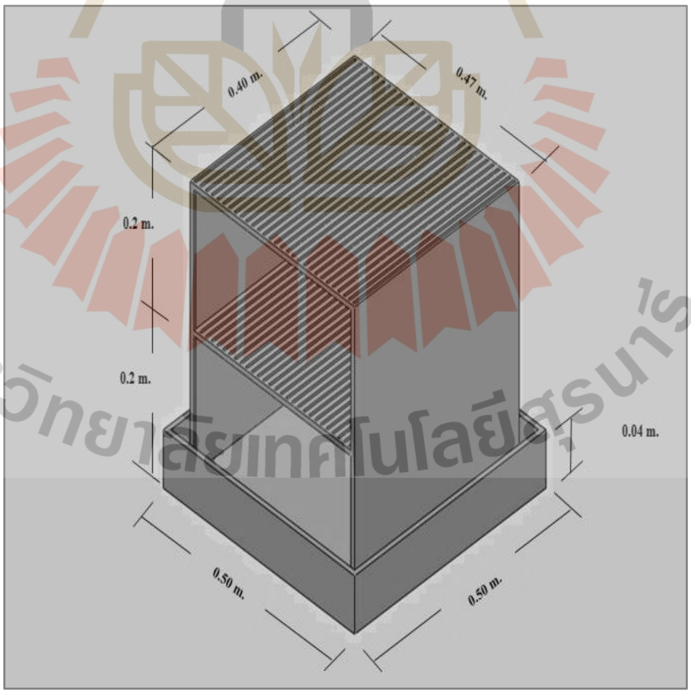


Figure 3.8 Schematic diagram of aluminum mesh screen and aluminum rectangular box for ash collection

2. **Electronic balance**: All electronic balances were checked with the standard external weights daily prior to the experiment. The external check was done daily to check the reading of the electronic balances.
3. **Testo 350**: CO, CO_2, SO_2, NO, NO_2, NO_x, and O_2 sensors are factory calibrated and brand new. Each of sensor calibrate with the actual concentration value or a reference standard. Calibration involves checking the instrument with a known concentration of a gas to observe the proper response. Testo 350 (Testo AG, Germany) consists of sensors of respective gases. The gas probe takes gas samples in channels. The assembled pump draws the gases from the gas channel and transmits them to the sensors mounted in the instrument. After the time necessary for the instrument to provide the results, the measurement results are displayed on the screen and logged in a file (Besire et al., 2010).
4. **Gas Chromatography – Flame Ionization Detector (GC-FID):** The quantitative concentration of CH_4 was analyzed by the gas chromatograph (Agilent 7890A, USA). Flame ionization detector was used as a detector. The GC was calibrated daily with a standard CH_4 gas (certified at 19.5 ppm, Air Liquid, Thailand). The GC column was a capillary column (Model HP-AL/S, produced by Agilent). The length, diameter, and film of capillary column were 30 m, 250 µm, and 5 µm, respectively. Analysis GC conditions including:
   - Column temperature 50 °C
   - Injection temperature 200 °C
   - FID detector temperature 250 °C

- Carrier gas (He) flow 5 mL/min
- split ratio 20:1
- split flow 100 mL/min

5. **Pump and ANDERSEN eight-stage impactor:** Particulate matters with cut-size diameter sampling with the ANDERSEN eight-stage impactor (Gresby-Andersen, USA). A pump was calibrated at the sampling conditions. Adjust the pump valve until it reached 28.3 L/min over three minute test periods. After maintaining at 28.3 L/min for three minutes, the lock nut was on the tighten adjustment valve. When the air was drawn through the multiple jets, any airborne particles were drawn toward the surface of the collection plate for that stage. Whether a particle is impacted on any given stage depends on its aerodynamic dimension. Larger particles are collected in the initial stages and smaller particles in the final stages. The weight of PM for each stage was determined by comparing the initial tare weights of the impactor substrates with the posttest values.

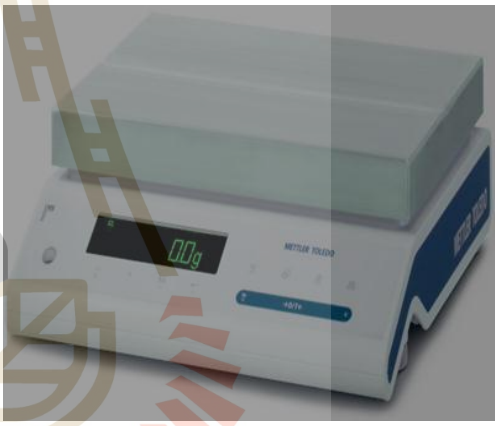
3.5 Measurement of gaseous and particulate matters

Measurement of gaseous and particulate matters requires preparation of the samples and materials. In this study, measurement of CO, NO_x, SO_2, and CO_2, were performed by Testo 350, while CH_4 were measured by GC-FID. Particulate matters were collected using ANDERSEN eight-stage, as shown in Figure 3.9

(a). Aluminum foil

(b). Aluminum pan

(c). Balance for weighing meat and stick

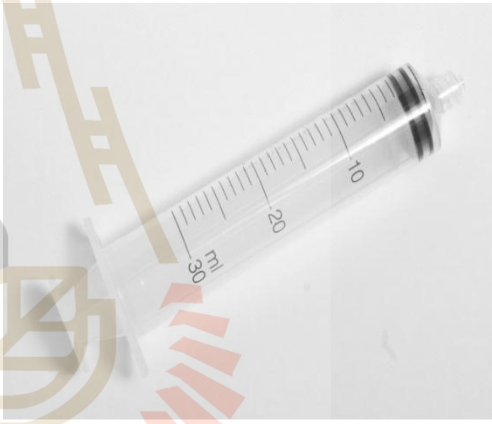


(d). Balance for weighing meat and charcoal

(e). Aluminum mesh screen

(f). Testo 350 (CO, NO_x, SO_2, and CO_2)

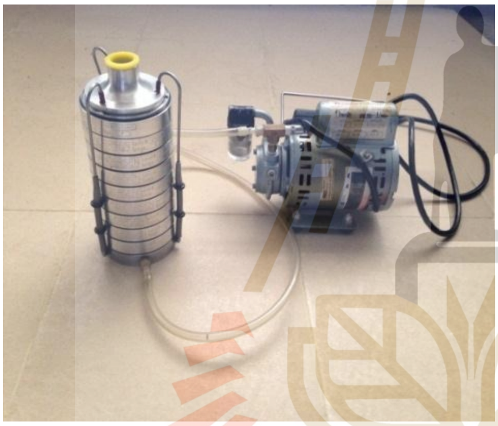
(g). GC-FID (CH_4)



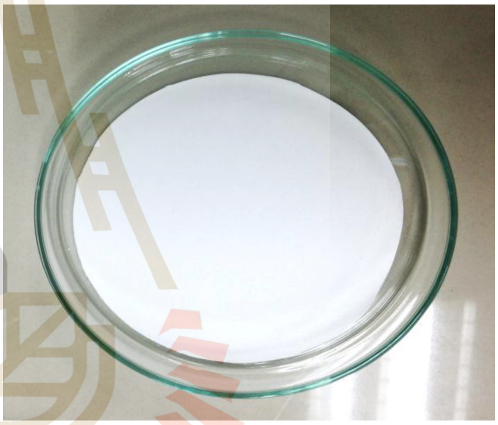
(h). Syringe

(i). Gas Sampling Bags

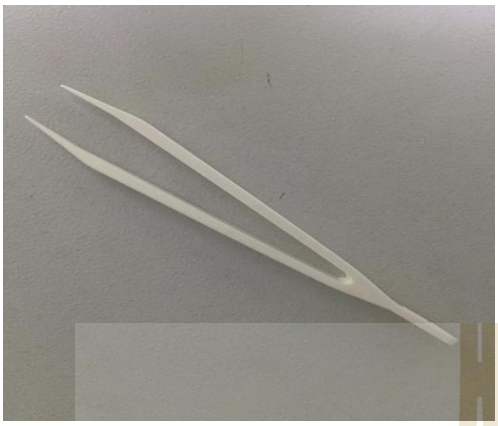
(j). Standard gas of CH_4



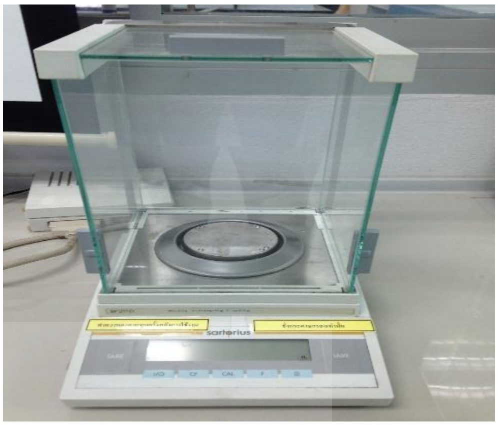
(k). Pump and ANDERSEN eight-stage impactor



(l). Glass fiber filter



(m). Forceps used for glass fiber filter



(n). Balance for weighing filters

Figure 3.9 Equipment used for measurement of gaseous and particulate matters (a)-(n).

1. Experimental setup

1.1 The electronic balance (MS32001L, Mettler Toledo, Switzerland) was placed under the combustion equipment and connected to a computer to record mass changes. LabX^{TM} software was used as the interface to continuously monitor the mass.

1.2 Testo 350: The sampling point for gases, temperature and velocity of airflow was in the stack about 0.5 m below the top. The probe was inserted into sampling port after the charcoal light up and reaching steady burning in half a minute. Testo 350 measured concentrations of CO, NO_x, SO_2, CO_2, temperature and velocity of airflow. Testo 350 was connected to a computer to record concentration of CO, NO_x, SO_2, CO_2 during the experiment. The Testo easyEmission^{TM} software was used as the interface to continuously monitor the concentration of gases.

1.3 GC-FID: 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. CH_4 was quantified by a GC- FID (Agilent 7890A, USA). The GC was calibrated daily with a standard CH_4 gas (certified at ppm, Air Liquid, Thailand). All gas sample bags were analyzed within 24 hours in a laboratory. All gas sampling bags used in each experiment were flushed adequately with compressed clean air for at least three times and evacuated prior to the next use.

1.4 The ANDERSEN eight-stage impactor was placed in stack. The combustion testing equipment has an opening for impactor installation to measure particulate matter. PM_{10} were measured using the ANDERSEN eight-stage cascade impactor. The impactor separated particles into different aerodynamic diameters (D_a) (<0.4, 0.4-0.7, 0.7-1.1, 1.1-2.1, 2.1-3.3, 3.3-4.7, 4.7-5.8, 5.8-9.0, and 9.0-10.0 µm) at a flow rate of 28.3 L/min. A pump of impactor was calibrated with a primary flow meter.

1.5 Aluminum pan: Each aluminum foil was weighted prior to use. Wrap aluminum pan with the foil.

1.6 Meat and stick: Weight meat with stick and charcoal on the balance and record the initial weight.

2. Measurement

Meat and stick were analyzed for moisture content and charcoal was analyzed for calorific value. This study used two conditions for emission measurements: charcoal only and meat grilling with charcoal. Background concentration of test gases was measured for 5 minutes at the beginning of each test. Particulate matter was measured inside the stack, therefore, the ambient concentration was not considered. Place the aluminum mesh screen on the aluminum pan before the test and pull out after the test were very carefully for each batch of the test.

2.1 Charcoal emission test:

2.1.1 Charcoal was weighted and placed on the aluminum mesh screen. Aluminum foil was placed under the mesh screen to collect remaining ash.

2.1.2 Light up the charcoal. Torch was used to lit up the charcoal.

2.1.3 After reached the steady burning in about half a minute, the sampling instrument and test equipment were simultaneously operated (Jenkins et al., 1996) with the exception of CH_4 gas the grab sampling started after steady burning in about half a minute and were sampled every 3 minutes.

2.1.4 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.

2.2 Charcoal and meat grilling emission test:

2.2.1 Charcoal and meat were weighted and placed on the aluminum mesh screen. Aluminum foil was placed under to collect remaining ash.

2.2.2 Light up the charcoal. Torch was used to lit up the charcoal.

2.2.3 After reached the steady burning in about half a minute, the sampling instrument and test equipment were simultaneously operated (Jenkins et al., 1996) with the exception of CH_4 gas the grab sampling started after steady burning in about half a minute and every 3 minutes.

2.2.4 Emissions were recorded during the grilling 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.

2.3 Allowed the samples to cool, weighted and recorded the final mass.

2.4 Collected the ash. Allowed to cool, and recorded the weight.

2.5 Repeated the experiment as replicate at least 9 times to assure the experimental results and assess uncertainty.

3. Operating procedures of the instrument

3.1 Continuous gas emission analyzer, Testo 350, was used as the principal instrument for CO, NO_x, SO_2, and CO_2, measurements. The operational procedures are described in Figure 3.10

3.2 Procedure for particulate matters (PM_{10}) measurement

3.2.1 Glass fiber filters of 81 mm in diameter were used for PM_{10} sampling.

3.2.2 Preheated the filters at 103-105 ºC for 3 hours.

3.2.3 Each filter was placed in a clean petri dish during transport and storage.

3.2.4 All filters were equilibrated in a desiccator at least 24 hours with constant humidity and temperature before using.

3.2.5 Pre weigh of filters were made using and electronic balance (BP211D, Sartorius, Germany) with a sensitivity 10^{-5}g (W_i).

3.2.6 Placed glass fiber filters into the ANDERSEN eight stage impactor.

3.2.7 Adjusted flow rate of pump is 28.3 L/min.

3.2.8 Started sampling particulate matter until grilling activities was done.

3.2.9 After sampling, the glass fiber filters were removed and weighted again, to obtain the final weight of the filters (W_f).

3.2.10 The following equation was used for the calculation of the particle mass concentration according to U.S. EPA, (2003).

$$C_{PM} = \frac{(W_f - W_i)}{V_{std}} \qquad (3.7)$$

where: C_{PM} = particulate mass concentration in mg/m^3

W_f = final weight of glass fiber filters (mg)

W_i = initial weight of glass fiber filters (mg)

V_{std} = air volume at standard temperature and pressure (m^3)

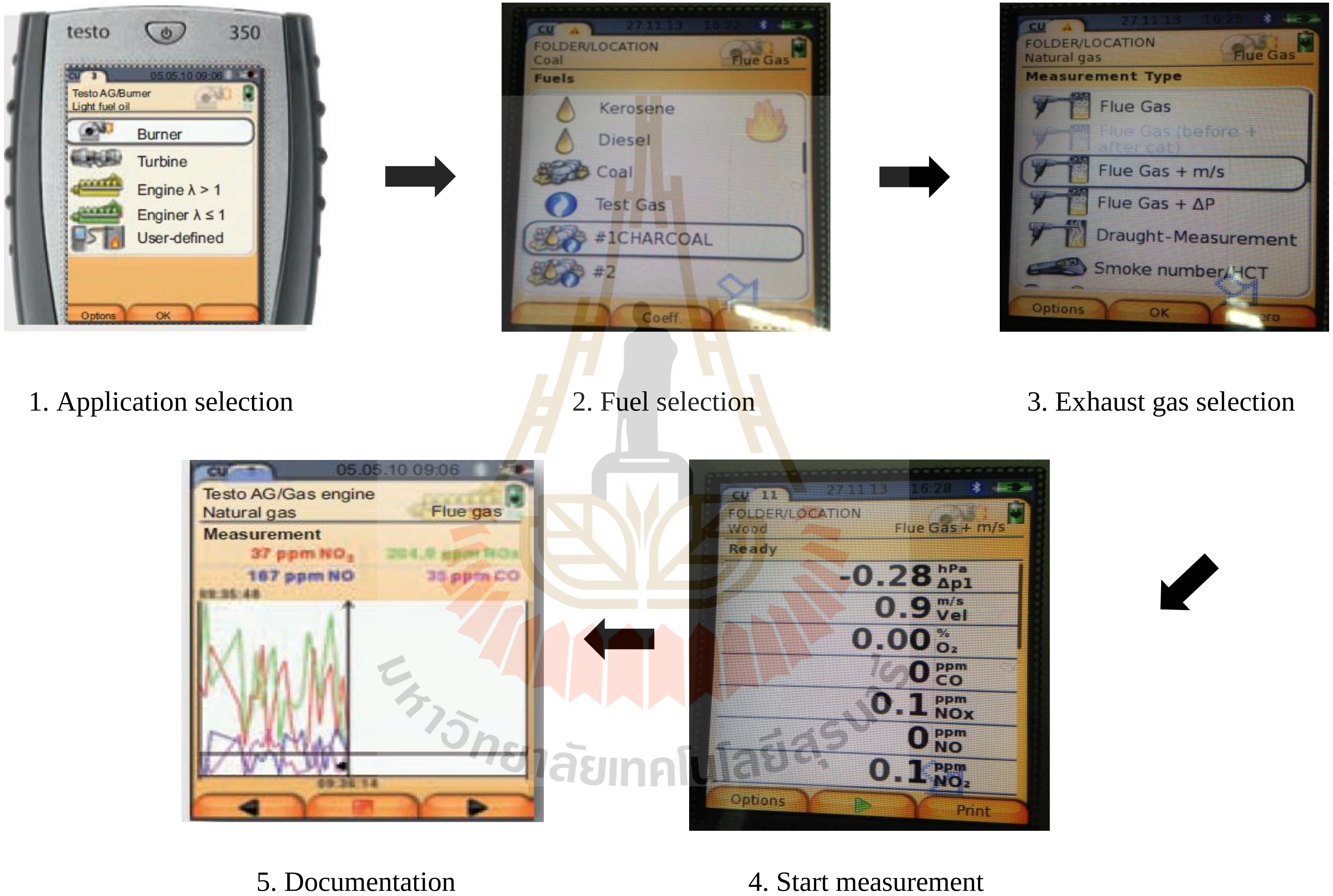


Figure 3.10 Operational step for measurement of CO, NO_x, SO_2, and CO_2, (Testo 350).

3.6 Evaluation of local emission factors for gases and particulate matters emitted from grilling activities

1. Data analysis

Data were analyzed using descriptive statistics for each of gas and particulate matters emitted from grilling activities. Relationships between emissions and time were graphically plotted to observe time-series information.

2. Calculations

Emission factors (EFs) of particulate matter was calculated according to equation 2.10. Emission factors of gaseous species were calculated followed equation 2.12 (Jenkins et al., 1996).

3. Evaluation

Emission factors from this study were summarized and compare with other international values.

CHAPTER IV

RESULTS AND DISCUSSION

In this study, experimental development of emission factors for gases and particulate matter emitted from meat grilling activities were discussed separately by dividing into five parts.

4.1 Fuel tested

4.1.1 Properties of charcoal and meat

4.1.1.1 Chemical content

This study investigated the chemical contents of two types of charcoal. Each charcoal was analyzed for C, H, N, S, and O contents. The results indicated that carbon was the main component in the charcoal. The chemical contents of charcoal made from eucalyptus wood and charcoal made from jackfruit wood were relatively similar. Carbon content in charcoal made from eucalyptus wood was 83.72±1.54%, higher than other elements, followed by 9.33±0.49% of oxygen, 1.89±0.05% of hydrogen, 0.37±0.03% of nitrogen, and 0.01±0.004% of sulfur. Charcoal made from jackfruit wood had 85.52±0.81% of carbon content, followed by 9.35±0.56% of oxygen, 1.76±0.06% of hydrogen, 0.70±0.06% of nitrogen, and 0.04±0.09% of sulfur (Table 4.1). Each element was converted from the percentage of C, H, N, S, and O to moles. The moles of each element was used in the complete combustion equation to calculate the percentage of CO_2 maximum. Calculation the percentage of CO_2

maximum is shown in Appendix A. The chemical formulas of charcoal made from eucalyptus wood and jackfruit wood were $C_{17443}H_{4735}N_{68}SO_{1458}$ and $C_{3563}H_{880}N_{25}SO_{292}$, respectively. The percentage of CO_2 maximum from balanced complete combustion equation were 19.94% and 20.03% for charcoal made from eucalyptus wood and jackfruit wood, respectively. Charcoal made from eucalyptus wood was used as the solely fuel for grilling activities in this thesis. The percentage of CO_2 maximum values of eucalyptus charcoal were applied to specific coefficient in Testo 350 for appropriate emission measurements from meat grilling activities.

Table 4.1 Chemical contents of charcoal.

Type of charcoal	%				
	Carbon	**Hydrogen**	**Nitrogen**	**Sulfur**	**Oxygen**
Eucalyptus	83.72±1.54	1.89±0.05	0.37±0.03	0.01±0.004	9.33±0.49
Jackfruit	85.52±0.81	1.76±0.06	0.70±0.06	0.04±0.09	9.35±0.56

4.1.1.2 Moisture

All meats, wooden stick, and charcoal samples were tested for moisture content according to AOAC (2000) method (Table 4.2). The results were used in the calculations as a dry mass basis. High moisture contents caused difficulty in combustion and influenced the emission concentrations. Charcoal was relatively dry with the moisture content of 6.11±1.79% for eucalyptus and 6.24±1.57% for jackfruit, respectively. Wooden stick had moisture content ranged from 4.79±0.60% to 6.30±0.33%. Meats had moisture ranged from 48.77±2.42% to 77.53±2.83%.

Table 4.2 Moisture content of meat and wooden stick.

Type of meat	Moisture content (%)		N
	Meat	Stick	
Pork	69±1.55	6.08±1.52	15
Chicken	67.82±2.41	5.8±0.77	15
Chicken wing	57.73±7.75	4.79±0.59	15
Chicken liver	69.29±0.98	4.87±0.60	15
Catfish	64.30±4.20	-	15
Tilapia	73.56±5.95	-	15
Ruby fish	72.12±1.26	-	15
Shrimp	74.64±3.57	5.11±0.59	15
Squid	77.53±2.83	5.38±0.47	15
Thai sausage	48.77±2.42	4.90±0.44	15
Thai sour pork	52.13±3.03	6.30±0.33	15
Meatball	55.25±10.62	5.05±0.56	15
Pork ball	57.60±4.53	5.70±0.51	15
Fish ball	77.35±1.81	5.47±0.46	15
Chicken ball	52.02±5.31	5.33±0.54	15

N = Sample size

4.1.1.3 Calorific value

The results of calorific value from charcoal samples were determined by calculating the heat provided by the combustion of a specified quantity of the sample product in a bomb calorimeter. The average calorific values were 28.55 MJ/kg for eucalyptus charcoal and 29.88 MJ/kg for jackfruit charcoal, respectively.

4.1.2 Emission test from charcoal

Descriptive statistics and comparison of emission test between charcoal made from eucalyptus wood and jackfruit wood is shown in Table 4.3. Since these data were normal distribution with homogeneity of variances, t-test was suitable for the analysis of variations of emission test from different charcoal type. Emission concentrations of gases from both types of charcoal were not significantly different ($p>0.05$) as shown in Table 4.3. All charcoal emission tests were unable to detect SO_2 due to low sulphur content in the charcoal. The Testo 350 is capable to measure SO_2 from 0 to 5000 ppm.

Table 4.3 Descriptive statistics and comparison of emission test between charcoal made from eucalyptus wood and jackfruit wood using t-test.

Pollutant/charcoal		**Emission (g/m^3)**			**t-test**	
		N	**Mean**	**S.D.**	**Mean different**	**Sig (2-tailed)**
CO	Eucalyptus	7	150.31	20.92	-13.83	0.289
	Jackfruit	7	164.13	25.44		
NO_x	Eucalyptus	7	0.52	0.21	0.15	0.130
	Jackfruit	7	0.37	0.12		
CO_2	Eucalyptus	7	2,378.30	628.76	-38.69	0.883
	Jackfruit	7	2,417.00	258.60		

N = Sample size

Due to eucalyptus charcoal is most frequently used for most of the meat grilling activities in the urban street food stall. Therefore, this study used charcoal made from eucalyptus as the solely fuel to minimize variations from fuel in meat grilling activities.

4.2 Emission from meat grilling

Each grilling took about 15-20 min. According to the observation of the flame and smoke from meat grilling, three different stages of burning were classified: (1) after 1 min of ignition (ignition stage), (2) after about 3 minutes, the charcoal glowing red and flames starting to flicker the over top of charcoal (smoldering stage), (3) and then a relatively steady condition (flaming stage). In this study, the ignition stage had the shortest duration and flaming stage had the longest duration. Real-time measurement data indicated that incomplete combustion from charcoal meat grilling led to high emissions, especially CO, whilst low concentrations of NO_x were observed.

4.2.1 CO emissions

CO emissions during ignition stage increased rapidly at the rate of about 29.54±14.46 to 125.33±29.96 ppm/sec. A large quantity of CO were generated during smoldering stage at the rate of about 98.53±29.07 to 174.41±21.56 ppm/sec and further increased during the flaming stage at the rate of about 153.32±30.74 to 212.63±14.67 ppm/sec. See Appendix B for details. Time-series of mean CO concentrations emitted of meat grilling activities is in Figure 4.1. Observation showed that the liquid content, probably fat from meats, dropped causing spike of CO concentrations. Real-time measurement data indicated that Thai sour pork grilling had higher mean of CO concentration than other meats during the grilling processes. Average CO concentrations from fifteen categories of meats grilling ranged from 123.01±30.75 to 229.00±30.24 g/m^3. Table 4.4 shows descriptive statistics for CO concentrations of meat grilling.

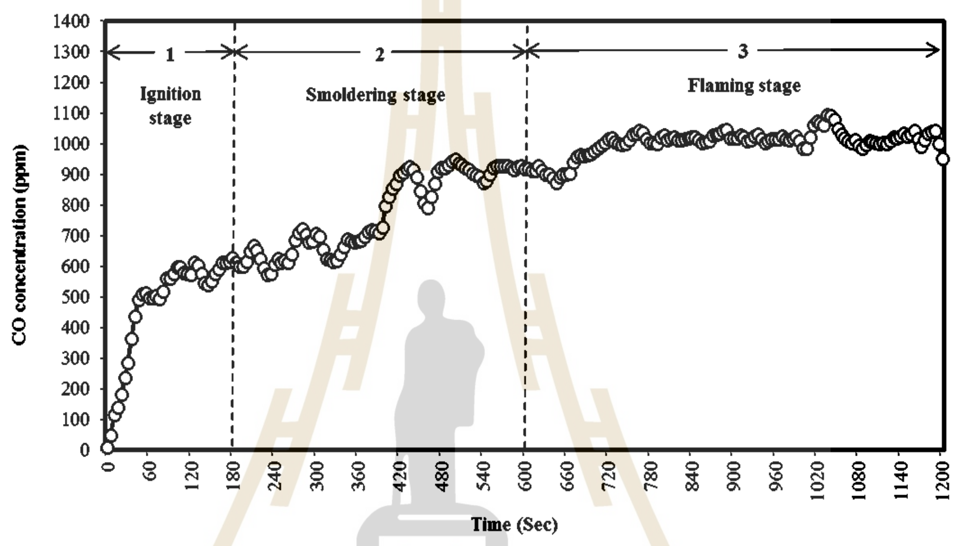


Figure 4.1 Example of time series for mean CO emissions from chicken grilling activities.

Table 4.4 Descriptive statistics of CO concentrations of meat grilling.

Meat	**Concentration of CO (g/m^3)**					
	N	**Mean**	**S.D.**	**Min**	**Max**	**Median**
Pork	6	201.93	18.77	179.75	225.09	199.34
Chicken	8	225.17	18.72	198.76	254.16	222.84
Chicken wing	9	208.59	23.47	182.76	245.11	201.89
Chicken liver	7	220.46	10.76	208.58	240.36	215.29

Table 4.4 Descriptive statistics of CO concentrations of meat grilling (Continued).

Meat	**Concentration of CO (g/m^3)**					
	N	**Mean**	**S.D.**	**Min**	**Max**	**Median**
Catfish	9	168.63	24.71	131.35	217.64	160.74
Ruby fish	8	174.89	12.97	160.58	193.97	172.54
Tilapia	9	186.71	41.40	120.27	235.55	189.91
Shrimp	9	164.56	16.30	140.78	182.67	171.93
Squid	9	152.04	12.85	131.24	168.99	152.52
Thai sausage	9	167.15	39.55	107.67	233.46	163.62
Thai sour pork	8	229.00	30.24	185.65	273.85	237.68
Meatball	9	175.58	18.54	151.09	202.57	174.63
Pork ball	9	154.37	19.34	133.51	187.05	160.74
Fish ball	7	170.69	5.30	164.04	180.90	170.36
Chicken ball	7	123.01	30.75	84.34	160.17	134.63

N = Sample size

4.2.2 NO_x emissions

Only eight types of meats showed gradual increase of NO_x emissions during the ignition stage, at the rate of 0.002±0.002 to 0.064±0.065 ppm/sec. NO_x was unable to detect for the grilling of catfish, ruby fish, shrimp, Thai sausage, meatball, fish ball and chicken ball. During smoldering stage, NO_x was generated more rapidly at the rate of 0.012±0.010 to 0.111±0.029 ppm/sec for 12 types of meat grilling while 3 types of meat grilling was unable to detected NO_x included catfish, ruby fish, and Thai sausage, and further increased during the flaming stage at the rate of

0.040±0.027 to 0.533±0.295 ppm/sec. Time-series of mean NO_x concentrations emitted during meat grilling activities is shown in Figure 4.2. Real-time measurement data indicated that chicken wing grilling had the mean of NO_x concentration higher than other meat grilling. Average NO_x concentrations from fifteen categories of meats grilling ranged from 0.04±0.04 to 0.61±0.32 g/m^3. Table 4.5 shows descriptive statistics for NO_x concentrations of meat grilling.

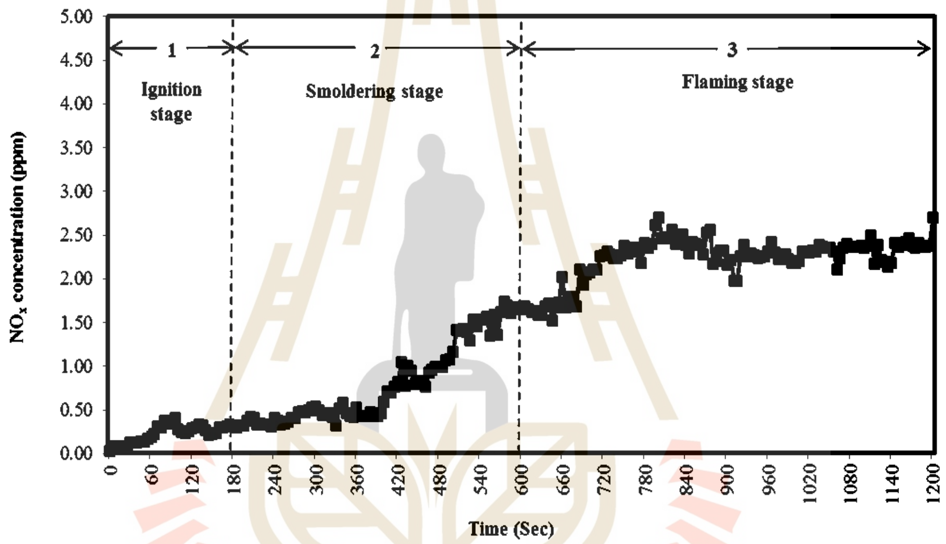


Figure 4.2 Example of time series for mean NO_x emissions from chicken grilling activities.

Table 4.5 Descriptive statistics of NO_x concentrations of meat grilling.

Meat	Concentration of NO_x (g/m^3)					
	N	**Mean**	**S.D.**	**Min**	**Max**	**Median**
Pork	7	0.42	0.33	0.05	1.03	0.35
Chicken	9	0.48	0.40	0.06	1.10	0.29
Chicken wing	9	0.61	0.32	0.20	1.31	0.57
Chicken liver	7	0.20	0.15	0.06	0.43	0.15
Catfish	9	0.10	0.06	0.01	0.19	0.08
Ruby fish	6	0.05	0.03	0.005	0.08	0.05
Tilapia	8	0.09	0.06	0.01	0.17	0.07
Shrimp	9	0.08	0.08	0.002	0.22	0.05
Squid	7	0.10	0.05	0.06	0.16	0.07
Thai sausage	7	0.07	0.04	0.02	0.15	0.06
Thai sour pork	8	0.18	0.11	0.07	0.35	0.14
Meatball	9	0.09	0.05	0.03	0.18	0.09
Pork ball	8	0.06	0.05	0.003	0.12	0.05
Fish ball	9	0.08	0.04	0.03	0.13	0.07
Chicken ball	6	0.04	0.04	0.001	0.09	0.03

N = Sample size

4.2.3 PM_{10}/Particle size distribution

The highest mass concentration of PM_{10} from meat grilling was from chicken wing with the mean of 4.16±0.78 mg/m^3 and the lowest mass concentration of PM_{10} was chicken ball with the mean of 1.84±0.64 mg/m^3. Descriptive statistics for PM_{10} mass concentration of all meat grilling are shown in Table 4.6.

In this study, particulate matters were collected in-stack using the ANDERSEN eight-stage impactor thus the results from eight-stage impactor was analyzed for particle size distribution (PSD). Trimodal particle size distribution were observed for all types of meat grilling. The most dominant size of particle emitted during meat grilling were size between 9.0 and 10.0 µm. The characterization of trimodal distribution from meat grilling had two patterns; pattern 1: the first mode having a diameter size between 9.0 and 10.0 µm, the second mode having a diameter size between 0.4 and 0.7 µm, and the third mode having a diameter size between 4.7 and 5.8 µm (Figure. 4.3) included pork, chicken, chicken wing, and Thai sour pork; pattern 2: the first mode having a diameter size between 9.0 and 10.0 µm, the second mode having a diameter size between 4.7 and 5.8 µm, and the third mode having a diameter size between 0.4 and 0.7 µm included chicken liver, catfish, ruby fish, tilapia, shrimp, squid, Thai sausage, meatball, pork ball, fish ball, and chicken ball (Figure 4.4). The particle mass size distribution was based on the calculation of particle mass concentration, therefor particle mass concentration for each diameter size are shown in Appendix C. The result of particle mass size distribution measurements is summarized in Table 4.7. Particle size distribution for all meat grilling are shown in Appendix D.

Table 4.6 Descriptive statistics of PM_{10} mass concentrations of meat grilling.

Meat	PM_{10} mass concentration (mg/m^3)					
	N	**Mean**	**S.D.**	**Min**	**Max**	**Median**
Pork	6	3.36	0.49	2.56	3.87	3.50
Chicken	9	3.32	0.50	2.67	4.26	3.25
Chicken wing	9	4.16	0.78	2.88	5.17	4.30
Chicken liver	8	2.49	0.18	2.30	2.80	2.50
Catfish	9	2.97	0.47	2.27	3.76	2.99
Ruby fish	9	1.88	0.30	1.43	2.22	1.84
Tilapia	8	2.31	0.48	1.55	2.94	2.22
Shrimp	9	3.60	0.97	1.92	4.57	4.08
Squid	9	2.71	1.19	1.58	5.00	2.02
Thai sausage	9	3.37	1.06	1.74	4.68	3.66
Thai sour pork	8	3.75	0.82	2.95	5.13	3.54
Meatball	9	2.39	0.85	1.35	3.87	2.65
Pork ball	9	1.97	0.46	1.26	2.40	2.14
Fish ball	7	2.06	0.25	1.75	2.41	2.06
Chicken ball	6	1.73	0.41	1.21	2.19	1.84

N = Sample size

Table 4.7 Descriptive statistics of particle size distribution of meat grilling.

Meat		**Particle size distributions (µm) (mg/m^3)**								
		9.0-10	**5.8-9.0**	**4.7-5.8**	**3.3-4.7**	**2.1-3.3**	**1.1-2.1**	**0.7-1.1**	**0.4-0.7**	**<0.4**
Pork	Median	71.66	13.31	26.05	17.40	12.80	8.99	18.79	25.98	7.64
	Max	77.39	16.00	31.85	18.77	12.90	9.80	30.30	58.95	13.07
	Min	60.20	12.18	12.28	15.56	9.21	8.56	13.62	24.27	5.41
	Mean	70.43	13.67	23.84	17.31	11.72	9.02	19.93	33.82	7.86
	SD	6.63	1.42	7.71	1.26	1.65	0.49	6.29	14.56	3.13
	N	5	5	5	5	5	5	5	5	5
Chicken	Median	66.08	14.91	27.81	16.42	11.86	10.17	21.25	41.78	9.51
	Max	85.20	18.09	36.66	20.14	14.42	16.24	32.94	62.66	14.53
	Min	55.49	13.40	23.89	13.14	10.50	8.21	13.28	32.04	4.75
	Mean	68.77	15.08	28.99	16.17	12.28	11.06	23.18	45.54	9.54
	SD	10.57	1.74	4.40	2.59	1.37	2.92	7.65	12.24	5.05
	N	6	6	6	6	6	6	6	6	6
Chicken wing	Median	86.05	16.29	30.33	16.88	11.03	11.46	21.71	44.30	5.99
	Max	103.35	19.90	34.51	22.64	15.10	13.22	25.72	62.23	16.68
	Min	63.63	10.24	21.74	9.88	6.27	5.86	13.09	34.99	3.47
	Mean	87.51	17.10	30.69	18.34	12.07	11.49	22.31	48.70	8.94
	SD	12.43	3.25	5.01	4.27	3.22	2.47	4.31	9.40	5.33
	N	7	7	7	7	7	7	7	7	7

Table 4.7 Descriptive statistics of particle size distribution of meat grilling (Continued).

Meat		Particle size distributions (µm) (mg/m^3)								
		9.0-10	**5.8-9.0**	**4.7-5.8**	**3.3-4.7**	**2.1-3.3**	**1.1-2.1**	**0.7-1.1**	**0.4-0.7**	**<0.4**
Chicken liver	Median	50.09	10.76	23.64	13.27	8.22	6.15	10.32	16.63	2.62
	Max	56.23	13.66	25.99	16.84	12.29	7.90	16.46	18.97	5.80
	Min	45.87	9.71	19.99	10.35	6.33	3.88	6.28	9.43	2.24
	Mean	50.13	11.38	23.48	13.15	8.51	5.97	10.71	15.38	3.29
	SD	3.83	1.69	2.17	2.28	2.15	1.34	3.71	3.59	1.43
	N	6	6	6	6	6	6	6	6	6
Catfish	Median	56.00	14.27	23.42	14.25	10.41	5.97	10.98	18.21	3.33
	Max	63.53	16.88	25.62	14.40	12.96	6.68	18.16	27.54	3.55
	Min	45.39	11.94	21.80	13.39	8.05	4.61	8.65	14.31	2.56
	Mean	55.03	14.15	23.50	14.07	10.16	5.84	12.46	19.46	3.11
	SD	7.24	1.83	1.50	0.41	1.99	0.79	3.81	5.31	0.46
	N	5	5	5	5	5	5	5	5	5
Ruby fish	Median	40.35	8.05	13.31	7.85	5.63	4.42	10.17	14.64	1.64
	Max	44.31	10.35	17.79	11.46	6.81	6.09	21.68	21.07	2.84
	Min	28.66	7.60	11.15	6.78	2.99	2.91	4.18	6.37	0.13
	Mean	38.77	8.66	14.11	8.41	5.41	4.51	11.42	14.52	1.65
	SD	6.45	1.23	2.48	1.78	1.35	1.26	6.32	6.50	0.99
	N	6	6	6	6	6	6	6	6	6

Table 4.7 Descriptive statistics of particle size distribution of meat grilling (Continued).

Meat		Particle size distributions (µm) (mg/m^3)								
		9.0-10	**5.8-9.0**	**4.7-5.8**	**3.3-4.7**	**2.1-3.3**	**1.1-2.1**	**0.7-1.1**	**0.4-0.7**	**<0.4**
Tilapia	Median	48.95	11.13	22.47	11.77	7.06	6.80	12.06	21.96	1.74
	Max	58.75	14.58	27.56	13.87	9.66	12.31	17.58	27.46	2.05
	Min	42.20	5.82	18.78	7.80	4.80	2.71	6.25	10.42	1.18
	Mean	49.95	10.79	22.76	11.32	7.24	6.60	11.94	20.40	1.68
	SD	7.20	3.23	3.22	2.36	1.83	3.37	4.06	6.87	0.28
	N	6	6	6	6	6	6	6	6	6
Shrimp	Median	81.59	11.70	37.61	18.85	13.11	5.21	9.08	12.74	2.85
	Max	91.36	22.06	47.78	22.64	18.42	9.89	13.80	22.84	6.36
	Min	48.22	9.93	22.16	10.53	3.32	2.02	6.75	5.58	1.99
	Mean	74.43	14.15	33.47	17.67	12.45	5.67	9.79	12.66	3.27
	SD	16.21	5.10	10.01	5.00	4.77	3.08	2.46	5.84	1.51
	N	7	7	7	7	7	7	7	7	7
Squid	Median	49.41	16.35	24.81	18.32	8.68	4.04	6.40	10.17	3.33
	Max	103.59	25.86	53.16	39.16	19.82	13.34	17.79	17.87	6.31
	Min	36.41	8.96	12.47	6.23	3.74	2.67	2.71	5.91	1.11
	Mean	62.17	16.06	28.82	19.91	10.58	6.84	9.20	11.25	3.52
	SD	27.14	6.77	15.85	11.13	6.55	4.22	5.27	3.76	1.76
	N	9	9	9	9	9	9	9	9	9

Table 4.7 Descriptive statistics of particle size distribution of meat grilling (Continued).

Meat		Particle size distributions (μm) (mg/m^3)								
		9.0-10	**5.8-9.0**	**4.7-5.8**	**3.3-4.7**	**2.1-3.3**	**1.1-2.1**	**0.7-1.1**	**0.4-0.7**	**<0.4**
Thai sausage	Median	70.10	18.27	32.58	18.97	11.86	8.74	15.19	23.24	4.05
	Max	90.41	21.85	36.40	24.56	13.59	9.35	23.40	26.89	5.26
	Min	39.96	8.26	16.10	3.06	2.40	5.57	10.44	10.74	0.18
	Mean	66.60	15.91	28.43	15.60	10.03	8.10	15.61	21.01	3.20
	SD	18.79	5.58	8.48	8.09	4.36	1.40	5.26	6.26	2.20
	N	6	6	6	6	6	6	6	6	6
Thai sour pork	Median	70.82	15.49	24.65	15.47	11.95	11.04	22.16	30.03	3.40
	Max	102.69	22.41	27.03	22.86	15.65	14.56	28.83	39.76	3.57
	Min	59.05	12.77	18.62	9.111	8.35	6.64	11.37	17.40	2.24
	Mean	74.20	16.97	23.84	15.71	11.72	11.05	20.52	29.29	3.20
	SD	16.12	3.74	3.23	4.63	2.63	2.79	6.33	7.75	0.50
	N	6	6	6	6	6	6	6	6	6
Meatball	Median	52.94	11.14	20.12	13.00	8.96	5.51	5.47	7.34	2.02
	Max	58.11	16.81	30.63	18.97	11.79	11.91	8.56	8.71	3.39
	Min	27.04	5.60	12.94	6.63	4.28	2.91	2.94	4.98	0.51
	Mean	45.60	10.75	21.20	12.48	8.00	6.09	5.74	7.27	2.01
	SD	14.01	4.20	7.17	4.75	3.09	3.19	1.93	1.29	1.04
	N	7	7	7	7	7	7	7	7	7

Table 4.7 Descriptive statistics of particle size distribution of meat grilling (Continued).

Meat		Particle size distributions (µm) (mg/m^3)								
		9.0-10	**5.8-9.0**	**4.7-5.8**	**3.3-4.7**	**2.1-3.3**	**1.1-2.1**	**0.7-1.1**	**0.4-0.7**	**<0.4**
Pork ball	Median	42.72	10.98	16.67	8.94	7.44	4.08	8.09	9.26	1.35
	Max	47.92	12.58	23.40	13.04	9.09	5.45	12.67	13.98	2.64
	Min	25.20	6.20	12.90	5.75	4.07	2.80	5.99	4.93	0.77
	Mean	39.30	9.83	18.14	9.81	7.20	4.33	8.29	9.29	1.56
	SD	9.26	2.28	3.53	2.70	1.69	0.93	2.06	3.05	0.60
	N	9	9	9	9	9	9	9	9	9
Fish ball	Median	41.16	8.16	14.84	8.37	5.48	3.92	7.01	9.84	1.25
	Max	48.12	12.14	23.42	12.06	11.33	5.68	11.48	16.07	2.01
	Min	35.09	3.51	10.71	6.56	2.39	2.10	4.82	5.38	0.66
	Mean	41.22	8.09	15.31	8.55	5.63	3.86	7.20	10.18	1.21
	SD	4.92	2.58	4.24	1.85	2.83	1.27	2.27	3.73	0.48
	N	7	7	7	7	7	7	7	7	7
Chicken ball	Median	36.80	8.14	12.48	7.92	4.38	3.12	6.88	6.59	0.78
	Max	43.71	11.10	16.69	11.94	6.46	4.55	8.26	12.76	1.81
	Min	24.27	5.60	7.96	3.91	2.69	2.06	5.32	5.88	0.08
	Mean	34.57	8.24	12.65	7.83	4.46	3.18	6.75	8.22	0.80
	SD	8.11	1.92	2.95	2.94	1.77	1.02	1.26	3.03	0.60
	N	6	6	6	6	6	6	6	6	6

N = Sample size

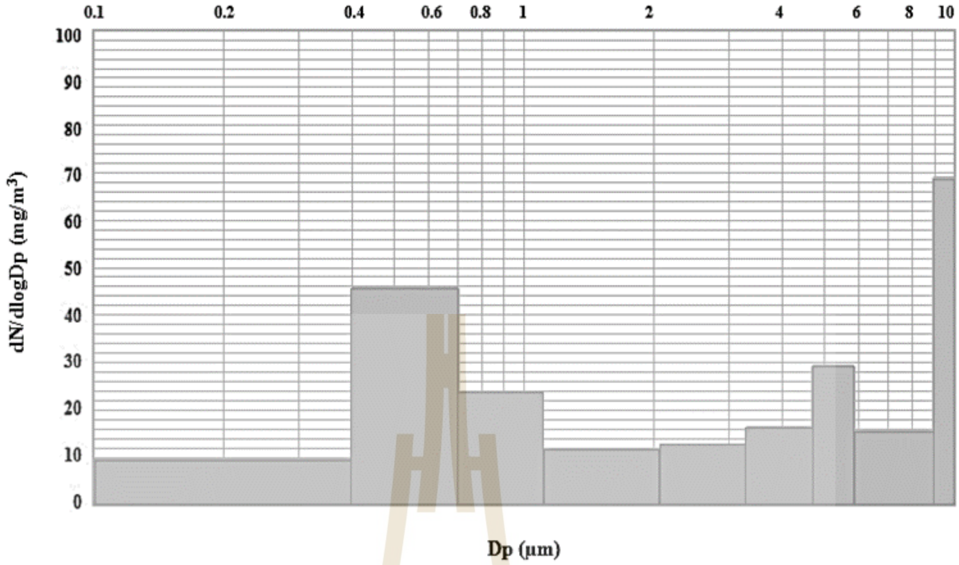


Figure 4.3 Particle size distribution emitted from chicken grilling (pattern 1).

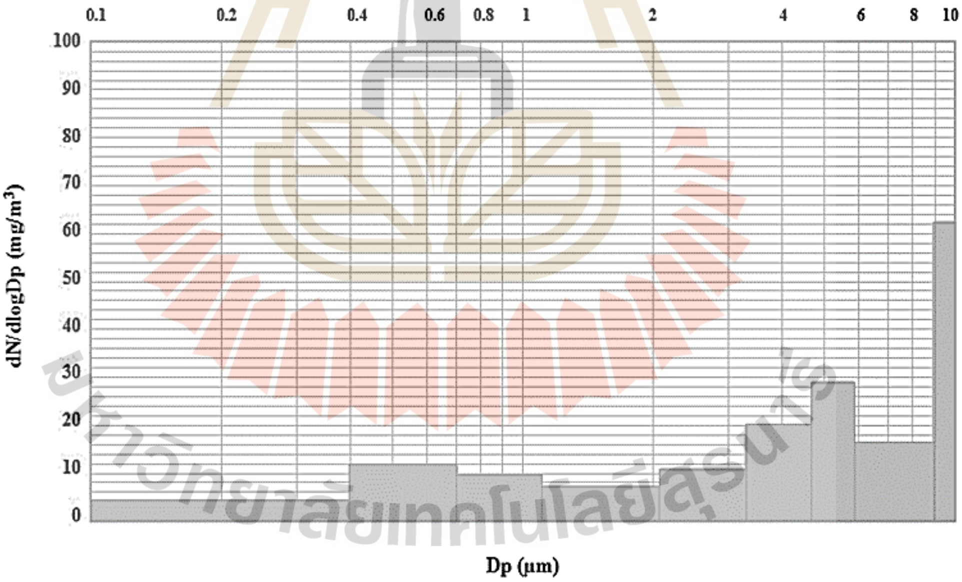


Figure 4.4 Particle size distribution emitted from squid grilling (pattern 2).

4.2.4 CO_2 emissions

All of sample concentrations of CO_2 increased quickly about 3 minutes after ignition and increased gradually until the end. The rate of CO_2 concentrations at the ignition stage, smoldering stage and flaming stage were 251.39±145.28 to 846.89±177.43 ppm/sec, 746.81±124.51 to 1,303.48±216.50 ppm/sec, and 1,237.53±441.50 to 1,972.77±78.81 ppm/sec, respectively. The time series of mean CO_2 concentrations emitted is shown in Figure 4.5. Real-time measurement data indicated that chicken grilling had the mean of CO_2 concentrations higher than other meat grilling. Average CO_2 concentrations from fifteen categories of meats grilling ranged from 1,405.05 ±400.62 to 3,099.08±318.21 g/m^3. It is important to note that ambient CO_2 was not measured during the grilling. Descriptive statistics for CO_2 concentration of all meat grilling are shown in Table 4.8.

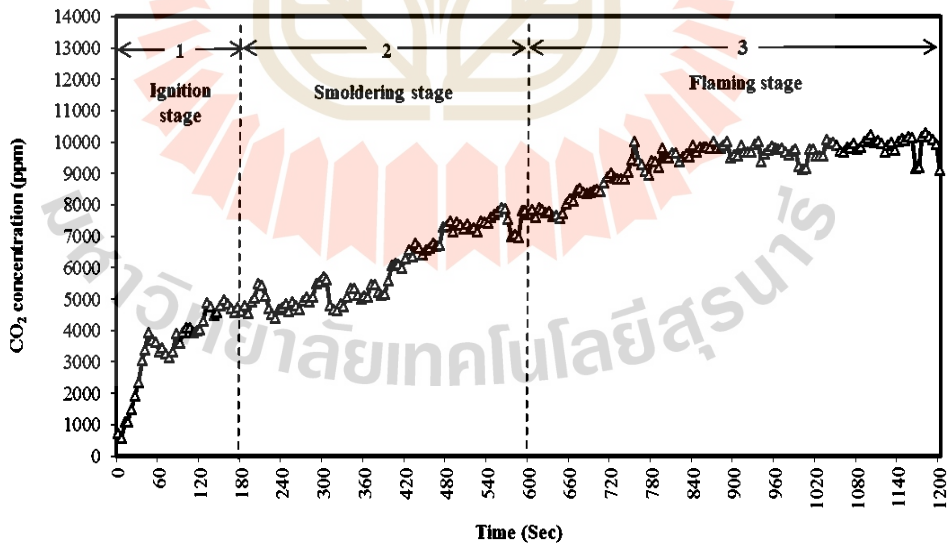


Figure 4.5 Example of time series for mean CO_2 concentration from chicken grilling.

Table 4.8 Descriptive statistics of CO_2 concentrations of meat grilling.

Meat	**Concentration of CO_2 (g/m^3)**					
	N	**Mean**	**S.D.**	**Min**	**Max**	**Median**
Pork	7	3,041.63	629.15	1,986.32	3,749.87	2,954.15
Chicken	8	3,099.08	318.21	2,639.77	3,564.27	3,169.24
Chicken wing	9	2,796.19	221.81	2,436.30	3,081.27	2,765.32
Chicken liver	7	2,918.55	91.47	2,831.60	3,047.30	2,867.17
Catfish	9	2,289.70	317.33	1,895.65	2,723.69	2,359.86
Ruby fish	8	2,320.44	183.62	2,033.25	2,635.18	2,304.46
Tilapia	9	2,399.78	569.17	1,474.54	3,142.69	2,412.67
Shrimp	9	2,069.95	152.30	1,907.02	2,303.78	2,016.89
Squid	9	2,018.82	188.69	1,790.78	2,336.67	1,988.17
Thai sausage	9	2,373.21	471.99	1,765.44	3,256.11	2,290.04
Thai sour pork	8	2,783.70	497.31	2151.58	3513.38	2,724.70
Meatball	9	2,161.89	302.82	1,742.21	2,599.99	2,166.51
Pork ball	8	1,680.15	290.09	1,302.35	2,213.36	1,659.77
Fish ball	9	2,016.42	254.05	1,574.79	2,363.15	1,960.00
Chicken ball	7	1,405.05	400.62	942.56	2,034.84	1,358.48

N = Sample size

4.2.5 CH_4 emissions

CH_4 concentrations emitted from meat grilling activities had three patterns; pattern 1: CH_4 concentrations were slowly increase during ignition stage and higher in smoldering stage. CH_4 concentrations were slowly decrease in flaming stage and were the lowest at the end of the grilling activity for chicken, chicken wing, catfish, tilapia, ruby fish, shrimp, squid, Thai sausage, meatball, fish ball, and chicken ball (Figure 4.6); pattern 2: CH_4 concentrations were increase quickly during ignition stage and slowly decrease in smoldering stage and flaming stage and lowest at the end of the grilling activity for pork and chicken liver (Figure 4.7); pattern 3: CH_4 concentrations were slowly increase during ignition stage and highest in smoldering stage and then slowly decrease before flaming stage. CH_4 concentrations increase a little more in flaming stage and lowest at the end of the grilling activity for Thai sour pork and pork ball (Figure 4.8). The rate of CH_4 concentrations at the ignition stage, smoldering stage and flaming stage were 0.32±0.15 to 1.00±0.28 ppm/sec, 0.25±0.04 to 0.43±0.11 ppm/sec, and 0.17±0.05 to 0.40±0.09 ppm/sec, respectively. Real-time measurement data indicated that Thai sour pork grilling had the mean of CH_4 concentration higher than other meat grilling. The range of mean CH_4 concentration from fifteen categories of meats grilling are 0.21±0.06 to 0.38±0.12 g/m^3. Descriptive statistics for CH_4 concentration of all meat grilling are shown in Table 4.9.

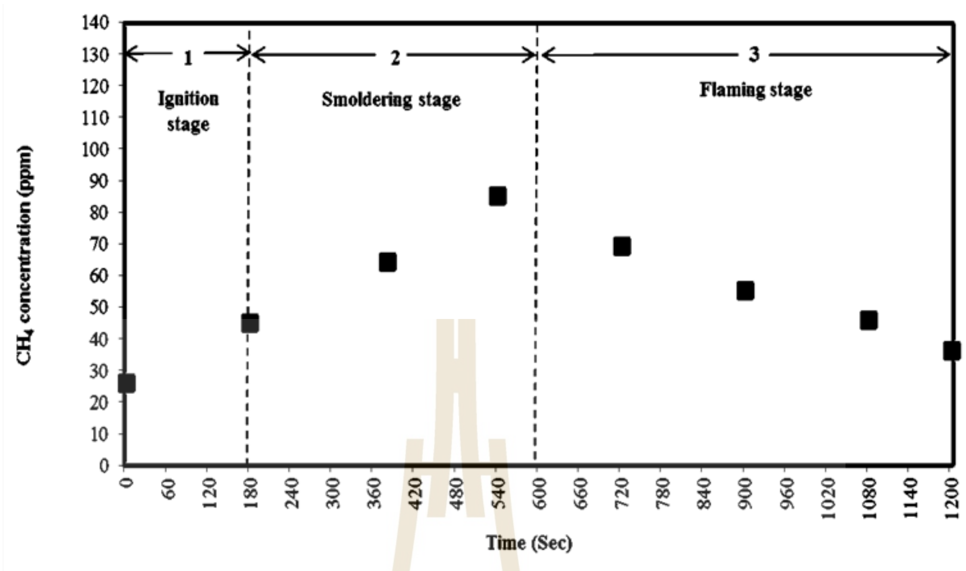


Figure 4.6 Example of time series for mean CH_4 concentration from catfish grilling activities (pattern 1).

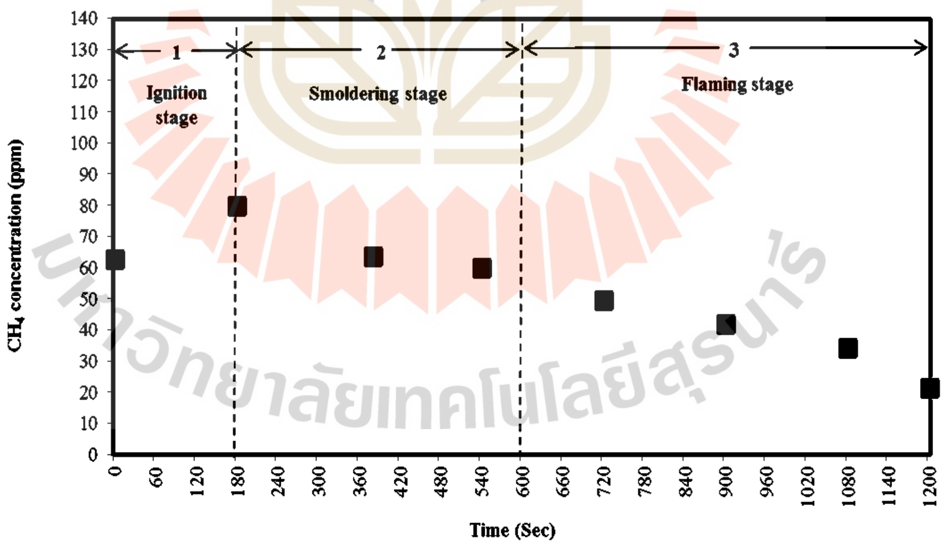


Figure 4.7 Example of time series for mean CH_4 concentration from pork grilling activities (pattern 2).

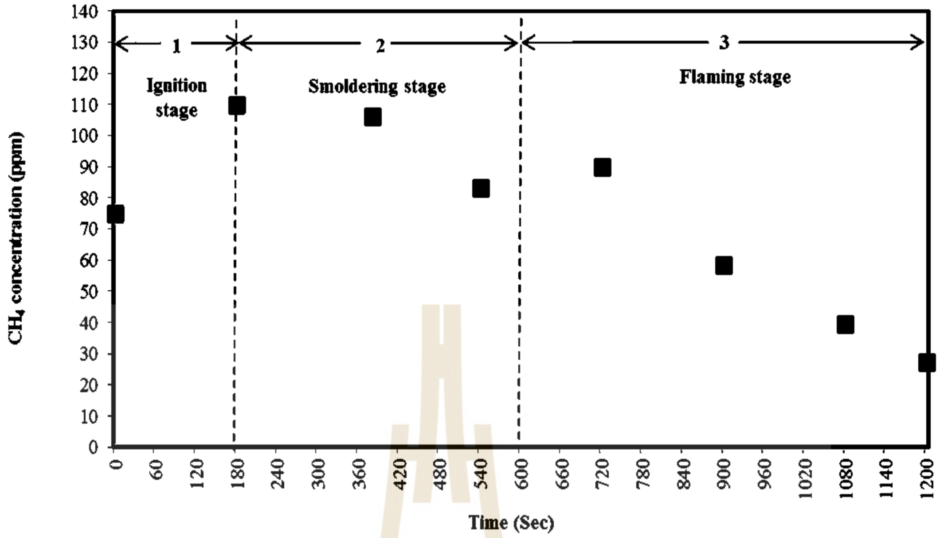


Figure 4.8 Example of time series for mean CH_4 concentration from Thai sour pork grilling activities (pattern 3).

Table 4.9 Descriptive statistics of CH_4 concentrations of meat grilling.

Meat	Concentration of CH_4 (g/m^3)					
	N	**Mean**	**S.D.**	**Min**	**Max**	**Median**
Pork	7	0.28	0.06	0.18	0.36	0.29
Chicken	9	0.22	0.05	0.16	0.31	0.21
Chicken wing	9	0.21	0.06	0.11	0.29	0.19
Chicken liver	8	0.32	0.04	0.23	0.37	0.33
Catfish	9	0.27	0.05	0.21	0.34	0.27
Ruby fish	7	0.25	0.04	0.20	0.33	0.24
Tilapia	9	0.24	0.06	0.15	0.34	0.24
Shrimp	9	0.27	0.07	0.17	0.36	0.28
Squid	9	0.27	0.08	0.15	0.37	0.27

Table 4.9 Descriptive statistics of CH_4 concentrations of meat grilling (Continued).

Meat	Concentration of CH_4 (g/m^3)					
	N	**Mean**	**S.D.**	**Min**	**Max**	**Median**
Thai sausage	7	0.27	0.02	0.25	0.30	0.26
Thai sour pork	8	0.38	0.12	0.21	0.60	0.36
Meatball	9	0.29	0.09	0.14	0.44	0.27
Pork ball	8	0.27	0.04	0.22	0.33	0.27
Fish ball	9	0.28	0.06	0.22	0.39	0.27
Chicken ball	7	0.24	0.05	0.17	0.30	0.25

N = Sample size

4.2.6 SO_2 emissions

All of meat grilling activities was unable to detected SO_2 since sulfur was negligible in both fuel and meats used in the experiments. The Testo 350 is capable to measure SO_2 from 0 to 5000 ppm.

4.3 Time-series of emissions, temperature, and meat grilling stage

Emissions, temperature, and time were graphically plotted to observe emission-time variations. When temperature increased, the emissions during ignition stage increased rapidly. Larger quantity of CO, NO_x, and CO_2 were generated during smoldering stage and further increased during the flaming stage. In contrast, CH_4 concentrations were slowly increase during ignition stage and higher in smoldering stage. CH_4 concentrations were slowly decrease in flaming stage and were lowest at the end of the chicken grilling activity (Figures 4.9 and 4.10). The relationships between emissions, flame temperature, and time for all meat grilling is shown in Appendix E.

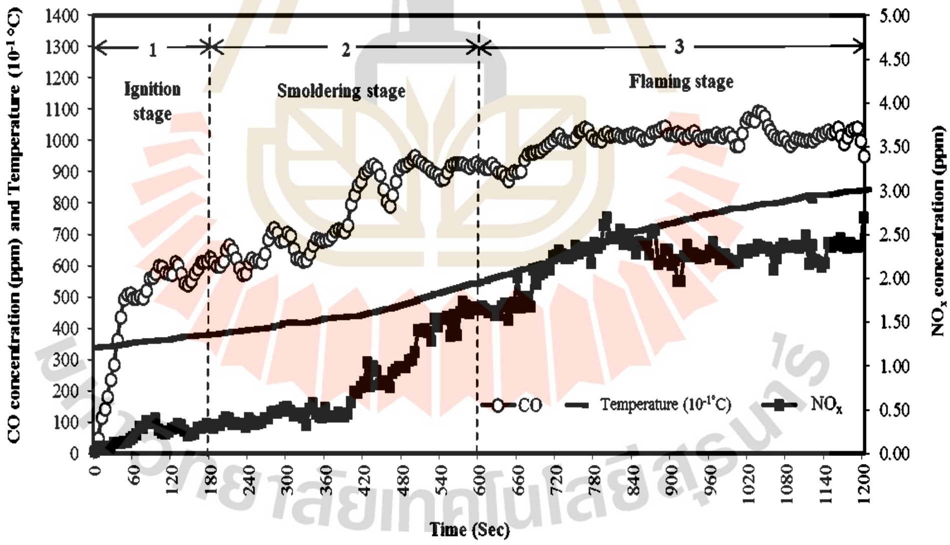


Figure 4.9 Example of relationships between the change of mean CO, NO_x concentrations, and flame temperature during chicken grilling.

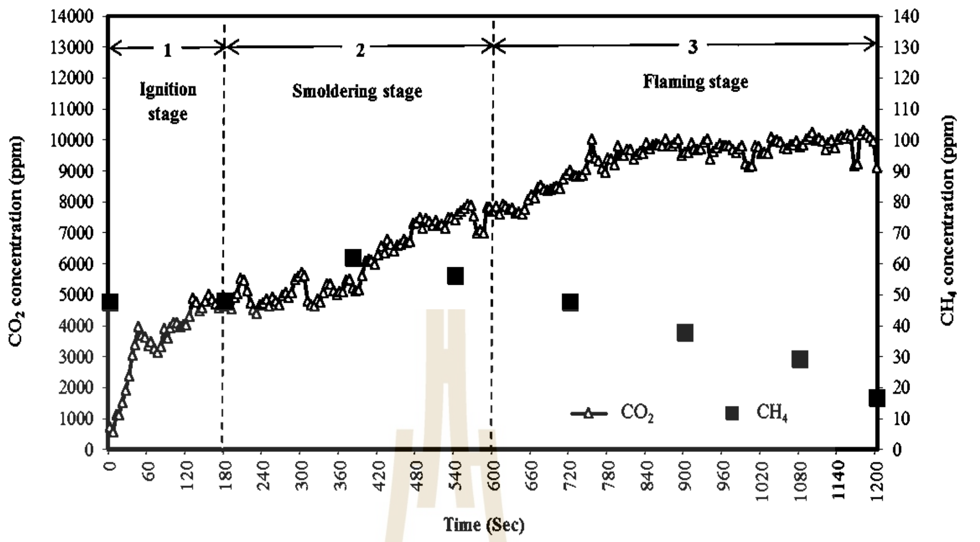


Figure 4.10 Example of relationships between the change of two greenhouse gases (mean CO_2 and CH_4 concentrations) during chicken grilling

4.4 Mass balance of meat grilling

Mass balance was determined by accounting all inputs (mass in) included pre-weight of meat, stick and fuel and outputs (mass out) in the form of CO, NO_x, other PM, PM_{10}, post weight of meat and stick, burned residue, ash, and unaccounted mass expressed as a percent of the total mass in. Unaccounted mass was all the mass generated during meat grilling activities but cannot account for in the mass balance of this study. Meat grilling emitted major air pollutants mass of CO, NO_x, other PM, and PM_{10} in the range of 10.92% to 19.97%, 0.003% to 0.057%, 0.0008% to 0032% and 0.0001% to 0.0005%, respectively. Furthermore, post-weight of meat and stick, burned residue, ash, and unaccounted mass were in the range of 7.88% to 36.65%, 21.58% to 60.16%, 0.83% to 2.35%, and 5.82% to 31.48%, respectively. Our findings suggested that CO accounted more than 10%, higher than other emissions for mass out. All meat grilling activities was unable to detect SO_2. NO_x and PM were less than 1% of mass out. Figure 4.11 shows the varying of outputs from the grilling process. Table 4.10 shows the quantity of inputs and outputs from meat grilling activities for each meat.

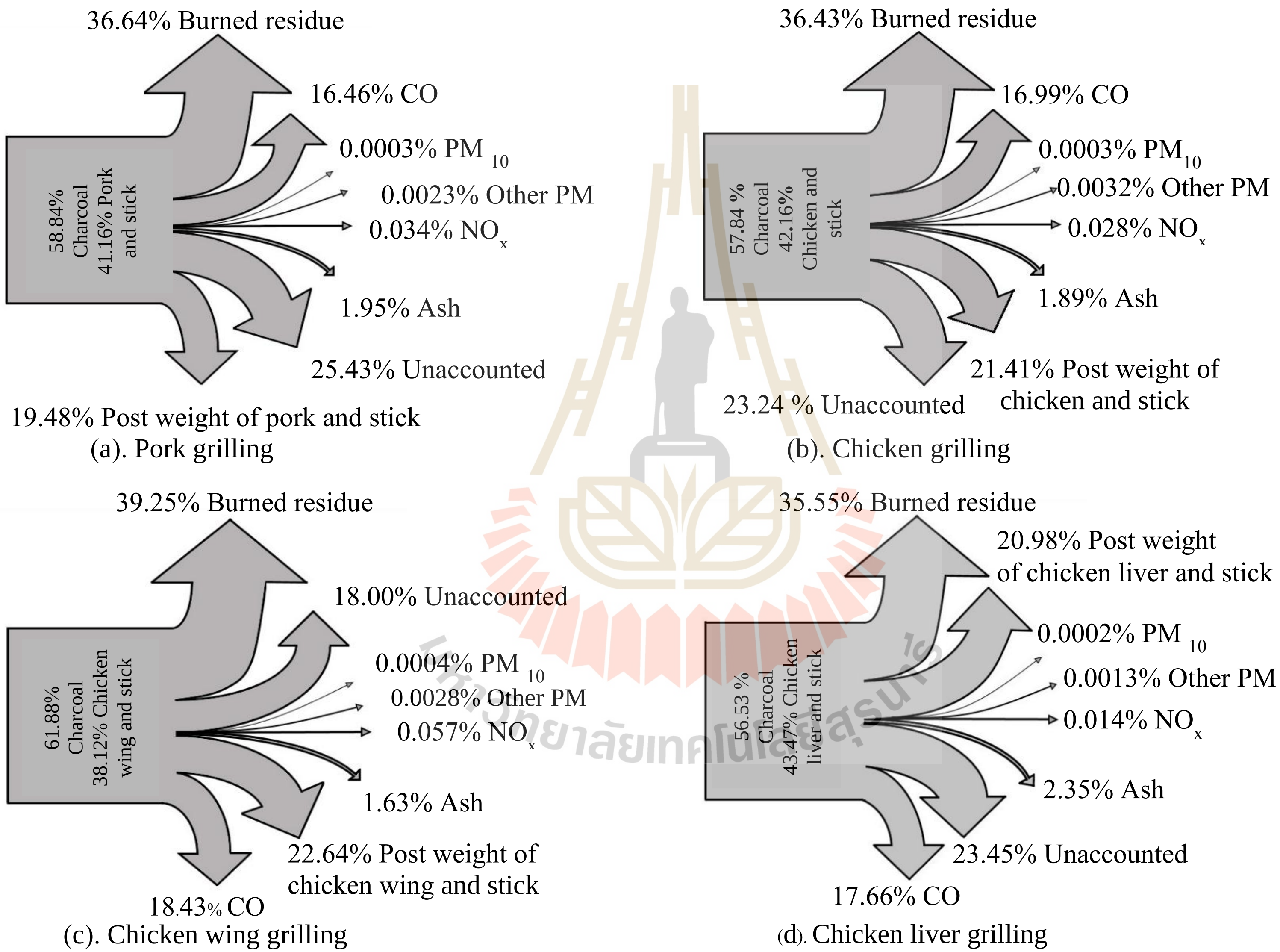
Table 4.10 Quantity of inputs and outputs from meat grilling activities.

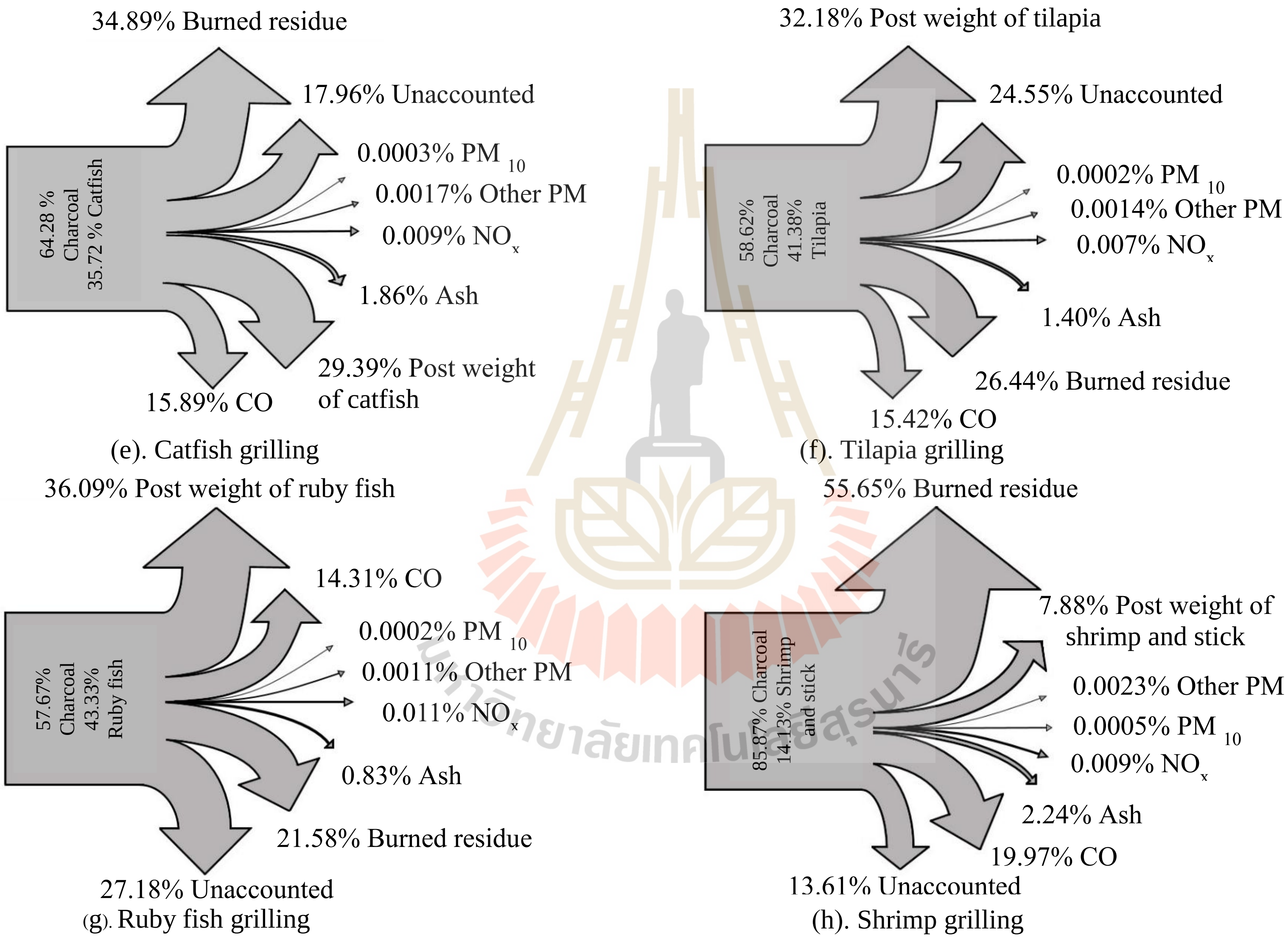
Meat	Mass in			Mass out								Unaccounted	N
	pre-weight of meat and stick (g)	pre-weight of fuel (g)	Total (g) Mass in	CO (g)	NO_x (g)	PM_{10} (g)	Other PM (g)	post-weight of meat and stick (g)	post-weight of fuel (g)	Ash (g)	Total (g) Mass out		
Pork	494.54	706.70	1,201.24	197.82	0.40	0.0035	0.0274	234.08	439.95	23.34	895.62	305.62	5
Chicken	521.78	714.94	1,236.72	209.72	0.35	0.0035	0.0390	264.87	450.07	23.43	948.49	288.24	5
Chicken wing	443.54	715.33	1,158.87	212.36	0.65	0.0042	0.0321	264.14	451.19	18.82	947.20	211.67	7
Chicken liver	546.93	708.14	1,255.07	221.44	0.17	0.0024	0.0160	264.78	443.36	29.46	959.23	295.84	5
Catfish	391.35	701.14	1,092.49	172.56	0.10	0.0028	0.0190	322.15	378.99	20.04	893.86	198.63	5
Tilapia	495.92	701.78	1,197.70	184.77	0.09	0.0025	0.0169	385.71	316.07	16.71	903.37	294.34	5
Ruby fish	517.11	702.57	1,219.68	174.23	0.13	0.0018	0.0135	441.19	261.39	10.08	887.02	332.66	7
Shrimp	116.11	705.09	821.20	163.89	0.07	0.0037	0.0187	64.70	456.99	18.40	704.07	111.57	7

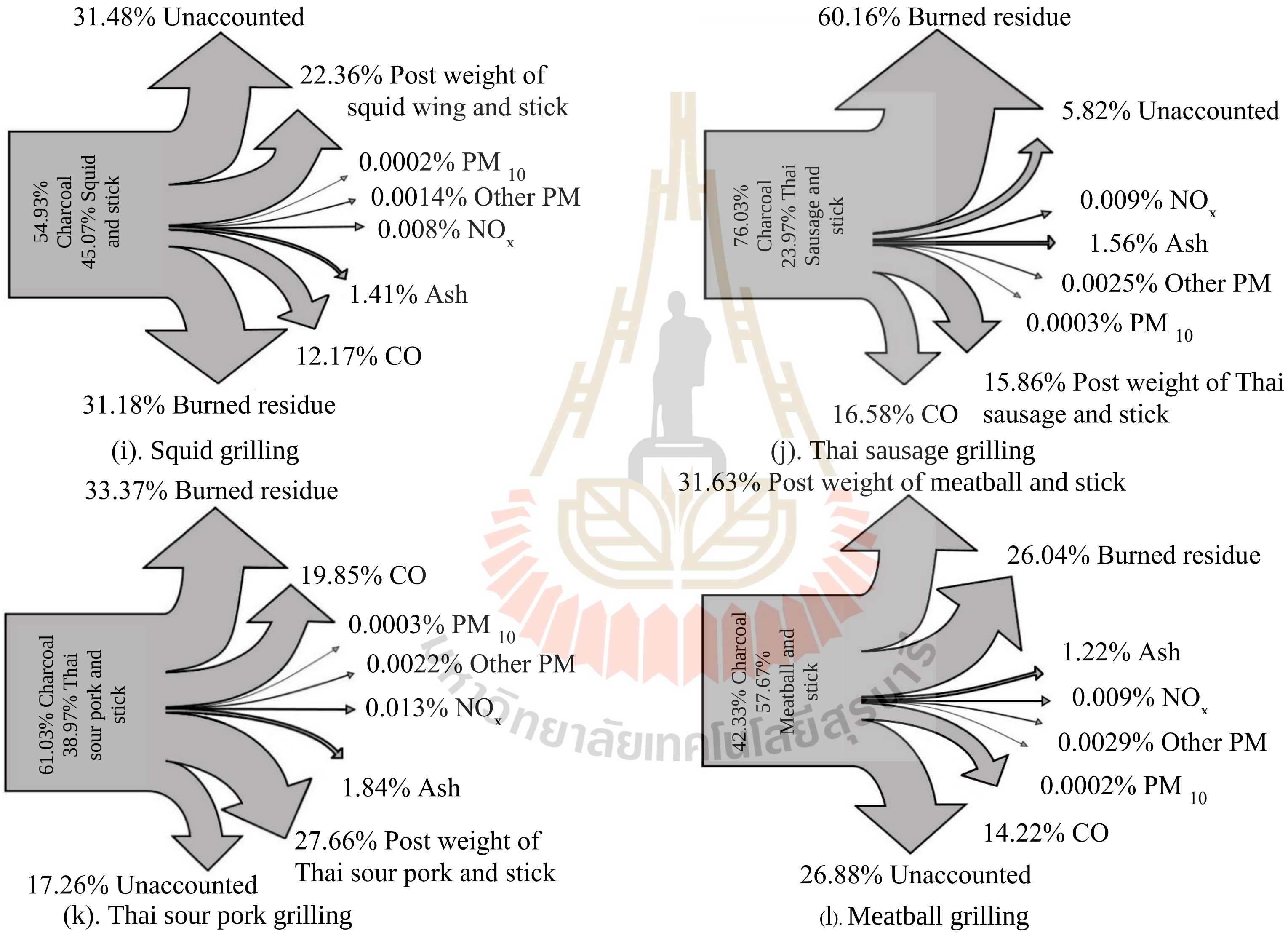
Table 4.10 Quantity of inputs and outputs from meat grilling activities (Continued).

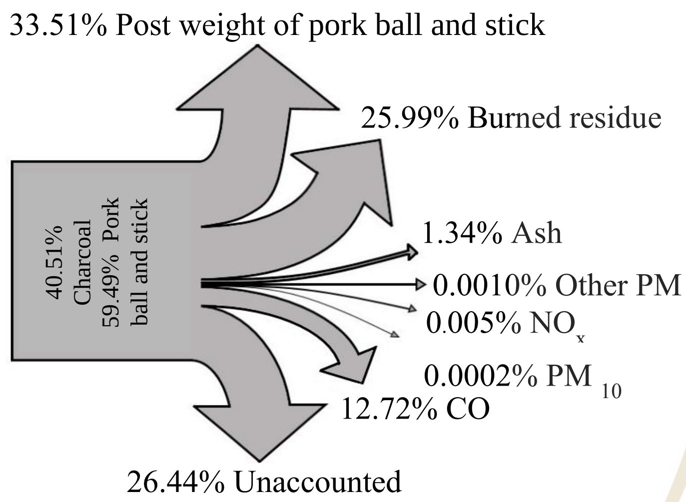
Meat	Mass in			Mass out								Unaccounted	N
	pre-weight of meat and stick (g)	pre-weight of fuel (g)	Total (g) Mass in	CO (g)	NO_x (g)	PM_{10} (g)	Other PM (g)	post-weight of meat and stick (g)	post-weight of fuel (g)	Ash (g)	Total (g) Mass out		
Squid	579.67	706.14	1,285.81	156.44	0.10	0.0025	0.0183	286.96	419.18	18.08	880.78	405.03	7
Thai sausage	221.33	701.46	922.79	152.74	0.08	0.0031	0.0231	146.50	554.96	14.34	868.64	54.15	5
Thai sour pork	449.08	703.13	1,152.21	228.76	0.15	0.0037	0.0255	318.57	384.57	21.20	953.26	198.94	6
Meatball	516.51	703.27	1,219.78	173.46	0.10	0.0023	0.0351	385.85	317.42	14.89	891.76	328.02	7
Pork ball	481.34	704.58	1,185.91	150.28	0.06	0.0021	0.0124	398.80	305.78	15.82	870.75	315.17	8
Fish ball	417.42	702.90	1,120.32	171.44	0.08	0.0020	0.0100	292.37	410.53	14.30	888.73	231.58	5
Chicken ball	480.79	704.43	1,185.22	129.45	0.04	0.0017	0.0092	405.81	298.63	23.60	857.53	327.69	6

N = Sample size

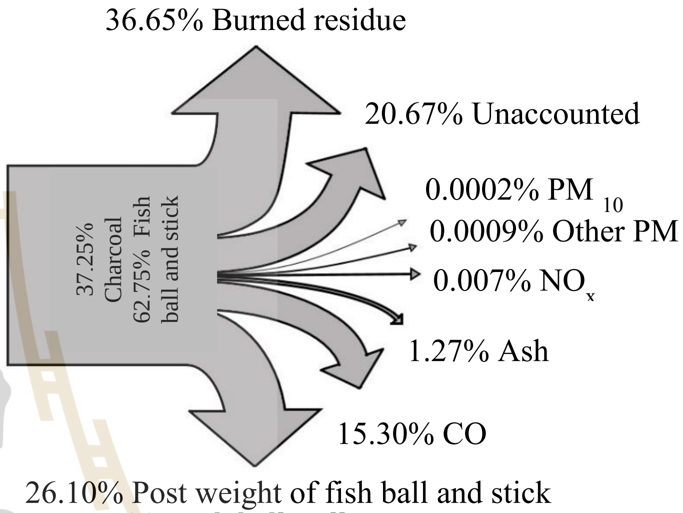

36.64% Burned residue
16.46% CO
0.0003% PM 10
0.0023% Other PM
0.034% NOx
1.95% Ash
25.43% Unaccounted
19.48% Post weight of pork and stick
58.84% Charcoal 41.16% Pork and stick
(a). Pork grilling
36.43% Burned residue
16.99% CO
0.0003% PM10
0.0032% Other PM
0.028% NOx
1.89% Ash
21.41% Post weight of chicken and stick
23.24 % Unaccounted
57.84 % Charcoal 42.16% Chicken and stick
(b). Chicken grilling
39.25% Burned residue
18.00% Unaccounted
0.0004% PM 10
0.0028% Other PM
0.057% NOx
1.63% Ash
22.64% Post weight of chicken wing and stick
18.43% CO
61.88% Charcoal 38.12% Chicken wing and stick
(c). Chicken wing grilling
35.55% Burned residue
20.98% Post weight of chicken liver and stick
0.0002% PM 10
0.0013% Other PM
0.014% NOx
2.35% Ash
23.45% Unaccounted
17.66% CO
56.53 % Charcoal 43.47% Chicken liver and stick
(d). Chicken liver grilling


34.89% Burned residue
17.96% Unaccounted
0.0003% PM 10
0.0017% Other PM
0.009% NOx
1.86% Ash
29.39% Post weight of catfish
15.89% CO
64.28 % Charcoal 35.72 % Catfish
(e). Catfish grilling
32.18% Post weight of tilapia
24.55% Unaccounted
0.0002% PM 10
0.0014% Other PM
0.007% NOx
1.40% Ash
26.44% Burned residue
15.42% CO
58.62% Charcoal 41.38% Tilapia
(f). Tilapia grilling
36.09% Post weight of ruby fish
14.31% CO
0.0002% PM 10
0.0011% Other PM
0.011% NOx
0.83% Ash
21.58% Burned residue
27.18% Unaccounted
57.67% Charcoal 43.33% Ruby fish
(g). Ruby fish grilling
55.65% Burned residue
7.88% Post weight of shrimp and stick
0.0023% Other PM
0.0005% PM 10
0.009% NOx
2.24% Ash
19.97% CO
13.61% Unaccounted
85.87% Charcoal 14.13% Shrimp and stick
(h). Shrimp grilling

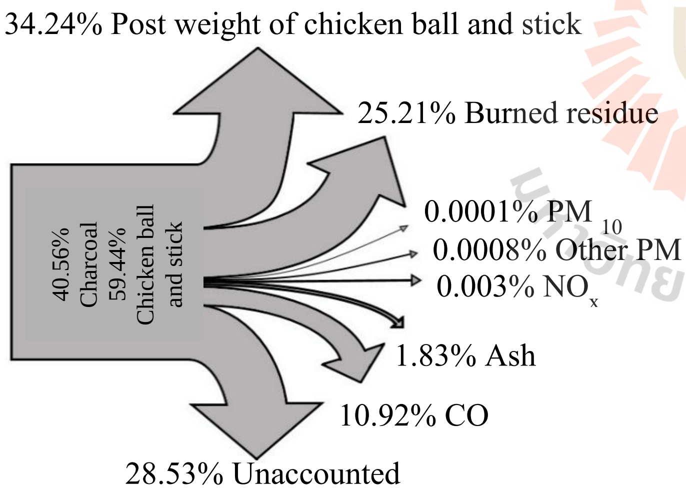

31.48% Unaccounted
22.36% Post weight of squid wing and stick
0.0002% PM 10
0.0014% Other PM
0.008% NOx
1.41% Ash
12.17% CO
31.18% Burned residue
54.93% Charcoal 45.07% Squid and stick
(i). Squid grilling
60.16% Burned residue
5.82% Unaccounted
0.009% NOx
1.56% Ash
0.0025% Other PM
0.0003% PM 10
15.86% Post weight of Thai sausage and stick
16.58% CO
76.03% Charcoal 23.97% Thai Sausage and stick
(j). Thai sausage grilling
33.37% Burned residue
19.85% CO
0.0003% PM 10
0.0022% Other PM
0.013% NOx
1.84% Ash
27.66% Post weight of Thai sour pork and stick
17.26% Unaccounted
61.03% Charcoal 38.97% Thai sour pork and stick
(k). Thai sour pork grilling
31.63% Post weight of meatball and stick
26.04% Burned residue
1.22% Ash
0.009% NOx
0.0029% Other PM
0.0002% PM 10
14.22% CO
26.88% Unaccounted
42.33% Charcoal 57.67% Meatball and stick
(l). Meatball grilling



(m). Pork ball grilling



(n). Fish ball grilling



(o). Chicken ball grilling

Figure 4.11 Illustrates the mass balance of occurring while meat grilling activities (a)-(o).

4.5 Constructing emission factor of meat grilling

The major air pollutants namely CO, NO_x, SO_2, particulate matter (PM_{10}) and two greenhouse gases (CO_2 and CH_4) were included. The emission factors developed in this study are expressed as mass of emitted pollutant divided by a units of mass of fuel used (g/kg of fuel), mass of meat consumed (g/kg of meat), mass of material consumed (g/kg of material), and energy (g/MJ) (based on wet weight and dry weight basis of fuel and meat).

Table 4.11 shows the emission factors of particulate matter and gases from charcoal meat grilling were expressed as mass of emitted pollutant divided by the mass of fuel used (g/kg of fuel) based on wet weight of fuel basis. It was found that among fifteen meats, grilling shrimp had the highest emission factors of CO, PM_{10}, CO_2, and CH_4 while grilling the chicken had the highest emission factor of NO_x. The emission factors of CO, NO_x, PM_{10}, CO_2, and CH_4 ranged from 386.22±117.75 to 3,457.61±315.39, 0.01±0.11 to 2.40±1.73, 0.004±0.001 to 0.056±0.016, 4,372.59±1,349.64 to 44,007.51±6,126.42, and 20.30±3.31 to 173.22±61.25 g/kg of fuel, respectively.

Table 4.11 Emission factors of particulate matter and gases from charcoal meat grilling (g/kg of fuel, based on wet weight basis).

Meat	Emission factors (g/kg of fuel)	N	Mean	S.D.	Min	Max	Median
Pork	CO	7	914.01	163.94	679.14	1,059.53	1,017.69
	NO_x	6	1.50	0.93	0.29	2.56	1.68
	PM_{10}	6	0.014	0.003	0.009	0.017	0.015
	CO_2	7	14,504.07	2,673.16	10,844.67	2,673.16	15,595.27
	CH_4	7	41.25	13.50	19.69	13.50	37.70

Table 4.11 Emission factors of particulate matter and gases from charcoal meat grilling (g/kg of fuel, based on wet weight basis) (Continued).

Meat	Emission factors (g/kg of fuel)	N	Mean	S.D.	Min	Max	Median
Chicken	CO	9	1,042.36	158.06	803.42	1,233.77	1,086.62
	NO_x	9	2.40	1.73	0.26	5.32	1.57
	PM_{10}	9	0.013	0.002	0.010	0.016	0.013
	CO_2	9	14,328.17	3,215.15	9,368.03	3,215.15	14,821.93
	CH_4	9	31.53	9.93	17.84	9.93	29.33
Chicken wing	CO	9	905.01	320.63	513.76	1,373.15	745.04
	NO_x	8	2.15	0.82	0.71	3.33	2.27
	PM_{10}	9	0.016	0.003	0.012	0.020	0.015
	CO_2	9	12,148.20	4,152.11	7,063.10	4,152.11	10,183.67
	CH_4	7	20.30	3.31	13.69	3.31	21.50
Chicken liver	CO	9	1,064.75	350.83	606.92	1,749.13	992.87
	NO_x	7	1.06	0.79	0.22	2.16	0.94
	PM_{10}	9	0.009	0.002	0.006	0.013	0.010
	CO_2	8	12,932.73	3,079.34	7,751.26	3,079.34	13,394.09
	CH_4	9	42.50	17.74	13.94	17.74	36.77
Catfish	CO	9	693.30	192.63	432.34	975.49	690.39
	NO_x	9	0.44	0.31	0.02	0.90	0.42
	PM_{10}	9	0.009	0.001	0.007	0.011	0.009
	CO_2	9	9,505.55	2,737.98	5,625.26	2,737.98	10,269.18
	CH_4	9	36.41	12.25	23.50	12.25	31.29
Ruby fish	CO	9	567.82	145.94	380.42	745.32	589.35
	NO_x	7	0.23	0.16	0.02	0.52	0.20
	PM_{10}	9	0.004	0.001	0.003	0.006	0.004
	CO_2	9	7,149.06	1,836.48	4,725.62	1,836.48	7,483.40
	CH_4	8	22.97	6.84	11.85	6.84	24.08
Tilapia	CO	9	751.44	324.21	446.85	1,298.78	605.27
	NO_x	8	0.38	0.29	0.03	0.77	0.25
	PM_{10}	7	0.006	0.001	0.005	0.008	0.006
	CO_2	9	9,645.50	4,157.09	5,481.24	4,157.09	7,378.57
	CH_4	9	29.82	10.95	15.35	10.95	27.88
Shrimp	CO	8	3,457.61	315.39	3,085.78	3,927.51	3,472.66
	NO_x	9	1.71	1.78	0.06	4.51	1.15
	PM_{10}	9	0.056	0.016	0.030	0.074	0.054
	CO_2	8	44,007.51	6,126.42	33,905.65	6,126.42	45,109.34
	CH_4	9	173.22	61.25	110.63	61.25	141.45
Squid	CO	8	723.82	211.28	369.79	933.91	738.31
	NO_x	9	0.82	0.58	0.35	1.87	0.56
	PM_{10}	8	0.011	0.005	0.005	0.017	0.012
	CO_2	8	9,645.22	2,771.93	5,161.01	2,771.93	8,999.15
	CH_4	6	39.49	4.52	35.56	4.52	37.86
Thai sausage	CO	9	1,651.67	476.94	1,109.71	2,446.51	1,505.44
	NO_x	8	0.93	0.75	0.15	2.36	0.57
	PM_{10}	9	0.024	0.010	0.011	0.040	0.024
	CO_2	9	20,536.27	9,327.19	1,821.25	9,327.19	21,350.11
	CH_4	8	81.38	12.97	65.80	12.97	81.81

Table 4.11 Emission factors of particulate matter and gases from charcoal meat grilling (g/kg of fuel, based on wet weight basis) (Continued).

Meat	Emission factors (g/kg of fuel)	N	Mean	S.D.	Min	Max	Median
Thai sour pork	CO	8	1,164.47	298.00	753.76	1,706.40	1,129.99
	NO_x	8	0.86	0.52	0.27	1.73	0.66
	PM_{10}	8	0.012	0.003	0.009	0.015	0.011
	CO_2	7	12,959.30	2,782.45	8,678.44	2,782.45	13,258.75
	CH_4	7	49.65	9.15	38.73	9.15	48.59
Meatball	CO	7	659.74	38.05	607.43	706.31	668.13
	NO_x	9	0.38	0.17	0.11	0.64	0.38
	PM_{10}	9	0.006	0.002	0.003	0.010	0.007
	CO_2	8	8,338.30	1,170.71	6,654.34	1,170.71	8,325.26
	CH_4	7	32.62	4.07	27.01	4.07	33.88
Pork ball	CO	7	450.84	82.12	319.89	548.30	457.62
	NO_x	8	0.20	0.19	0.001	0.51	0.13
	PM_{10}	9	0.005	0.001	0.004	0.006	0.005
	CO_2	7	4,891.12	889.67	3,794.42	889.67	4,668.24
	CH_4	9	26.14	7.25	13.99	7.25	27.21
Fish ball	CO	7	992.14	107.80	842.71	1,151.81	962.26
	NO_x	9	0.42	0.23	0.11	0.78	0.44
	PM_{10}	9	0.008	0.002	0.006	0.012	0.008
	CO_2	9	10,959.38	3,946.54	4,853.77	3,946.54	11,295.98
	CH_4	7	42.88	6.56	30.84	6.56	44.75
Chicken ball	CO	7	386.22	117.75	251.42	516.85	385.19
	NO_x	6	0.10	0.11	0.003	0.26	0.06
	PM_{10}	7	0.005	0.002	0.003	0.008	0.005
	CO_2	7	4,372.59	1,349.64	2,840.45	1,349.64	4,713.74
	CH_4	7	24.00	7.27	11.78	7.27	25.24

N = Sample size

Table 4.12 shows the emission factors of particulate matter and gases from charcoal meat grilling, expressed as mass of emitted pollutant per mass of meat consumed (g/kg of meat), and based on the basis of wet weight. It was found that among fifteen meats, grilling catfish had the highest emission factors of CO and CH_4 while grilling the chicken wing had the highest emission factor of NO_x. Grilling shrimp showed the highest emission factor of PM_{10} and Thai sausage had the highest emission factor of CO_2. The emission factors of CO, NO_x, PM_{10}, CO_2, and CH_4 ranged from 756.49±104.50 to 3,343.91±193.25, 0.42±0.42 to 3.58±0.85, 0.009±0.001 to 0.042±0.012, 10,587.62±2,380.06 to 47,236.79±12,428.16, and 30.39±10.19 to 171.12±35.09 g/kg of meat, respectively.

Table 4.12 Emission factors of particulate matter and gases from charcoal meat grilling (g/kg of meat, based on wet weight basis).

Meat	Emission factors (g/kg of meat)	N	Mean	S.D.	Min	Max	Median
Pork	CO	7	898.48	169.56	611.97	1,088.64	980.64
	NO_x	7	1.86	1.21	0.30	3.76	1.85
	PM_{10}	6	0.013	0.002	0.010	0.016	0.013
	CO_2	7	14,253.85	2,664.81	9,471.70	16,761.46	15,659.15
	CH_4	7	40.05	12.78	27.09	56.76	33.81
Chicken	CO	9	995.98	107.10	827.81	1,165.97	1,009.88
	NO_x	9	2.20	1.50	0.30	4.59	1.71
	PM_{10}	8	0.012	0.002	0.010	0.014	0.012
	CO_2	9	13,635.19	2,336.30	9,356.07	16,449.39	14,488.08
	CH_4	9	30.39	10.19	17.61	48.91	27.61
Chicken wing	CO	9	1,318.96	328.01	955.97	1,916.93	1,280.05
	NO_x	7	3.58	0.85	2.29	4.77	3.41
	PM_{10}	9	0.023	0.003	0.018	0.028	0.023
	CO_2	8	16,697.06	2,922.87	13,142.55	22,397.77	15,798.81
	CH_4	8	33.59	7.77	24.52	48.28	32.12
Chicken liver	CO	9	1,020.08	213.34	717.14	1,304.75	1,041.93
	NO_x	7	0.95	0.66	0.33	2.07	0.84
	PM_{10}	9	0.009	0.001	0.007	0.010	0.009
	CO_2	9	13,591.04	2,720.59	9,936.38	17,517.95	13,176.06
	CH_4	9	41.67	15.63	12.48	56.18	48.15
Catfish	CO	6	3,343.91	193.25	3,177.08	3,711.80	3,264.11
	NO_x	9	1.99	1.38	0.11	4.12	1.53
	PM_{10}	7	0.041	0.003	0.037	0.044	0.044
	CO_2	9	45,000.44	9,602.49	31,396.80	57,956.38	47,918.92
	CH_4	9	171.12	35.09	131.15	235.31	164.07
Ruby fish	CO	9	2,992.29	648.20	2,062.96	4,116.03	3,129.02
	NO_x	7	1.11	0.88	0.14	2.90	0.92
	PM_{10}	7	0.020	0.004	0.014	0.024	0.021
	CO_2	9	38,001.45	9,350.28	24,532.52	47,669.52	40,764.95
	CH_4	6	131.94	15.64	107.45	147.88	137.67
Tilapia	CO	9	2,566.39	747.02	1,483.07	3,462.82	2,684.03
	NO_x	8	1.14	0.59	0.23	2.04	1.02
	PM_{10}	9	0.026	0.013	0.013	0.045	0.019
	CO_2	9	32,364.09	6,881.15	21,507.65	40,189.56	35,326.38
	CH_4	8	98.06	43.31	40.90	167.07	98.73

Table 4.12 Emission factors of particulate matter and gases from charcoal meat grilling (g/kg of meat, based on wet weight basis) (Continued).

Meat	Emission factors (g/kg of meat)	N	Mean	S.D.	Min	Max	Median
Shrimp	CO	9	2,702.94	410.51	2,017.64	3,302.18	2,779.00
	NO_x	9	1.23	1.28	0.04	3.40	0.78
	PM_{10}	9	0.042	0.012	0.022	0.054	0.048
	CO_2	9	34,013.70	3,984.17	28,351.46	41,333.59	34,072
	CH_4	8	135.76	39.58	93.42	188.81	124.69
Squid	CO	7	756.49	104.50	616.67	864.29	753.86
	NO_x	8	0.71	0.50	0.30	1.67	0.47
	PM_{10}	9	0.011	0.005	0.005	0.018	0.012
	CO_2	8	10,587.62	2,380.06	7,842.27	15,561.12	9,800.23
	CH_4	7	33.52	11.71	14.97	44.56	35.57
Thai sausage	CO	9	3,221.21	1,078.82	1,980.66	5,153.43	3,052.33
	NO_x	6	1.08	0.63	0.20	2.04	1.06
	PM_{10}	8	0.041	0.009	0.027	0.054	0.044
	CO_2	8	47,236.79	12,428.16	27,874.86	64,921.67	45,106.02
	CH_4	8	167.67	43.00	105.83	215.32	175.57
Thai sour pork	CO	8	3,033.58	702.65	1,978.82	3,920.36	2,970.33
	NO_x	8	2.33	1.43	0.79	3.88	2.29
	PM_{10}	8	0.031	0.008	0.022	0.042	0.030
	CO_2	8	36,644.31	7,667.46	24,893.16	45,453.03	39,331.28
	CH_4	6	147.27	29.30	108.88	198.38	143.69
Meatball	CO	8	2,046.96	256.73	1,721.29	2,482.56	1,947.01
	NO_x	9	1.16	0.46	0.38	1.79	1.20
	PM_{10}	8	0.017	0.004	0.010	0.022	0.018
	CO_2	8	25,128.34	3,789.48	19,235.07	31,753.91	26,162.68
	CH_4	7	104.52	20.92	73.84	137.11	108.06
Pork ball	CO	8	2,594.88	346.79	2,025.45	3,110.45	2,593.76
	NO_x	9	1.06	0.96	0.01	2.59	0.85
	PM_{10}	7	0.027	0.003	0.023	0.032	0.028
	CO_2	8	26,524.08	5,109.03	17,452.22	34,025.26	26,817.90
	CH_4	9	122.29	44.82	53.53	172.51	130.55
Fish ball	CO	9	2,062.22	776.24	1,006.01	3,350.09	2,103.97
	NO_x	8	0.85	0.44	0.27	1.72	0.82
	PM_{10}	8	0.017	0.003	0.014	0.021	0.016
	CO_2	7	29,345.75	5,582.94	22,853.76	39,326.80	28,566.43
	CH_4	7	81.81	17.04	54.83	104.23	78.72
Chicken ball	CO	7	2,205.76	1,167.99	1,149.50	4,183.62	2,009.91
	NO_x	6	0.42	0.42	0.02	1.02	0.31
	PM_{10}	6	0.023	0.006	0.014	0.030	0.023
	CO_2	7	24,201.65	10,351.04	12,851.05	39,772.28	22,707.40
	CH_4	7	137.69	73.43	52.74	246.96	99.28

N = Sample size

Table 4.13 shows the emission factors of particulate matter and gases from charcoal meat grilling, expressed as mass of emitted pollutant per mass of material consumed (g/kg of material), and based on wet weight of fuel and meat. It was found that among fifteen meats, grilling shrimp had the highest emission factors of CO, PM_{10}, CO_2, and CH_4 while grilling the chicken wing had the highest emission factor of NO_x. The emission factors of CO, NO_x, PM_{10}, CO_2, and CH_4 ranged from 325.63±102.44 to 1,491.77±144.87, 0.08±0.09 to 1.30±0.47, 0.004±0.001 to 0.024±0.007, 3,653.08±1,097.46 to 19,580.66±2,718.86, and 12.31±1.92 to 73.79±24.67 g/kg of material, respectively.

Table 4.13 Emission factors of particulate matter and gases from charcoal meat grilling (g/kg of material, based on wet weight basis).

Meat	Emission factors (g/kg of material)	N	Mean	S.D.	Min	Max	Median
Pork	CO	6	502.31	55.01	430.09	563.21	497.65
	NO_x	7	1.01	0.72	0.15	2.18	0.88
	PM_{10}	6	0.007	0.001	0.005	0.008	0.007
	CO_2	6	8,013.33	1,013.75	6,816.66	9,469.87	7,653.99
	CH_4	7	20.78	6.02	15.31	30.75	17.73
Chicken	CO	9	505.96	48.13	432.16	560.54	527.64
	NO_x	9	1.14	0.80	0.14	2.47	0.78
	PM_{10}	8	0.006	0.001	0.005	0.007	0.006
	CO_2	9	6,942.07	1,245.16	5,039.08	8,257.92	7,561.87
	CH_4	9	15.37	4.80	8.87	22.63	13.61
Chicken wing	CO	9	534.95	165.75	334.62	793.78	471.76
	NO_x	8	1.30	0.47	0.44	1.94	1.37
	PM_{10}	9	0.009	0.002	0.008	0.012	0.010
	CO_2	9	7,180.77	2,118.09	4,600.36	10,683.25	6,305.20
	CH_4	7	12.31	1.92	8.92	14.57	12.61
Chicken liver	CO	9	513.32	123.47	366.91	721.70	516.87
	NO_x	8	0.70	0.65	0.13	2.09	0.55
	PM_{10}	9	0.004	0.001	0.004	0.005	0.004
	CO_2	8	7,319.22	1,163.97	4,713.96	8,346.82	6,602.15
	CH_4	9	20.69	7.60	6.59	30.22	22.25

Table 4.13 Emission factors of particulate matter and gases from charcoal meat grilling (g/kg of material, based on wet weight basis) (Continued).

Meat	Emission factors (g/kg of material)	N	Mean	S.D.	Min	Max	Median
Catfish	CO	9	571.08	147.29	361.51	758.47	569.66
	NO_x	9	0.36	0.26	0.02	0.74	0.34
	PM_{10}	9	0.008	0.001	0.006	0.009	0.007
	CO_2	9	7,825.88	2,110.47	4,778.55	10,560.94	8,551.75
	CH_4	9	29.91	9.14	19.96	45.73	26.95
Ruby fish	CO	9	476.61	97.04	368.93	609.09	501.27
	NO_x	8	0.31	0.37	0.01	1.18	0.20
	PM_{10}	9	0.004	0.001	0.003	0.005	0.003
	CO_2	9	5,951.22	1,388.69	4,069.23	8,068.03	5,864.46
	CH_4	7	20.80	4.15	12.67	25.68	21.61
Tilapia	CO	9	567.49	207.26	361.33	892.92	511.40
	NO_x	8	0.28	0.19	0.03	0.53	0.20
	PM_{10}	8	0.005	0.001	0.003	0.006	0.005
	CO_2	9	7,256.19	2,547.18	4,461.60	11,495.03	6,123.72
	CH_4	9	23.10	8.36	11.43	35.54	21.29
Shrimp	CO	8	1,491.77	144.87	1,227.86	1,673.48	1,503.78
	NO_x	9	0.71	0.75	0.02	1.90	0.47
	PM_{10}	9	0.024	0.007	0.013	0.031	0.027
	CO_2	9	19,580.66	2,718.86	16,825.68	25,180.20	19,261.20
	CH_4	9	73.79	24.67	44.02	111.45	66.94
Squid	CO	9	389.84	73.86	261.13	486.02	414.04
	NO_x	7	0.27	0.11	0.16	0.39	0.20
	PM_{10}	9	0.005	0.002	0.003	0.009	0.004
	CO_2	8	4,903.24	660.71	3,644.45	5,641.40	4,866.48
	CH_4	9	20.06	7.67	7.15	32.30	20.21
Thai sausage	CO	9.	1,077.78	314.30	733.58	1,662.82	1,020.38
	NO_x	8	0.62	0.50	0.09	1.57	0.39
	PM_{10}	9	0.015	0.005	0.008	0.023	0.016
	CO_2	8	15,738.32	3,476.14	9,582.69	20,450.89	15,325.73
	CH_4	9	50.55	15.30	18.58	66.68	45.87
Thai sour pork	CO	8	830.59	172.75	560.72	1,080.29	844.04
	NO_x	8	0.62	0.37	0.20	1.20	0.49
	PM_{10}	8	0.008	0.002	0.007	0.011	0.008
	CO_2	7	9,456.87	1,816.64	6,455.89	11,984.10	9,721.34
	CH_4	6	37.83	4.96	33.63	47.28	37.12
Meatball	CO	7	494.23	20.58	460.24	517.87	500.27
	NO_x	9	0.29	0.12	0.09	0.46	0.30
	PM_{10}	9	0.005	0.002	0.003	0.007	0.005
	CO_2	8	6,254.79	840.67	4,945.65	7,684.31	6,264.74
	CH_4	7	24.79	3.19	19.81	28.84	25.68
Pork ball	CO	7	379.67	70.34	262.99	457.89	390.49
	NO_x	9	0.22	0.23	0.001	0.70	0.15
	PM_{10}	9	0.004	0.001	0.003	0.005	0.005
	CO_2	7	4,117.60	757.37	3,119.45	5,306.34	3,937.68
	CH_4	9	21.25	5.80	11.50	27.48	22.95

Table 4.13 Emission factors of particulate matter and gases from charcoal meat grilling (g/kg of material, based on wet weight basis) (Continued).

Meat	Emission factors (g/kg of material)	N	Mean	S.D.	Min	Max	Median
Fish ball	CO	7	689.51	75.66	577.39	793.57	703.82
	NO_x	9	0.29	0.15	0.08	0.54	0.29
	PM_{10}	8	0.005	0.001	0.004	0.007	0.005
	CO_2	9	7,570.77	2,546.61	3,364.81	10,384.92	8,777.93
	CH_4	7	29.60	5.44	21.67	39.45	28.52
Chicken ball	CO	7	325.63	102.44	210.07	444.16	306.32
	NO_x	6	0.08	0.09	0.002	0.21	0.05
	PM_{10}	7	0.004	0.001	0.002	0.006	0.004
	CO_2	7	3,653.08	1,097.46	2,466.58	5,213.97	3,967.35
	CH_4	7	20.16	6.48	9.64	29.20	20.09
Chicken ball	CO	7	325.63	102.44	210.07	444.16	306.32
	NO_x	6	0.08	0.09	0.002	0.21	0.05
	PM_{10}	7	0.004	0.001	0.002	0.006	0.004
	CO_2	7	3,653.08	1,097.46	2,466.58	5,213.97	3,967.35
	CH_4	7	20.16	6.48	9.64	29.20	20.09

N = Sample size

Table 4.14 shows the emission factors of particulate matter and gases from charcoal meat grilling, expressed as mass of emitted pollutant per the unit of energy (g/MJ). It was found that among fifteen meats, grilling shrimp had the highest emission factors of CO, PM_{10}, CO_2, and CH_4 while grilling the chicken had the highest emission factor of NO_x. The emission factors of CO, NO_x, CO_2, and CH_4 ranged from 13.53±4.12 to 121.11±11.05, 0.004±0.005 to 0.084±0.062, 153.16±47.27 to 1,541.42±214.58, 0.75±0.06 to 6.07±2.15 g/MJ, respectively. The emission factor of PM_{10} ranged from 0.15±0.04 to 1.98±0.57 mg/MJ.

Table 4.14 Emission factors of particulate matter and gases from charcoal meat grilling (g/MJ).

Meat	Emission factors (g/MJ)	N	Mean	S.D.	Min	Max	Median
Pork	CO	7	32.02	5.74	23.79	37.11	35.65
	NO_x	6	0.052	0.033	0.010	0.090	0.055
	PM_{10} (mg/MJ)	6	0.50	0.11	0.33	0.59	0.54
	CO_2	7	508.02	93.63	379.85	625.17	546.24
	CH_4	7	1.44	0.47	0.69	2.00	1.32
Chicken	CO	9	36.51	5.54	28.14	43.21	38.06
	NO_x	9	0.084	0.062	0.010	0.190	0.050
	PM_{10} (mg/MJ)	9	0.46	0.07	0.36	0.57	0.46
	CO_2	9	501.86	112.62	328.13	671.54	519.16
	CH_4	9	1.10	0.35	0.62	1.66	1.03
Chicken wing	CO	9	31.70	11.23	18.00	48.10	26.10
	NO_x	8	0.075	0.032	0.010	0.120	0.080
	PM_{10} (mg/MJ)	9	0.55	0.12	0.42	0.70	0.54
	CO_2	9	425.51	145.43	247.39	638.07	356.70
	CH_4	6	0.75	0.06	0.65	0.82	0.76
Chicken liver	CO	9	37.30	12.29	21.26	61.27	34.78
	NO_x	8	0.051	0.048	0.020	0.150	0.045
	PM_{10} (mg/MJ)	9	0.32	0.08	0.22	0.46	0.34
	CO_2	8	452.98	107.86	271.50	619.88	469.15
	CH_4	9	1.49	0.62	0.49	2.30	1.29
Catfish	CO	9	24.28	6.75	15.14	34.17	24.18
	NO_x	9	0.016	0.010	0.010	0.030	0.010
	PM_{10} (mg/MJ)	9	0.32	0.04	0.26	0.38	0.31
	CO_2	9	332.94	95.90	197.03	451.68	359.69
	CH_4	9	1.27	0.43	0.82	2.06	1.09
Ruby fish	CO	9	19.89	5.11	13.32	26.11	20.64
	NO_x	4	0.010	0.000	0.001	0.010	0.010
	PM_{10} (mg/MJ)	9	0.15	0.04	0.11	0.20	0.13
	CO_2	9	250.40	64.32	165.52	351.94	262.12
	CH_4	7	0.86	0.20	0.50	1.10	0.89
Tilapia	CO	9	26.32	11.36	15.65	45.49	21.20
	NO_x	9	0.020	0.018	0.010	0.060	0.010
	PM_{10} (mg/MJ)	7	0.22	0.04	0.16	0.28	0.22
	CO_2	9	337.85	145.61	191.99	585.64	258.44
	CH_4	9	1.05	0.38	0.54	1.65	0.98
Shrimp	CO	8	121.11	11.05	108.08	137.57	122.64
	NO_x	9	0.060	0.063	0.0001	0.160	0.04
	PM_{10} (mg/MJ)	9	1.98	0.57	1.04	2.60	1.88
	CO_2	8	1,541.42	214.58	1,187.59	1,770.71	1,580.01
	CH_4	9	6.07	2.15	3.88	9.88	4.95
Squid	CO	8	25.35	7.40	12.95	32.71	25.86
	NO_x	9	0.027	0.022	0.002	0.070	0.020
	PM_{10} (mg/MJ)	9	0.38	0.15	0.17	0.59	0.38
	CO_2	8	337.85	97.09	180.77	503.10	315.21
	CH_4	6	1.39	0.16	1.25	1.65	1.33

Table 4.14 Emission factors of particulate matter and gases from charcoal meat grilling (g/MJ) (Continued).

Meat	Emission factors (g/MJ)	N	Mean	S.D.	Min	Max	Median
Thai sausage	CO	9	57.85	16.70	38.87	85.69	52.73
	NO_x	8	0.033	0.025	0.010	0.080	0.020
	PM_{10} (mg/MJ)	9	0.84	0.34	0.40	1.39	0.82
	CO_2	9	797.14	215.53	426.52	1,079.25	764.32
	CH_4	8	2.85	0.45	2.30	3.44	2.87
Thai sour pork	CO	8	40.79	10.44	26.40	59.77	39.58
	NO_x	8	0.031	0.017	0.010	0.060	0.025
	PM_{10} (mg/MJ)	8	0.41	0.09	0.31	0.54	0.40
	CO_2	7	453.91	97.46	303.97	606.40	464.40
	CH_4	7	1.74	0.32	1.36	2.39	1.70
Meatball	CO	7	23.11	1.33	21.28	24.74	23.40
	NO_x	9	0.013	0.006	0.004	0.020	0.010
	PM_{10} (mg/MJ)	9	0.21	0.07	0.12	0.33	0.25
	CO_2	8	292.06	41.01	233.08	354.84	291.61
	CH_4	7	1.14	0.14	0.95	1.36	1.19
Pork ball	CO	7	15.79	2.88	11.20	19.20	16.03
	NO_x	8	0.007	0.007	0.0001	0.020	0.006
	PM_{10} (mg/MJ)	9	0.18	0.02	0.14	0.20	0.19
	CO_2	7	171.32	31.16	132.90	220.17	163.51
	CH_4	9	0.92	0.25	0.49	1.27	0.95
Fish ball	CO	7	34.75	3.77	29.52	40.34	33.70
	NO_x	9	0.016	0.008	0.004	0.030	0.020
	PM_{10} (mg/MJ)	9	0.28	0.07	0.20	0.43	0.28
	CO_2	9	383.87	138.23	170.01	527.95	395.66
	CH_4	7	1.50	0.23	1.08	1.78	1.57
Chicken ball	CO	7	13.53	4.12	8.81	18.10	13.49
	NO_x	6	0.004	0.005	0.0001	0.010	0.002
	PM_{10} (mg/MJ)	7	0.17	0.06	0.10	0.27	0.17
	CO_2	7	153.16	47.27	99.49	228.47	165.10
	CH_4	6	0.91	0.19	0.61	1.17	0.89

N = Sample size

Emission factor on dry weight basis of fuel and meat are given in Table 4.15-4.17. Table 4.15 shows the emission factors of particulate matter and gases from charcoal meat grilling were expressed as mass of emitted pollutant per mass of fuel used (g/kg of fuel), and based on dry weight of fuel basis. It was found that among fifteen meats, grilling shrimp had the highest emission factors of CO, PM_{10}, CO_2, and

CH_4 while grilling the chicken had the highest emission factor of NO_x. The emission factors of CO, NO_x, PM_{10}, CO_2, and CH_4 ranged from 411.36±125.41 to 3,682.62±335.91, 0.11±0.12 to 2.55±1.85, 0.005±0.001 to 0.060±0.017, 4,657.14±1,437.47 to 46,871.34±6,525.10, 22.80±1.83 to 184.49±65.24 g/kg of fuel, respectively.

Table 4.15 Emission factors of particulate matter and gases from charcoal meat grilling (g/kg of fuel, based on dry weight basis).

Meat	Emission factors (g/kg of fuel)	N	Mean	S.D.	Min	Max	Median
Pork	CO	7	937.49	174.61	723.33	1,128.48	1,083.92
	NO_x	7	1.60	0.99	0.31	2.73	1.79
	PM_{10}	6	0.015	0.003	0.010	0.018	0.016
	CO_2	7	15,447.93	2,847.12	11,550.40	19,010.02	16,610.15
	CH_4	7	43.93	14.38	20.97	60.94	40.15
Chicken	CO	9	1,110.20	168.35	855.70	1,314.06	1,157.33
	NO_x	9	2.55	1.85	0.28	5.66	1.67
	PM_{10}	9	0.014	0.002	0.011	0.017	0.014
	CO_2	9	15,260.60	3,424.39	9,977.66	20,420.04	15,786.49
	CH_4	9	33.58	10.57	19.00	50.45	31.24
Chicken wing	CO	9	963.90	341.50	547.19	1,462.51	760.69
	NO_x	8	2.29	0.87	0.75	3.55	2.42
	PM_{10}	9	0.017	0.004	0.013	0.021	0.016
	CO_2	9	12,938.76	4,422.31	7,522.74	19,402.45	10,846.39
	CH_4	6	22.80	1.83	19.85	25.06	23.01
Chicken liver	CO	9	1,134.04	373.66	646.42	1,862.96	1,057.48
	NO_x	8	1.13	0.84	0.23	2.30	1.36
	PM_{10}	9	0.010	0.002	0.007	0.014	0.010
	CO_2	8	13,774.34	3,279.73	8,255.68	18,849.41	14,265.73
	CH_4	9	45.26	18.89	14.85	70.08	39.16
Catfish	CO	9	738.41	205.16	460.48	1,038.97	855.07
	NO_x	9	0.46	0.34	0.02	0.96	0.45
	PM_{10}	9	0.010	0.001	0.008	0.012	0.009
	CO_2	9	10,124.13	2,916.16	5,991.33	13,734.57	10,937.45
	CH_4	9	38.77	13.04	25.03	62.64	33.29
Ruby fish	CO	9	604.77	155.43	405.18	793.82	627.70
	NO_x	7	0.24	0.17	0.02	0.55	0.22
	PM_{10}	9	0.005	0.001	0.003	0.006	0.004
	CO_2	9	7,614.29	1,955.99	5,033.14	10,701.90	7,970.39
	CH_4	8	24.46	7.29	12.62	33.47	25.65

Table 4.15 Emission factors of particulate matter and gases from charcoal meat grilling (g/kg of fuel, based on dry weight basis) (Continued).

Meat	Emission factors (g/kg of fuel)	N	Mean	S.D.	Min	Max	Median
Tilapia	CO	9	800.34	345.31	475.93	1,383.30	889.94
	NO_x	8	0.40	0.30	0.03	0.83	0.27
	PM_{10}	7	0.007	0.001	0.005	0.009	0.007
	CO_2	8	9,331.34	3,644.18	5,837.94	15,991.35	7,789.10
	CH_4	9	31.76	11.66	16.35	50.11	29.70
Shrimp	CO	8	3,682.62	335.91	3,286.59	4,183.09	3,698.65
	NO_x	9	1.82	1.90	0.07	4.81	1.22
	PM_{10}	9	0.060	0.017	0.032	0.079	0.057
	CO_2	8	46,871.34	6,525.10	36,112.10	53,843.52	48,044.88
	CH_4	9	184.49	65.24	117.83	300.34	150.65
Squid	CO	8	770.13	225.02	393.86	994.69	786.36
	NO_x	9	0.87	0.61	0.38	1.99	0.60
	PM_{10}	9	0.011	0.005	0.005	0.018	0.011
	CO_2	8	10,272.90	2,952.32	5,496.87	15,298.25	9,584.78
	CH_4	6	42.06	4.81	37.87	50.27	40.33
Thai sausage	CO	9	1,759.16	507.98	1,181.93	2,605.72	1,603.41
	NO_x	8	0.99	0.80	0.16	2.52	0.61
	PM_{10}	9	0.026	0.010	0.012	0.042	0.025
	CO_2	9	24,239.53	6,553.97	12,969.48	32,817.88	23,241.29
	CH_4	8	86.68	13.82	70.09	104.50	87.13
Thai sour pork	CO	8	1,240.24	317.40	802.81	1,817.44	1,203.53
	NO_x	8	0.91	0.55	0.29	1.84	0.70
	PM_{10}	8	0.012	0.003	0.009	0.016	0.012
	CO_2	7	13,802.64	2,963.52	9,243.20	18,439.51	14,121.58
	CH_4	7	52.88	9.74	41.25	72.75	51.75
Meatball	CO	7	689.91	39.93	646.96	741.03	711.61
	NO_x	9	0.41	0.18	0.12	0.68	0.40
	PM_{10}	9	0.007	0.002	0.004	0.010	0.008
	CO_2	8	8,880.93	1,246.89	7,087.38	10,789.95	8,867.04
	CH_4	7	34.74	4.34	28.77	41.34	36.09
Pork ball	CO	7	480.18	87.47	340.71	583.98	487.40
	NO_x	8	0.21	0.20	0.001	0.54	0.13
	PM_{10}	9	0.005	0.001	0.004	0.006	0.006
	CO_2	7	5,209.41	947.56	4,041.35	6,694.88	4,772.03
	CH_4	9	27.81	7.73	14.90	38.50	28.98
Fish ball	CO	7	1,056.70	114.82	897.55	1,226.77	1,024.88
	NO_x	9	0.45	0.25	0.12	0.83	0.46
	PM_{10}	9	0.008	0.002	0.006	0.013	0.008
	CO_2	9	12,072.63	4,245.00	5,169.64	16,053.86	14,063.60
	CH_4	7	45.67	6.99	32.85	54.06	47.66
Chicken ball	CO	7	411.36	125.41	267.78	550.49	410.26
	NO_x	6	0.11	0.12	0.003	0.28	0.07
	PM_{10}	7	0.005	0.002	0.003	0.008	0.005
	CO_2	7	4,657.14	1,437.47	3,025.29	6,947.26	5,020.50
	CH_4	7	25.56	7.74	12.55	35.61	26.89

N = Sample size

Table 4.16 shows the emission factors of particulate matter and gases from charcoal meat grilling, expressed as mass of emitted pollutant per mass of meat consumed (g/kg of meat) and based on dry weight of meat basis. It was found that among fifteen meats, grilling ruby fish had the highest emission factors of CO and CO_2 while grilling the chicken wing had the highest emission factor of NO_x. Grilling shrimp showed the highest emission factor of PM_{10} and CH_4. The emission factors of CO, NO_x, PM_{10}, CO_2, and CH_4 ranged from 3,390.49±639.84 to 10,732.75±2,324.95, 0.87±0.88 to 9.67±2.31, 0.027±0.003 to 0.166±0.048, 45,151.60±7,903.92 to 136,303.61±33,537.60, 90.82±21.02 to 507.54±168.11 g/kg of meat, respectively.

Table 4.16 Emission factors of particulate matter and gases from charcoal meat grilling (g/kg of meat, based on dry weight basis).

Meat	Emission factors (g/kg of meat)	N	Mean	S.D.	Min	Max	Median
Pork	CO	7	3,390.49	639.84	2,309.30	4,108.06	3,700.53
	NO_x	7	7.03	4.59	1.14	14.20	6.98
	PM_{10}	6	0.049	0.007	0.040	0.061	0.049
	CO_2	7	53,788.14	10,055.88	35,742.27	63,250.79	59,091.15
	CH_4	7	151.15	48.22	102.23	214.19	127.59
Chicken	CO	9	3,797.11	408.33	3,155.96	4,445.17	3,850.11
	NO_x	9	8.42	5.72	1.14	17.51	6.51
	PM_{10}	8	0.046	0.006	0.037	0.054	0.048
	CO_2	9	51,983.18	8,906.98	35,669.36	62,712.14	55,234.77
	CH_4	9	115.85	38.86	67.15	186.46	105.27
Chicken wing	CO	9	3,528.78	940.40	2,585.09	5,183.69	3,212.93
	NO_x	7	9.67	2.31	6.19	12.91	9.23
	PM_{10}	9	0.063	0.009	0.049	0.076	0.061
	CO_2	8	45,151.60	7,903.92	35,539.62	60,567.24	42,722.58
	CH_4	8	90.82	21.02	66.31	130.56	86.86
Chicken liver	CO	9	4,148.35	867.60	2,916.41	5,306.02	4,237.20
	NO_x	8	3.88	2.66	1.36	8.41	4.00
	PM_{10}	9	0.036	0.005	0.028	0.041	0.037
	CO_2	9	55,270.59	11,063.80	40,408.23	71,240.13	53,583.02
	CH_4	9	169.44	63.58	50.74	228.48	195.82

Table 4.16 Emission factors of particulate matter and gases from charcoal meat grilling (g/kg of meat, based on dry weight basis) (Continued).

Meat	Emission factors (g/kg of meat)	N	Mean	S.D.	Min	Max	Median
Catfish	CO	6	9,366.68	541.31	8,899.39	10,397.20	9,143.16
	NO_x	9	5.58	3.87	0.30	11.54	4.28
	PM_{10}	7	0.114	0.008	0.103	0.124	0.115
	CO_2	9	126,051.65	26,897.73	87,946.23	162,342.81	134,226.67
	CH_4	9	479.32	98.28	367.36	659.12	459.75
Ruby fish	CO	9	10,732.75	2,324.95	7,399.42	14,763.36	11,223.16
	NO_x	7	3.99	3.16	0.52	10.41	3.29
	PM_{10}	7	0.072	0.013	0.051	0.085	0.075
	CO_2	9	136,303.61	33,537.60	87,993.27	170,981.07	146,215.75
	CH_4	6	473.24	56.11	385.41	530.42	493.79
Tilapia	CO	9	9,706.47	2,825.34	5,609.18	13,096.91	10,151.39
	NO_x	8	4.29	2.25	0.87	7.72	3.87
	PM_{10}	9	0.097	0.049	0.049	0.172	0.071
	CO_2	9	122,405.79	26,025.55	81,345.13	152,002.89	133,609.59
	CH_4	8	333.57	135.39	154.67	547.52	372.32
Shrimp	CO	9	10,658.28	1,618.75	7,955.99	13,021.20	10,958.21
	NO_x	9	4.83	5.05	0.16	13.40	3.08
	PM_{10}	9	0.166	0.048	0.087	0.213	0.190
	CO_2	9	134,123.41	15,710.45	111,795.98	162,987.34	134,356.05
	CH_4	9	507.54	168.11	285.25	744.52	441.41
Squid	CO	8	3,525.38	600.34	2,744.42	4,502.80	3,535.48
	NO_x	8	3.16	2.23	1.33	7.44	2.10
	PM_{10}	9	0.051	0.020	0.021	0.082	0.051
	CO_2	8	47,118.89	10,592.17	34,901.07	69,252.89	43,614.72
	CH_4	7	149.17	52.13	66.60	198.32	167.22
Thai sausage	CO	9	6,287.74	2,105.83	3,866.22	10,059.40	5,958.10
	NO_x	7	2.80	2.14	0.39	6.93	2.21
	PM_{10}	8	0.081	0.018	0.053	0.105	0.085
	CO_2	8	92,205.33	24,259.54	54,411.20	126,725.89	88,046.09
	CH_4	9	300.26	112.84	84.13	420.31	294.03
Thai sour pork	CO	8	6,337.11	1,467.84	4,133.73	8,189.60	6,205.00
	NO_x	8	4.86	2.98	1.65	8.10	4.78
	PM_{10}	8	0.064	0.016	0.045	0.088	0.063
	CO_2	8	76,549.63	16,017.25	52,001.59	94,950.96	82,162.68
	CH_4	6	307.63	61.21	227.45	414.41	300.17
Meatball	CO	8	4,574.20	573.71	3,846.46	5,547.61	4,350.87
	NO_x	9	2.60	1.03	0.85	3.99	2.68
	PM_{10}	8	0.039	0.009	0.022	0.048	0.040
	CO_2	8	56,273.39	8,468.11	42,983.39	70,958.45	58,464.09
	CH_4	7	233.56	33.23	165.00	306.39	241.48
Pork ball	CO	8	6,120.00	817.91	4,777.00	7,335.96	6,117.36
	NO_x	9	2.50	2.26	0.02	6.12	2.01
	PM_{10}	7	0.027	0.003	0.023	0.032	0.028
	CO_2	8	62,556.80	12,049.60	41,160.89	80,248.25	63,249.76
	CH_4	9	288.41	105.71	126.25	406.86	307.90

Table 4.16 Emission factors of particulate matter and gases from charcoal meat grilling (g/kg of meat, based on dry weight basis) (Continued).

Meat	Emission factors (g/kg of meat)	N	Mean	S.D.	Min	Max	Median
Fish ball	CO	9	9,104.74	3,427.11	4,441.56	14,790.71	9,289.05
	NO_x	8	3.75	1.94	1.19	7.59	361
	PM_{10}	8	0.076	0.013	0.063	0.094	0.069
	CO_2	7	129,561.82	24,648.73	100,899.62	173,628.26	126,121.10
	CH_4	7	361.18	75.22	242.08	460.16	347.53
Chicken ball	CO	7	4,597.25	2,434.33	2,395.78	8,719.51	4,189.06
	NO_x	6	0.87	0.88	0.05	2.12	0.64
	PM_{10}	6	0.047	0.013	0.028	0.062	0.047
	CO_2	7	50,441.12	21,573.66	26,784.18	82,893.45	47,326.79
	CH_4	7	286.98	153.05	109.93	514.71	206.92

N = Sample size

Table 4.17 shows the emission factors of particulate matter and gases from charcoal meat grilling, expressed as mass of emitted pollutant per mass of material consumed (g/kg of material) and based on the basis of dry weight of fuel and meat. It was found that among fifteen meats, grilling shrimp had the highest emission factors of CO, PM_{10}, CO_2, and CH_4 while grilling the chicken had the highest emission factor of NO_x. The emission factors of CO, NO_x, PM_{10}, CO_2, and CH_4 ranged from 369.12±118.24 to 2,707.67±235.08, 0.09±0.11 to 1.95±1.39, 0.004±0.001 to 0.044±0.012, 4,226.13±1,278.80 to 35.878.81±5,886.92, and 17.20±2.72 to 134.84±46.21 g/kg of material, respectively.

Table 4.17 Emission factors of particulate matter and gases from charcoal meat grilling (g/kg of material, based on dry weight basis).

Meat	Emission factors (g/kg of material)	N	Mean	S.D.	Min	Max	Median
Pork	CO	7	745.60	106.21	605.06	885.29	746.48
	NO_x	6	1.23	0.73	0.25	1.85	1.48
	PM_{10}	5	0.012	0.001	0.010	0.013	0.013
	CO_2	7	11,827.82	1,683.63	9,661.83	13,777.39	11,553.64
	CH_4	7	33.53	10.04	17.40	46.45	32.64
Chicken	CO	9	854.45	103.46	689.92	983.58	851.69
	NO_x	9	1.95	1.39	0.22	4.28	1.25
	PM_{10}	9	0.011	0.002	0.009	0.013	0.011
	CO_2	9	11,736.29	2,355.70	8,044.60	14,908.45	12,459.39
	CH_4	9	25.89	8.03	14.81	37.76	23.61
Chicken wing	CO	9	756.57	250.25	451.60	1,127.94	645.54
	NO_x	8	1.82	0.67	0.61	2.76	1.92
	PM_{10}	9	0.013	0.003	0.010	0.017	0.013
	CO_2	9	10,155.72	3,220.29	6,208.56	15,180.58	8,730.41
	CH_4	7	17.20	2.72	12.03	20.17	17.98
Chicken liver	CO	9	881.70	254.87	552.97	1,356.23	805.96
	NO_x	8	0.87	0.64	0.20	1.81	1.01
	PM_{10}	9	0.008	0.001	0.006	0.010	0.008
	CO_2	7	11,401.23	1,849.46	8,680.55	14,572.95	11,204.38
	CH_4	9	35.32	13.84	11.49	53.54	33.43
Catfish	CO	9	682.36	183.44	428.20	936.59	680.41
	NO_x	9	0.43	0.31	0.02	0.89	0.41
	PM_{10}	9	0.009	0.001	0.007	0.011	0.009
	CO_2	9	9,354.12	2,619.80	5,609.21	12,663.23	10,157.94
	CH_4	9	35.79	11.56	23.43	56.47	31.37
Ruby fish	CO	9	569.75	139.04	386.46	744.04	596.16
	NO_x	7	0.23	0.16	0.02	0.52	0.20
	PM_{10}	9	0.004	0.001	0.003	0.006	0.004
	CO_2	9	7,179.06	1,782.17	4,800.63	9,972.02	7,507.39
	CH_4	7	24.80	5.39	14.70	31.37	25.70
Tilapia	CO	9	732.06	298.77	446.94	1,226.15	612.81
	NO_x	8	0.37	0.27	0.03	0.73	0.25
	PM_{10}	7	0.006	0.001	0.005	0.008	0.006
	CO_2	8	8,584.31	3,128.60	5,482.31	14,126.97	7,252.22
	CH_4	9	29.30	10.62	14.91	45.91	27.30
Shrimp	CO	8	2,707.67	235.08	2,325.81	3,064.58	2,675.64
	NO_x	9	1.32	1.37	0.05	3.40	0.88
	PM_{10}	9	0.044	0.012	0.023	0.057	0.045
	CO_2	9	35,878.81	5,886.92	28,462.09	47,909.56	35,357.12
	CH_4	9	134.84	46.21	83.39	212.05	114.80
Squid	CO	9	670.76	187.86	358.09	967.40	736.66
	NO_x	8	0.57	0.36	0.30	1.33	0.43
	PM_{10}	9	0.009	0.004	0.005	0.015	0.008
	CO_2	9	8,886.63	2,407.47	4,997.63	12,530.26	7,975.98
	CH_4	6	35.54	5.16	30.38	45.25	34.11

Table 4.17 Emission factors of particulate matter and gases from charcoal meat grilling (g/kg of material, based on dry weight basis) (Continued).

Meat	Emission factors (g/kg of material)	N	Mean	S.D.	Min	Max	Median
Thai sausage	CO	9	1,363.51	386.05	954.43	2,069.62	1,272.08
	NO_x	8	0.77	0.63	0.11	1.97	0.49
	PM_{10}	9	0.020	0.007	0.010	0.030	0.020
	CO_2	9	18,807.76	5,039.70	10,473.10	25,453.99	17,902.21
	CH_4	9	63.36	18.34	24.58	83.00	59.55
Thai sour pork	CO	8	1,026.97	230.42	682.44	1,401.19	1,025.24
	NO_x	8	0.76	0.46	0.25	1.50	0.59
	PM_{10}	8	0.010	0.002	0.008	0.014	0.010
	CO_2	7	11,591.39	2,315.46	7,857.22	15,021.76	11,900.03
	CH_4	7	44.18	8.14	31.80	59.27	44.30
Meatball	CO	7	596.51	27.96	563.36	633.25	610.49
	NO_x	9	0.35	0.15	0.11	0.58	0.36
	PM_{10}	9	0.006	0.002	0.003	0.009	0.006
	CO_2	8	7,658.88	1,045.16	6,084.18	9,365.79	7,665.01
	CH_4	7	30.17	3.80	24.50	35.49	31.67
Pork ball	CO	7	442.50	81.26	310.25	535.79	452.02
	NO_x	9	0.26	0.28	0.001	0.87	0.12
	PM_{10}	9	0.005	0.001	0.004	0.005	0.005
	CO_2	7	4,799.86	878.10	3,680.03	6,179.35	4,583.42
	CH_4	9	25.17	6.86	13.56	32.63	26.71
Fish ball	CO	7	954.07	98.51	820.08	1,106.05	958.47
	NO_x	9	0.41	0.22	0.11	0.75	0.41
	PM_{10}	8	0.007	0.001	0.006	0.009	0.007
	CO_2	9	10,520.00	3,689.72	4,670.78	14,474.10	11,251.44
	CH_4	7	41.15	6.51	29.79	50.56	42.52
Chicken ball	CO	7	369.12	118.24	245.49	497.94	326.38
	NO_x	6	0.09	0.11	0.003	0.25	0.06
	PM_{10}	7	0.005	0.002	0.003	0.007	0.005
	CO_2	7	4,226.13	1,278.80	2,843.53	6,151.38	4,693.34
	CH_4	7	23.26	7.26	11.26	33.15	23.75

N = Sample size

4.6 Comparison/Uncertainty

U.S. EPA (1999) reported (Table 2.2) the emission factors of grilled chicken with fired-charbroiler for 157.9, 4.2, and 9.4 g/kg of meat for CO, NO_x, and PM_{10}, respectively. The CO emission factor from this study was higher than the values reported in the literature while NO_x and PM_{10} emission factors were lower based on wet weight basis of meat. In case of dry weight basis of meat the CO and NO_x emission factors from this study were higher than the values reported in the literature while PM_{10} emission factor was lower (Table 4.18). It is important to note that this study used in-stack sampling of particulate matter with eight-stage ANDERSON impactor.

Table 4.18 Comparison of emission factors from charcoal meat grilling**.**

Meat	**Fuel**	**Emission factors (g/kg of meat)**			**Reference**
		CO	**NO_x**	**PM_{10}**	
Chicken	Charcoal	157.9	4.2	9.4	U.S. EPA (1999)
Chicken (wet weight basis)	Charcoal	996.0	2.2	0.01	This study
Chicken (dry weight basis)	Charcoal	3,797.1	8.4	0.05	This study

Various factors influencing the emission factors include grilling method, fuel type, combustion condition (operating temperature and pressure), equipment and sampling procedure. These factors may contributed to the deviations and uncertainties.

Our experiment of meat grilling activity was stimulated similar to street food stalls commonly found in Thailand. The emissions were conducted in the combustion testing equipment with fixed grilling time. The grilling time was set at 20 minutes except seafood and meatball that used only 15 minutes to prevent burnt from overcook. Charcoal made from eucalyptus wood was used exclusively as the fuel. All of meat grilling used about 700 g of fuel/experiment.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Emission factors from meat grilling similar to street food stall can be developed with real-time measurements under combustion chamber testing. Real-time measurement of gases and temperatures provided insight dynamic of the emissions. The results showed that incomplete combustion of eucalyptus-derived charcoal used for meat grilling generated higher CO concentrations, based on a mass balance approach, than NO_x and PM_{10}. SO_2 was not detected in all samples due to negligible 0.01±0.004% in the charcoal. Observation during real-time measurements indicated that dropping of liquid, probably fatty content, from meats to burning charcoal related to high CO and NO_x emissions. Average emissions of fifteen types of meat grilling ranged from 123.01±30.75 to 229.00±30.24 g/m^3 for CO, 0.04±0.04 to 0.61±0.32 g/m^3 for NO_x, 1.84±0.64 to 4.16±0.78 mg/m^3 for $PM_{10,}$ 1,405.05±400.62 to 3,099.08± 318.21 g/m^3 for CO_2, and 0.21±0.06 to 0.38±0.12 g/m^3 for CH_4.

On wet weight basis of meat and fuel, the emission factors of particulate matter and gases from charcoal meat grilling were the following.

- Grilling shrimp had the highest emission factors of CO, PM_{10}, CO_2 and CH_4 (3,457.61±315.39, 0.056±0.016, 44,007.51±6,126.42 and 173.22± 61.25 g/kg of fuel, respectively).
- Grilling chicken had the highest emission factor of NO_x, 2.40±1.73 g/kg of fuel.

- Grilling catfish had the highest emission factors of CO and CH_4 (3,343.91±193.25 and 171.12±35.09 g/kg of meat, respectively).
- Grilling chicken wing had the highest emission factor of NO_x, 3.58± 0.85 g/kg of meat.
- Grilling shrimp had the highest emission factor of PM_{10}, 0.042±0.012 g/kg of meat.
- Thai sausage had the highest emission factor of CO_2, 47,236.79± 12,428.16 g/kg of meat.
- Grilling shrimp had the highest emission factors of CO, PM_{10}, CO_2 and CH_4 (1,491.77±144.87, 0.024±0.007, 19,580.66±2,718.86 and 73.79±24.67 g/kg of material, respectively).
- Grilling chicken wing had the highest emission factor of NO_x, 1.30± 0.47 g/kg of material.
- Grilling shrimp had the highest emission factors of CO, PM_{10}, CO_2 and CH_4 (121.11±11.05, 1.98±0.57, 1,541.42±214.58 and 6.07±2.15 g/MJ, respectively).
- Grilling chicken had the highest emission factor of NO_x, 0.084±0.062 g/MJ.

The emission factors addressed as the dry weight basis of meat and fuel may be more appropriate to compare due to variability of humidity contents in both meat and fuel. The followings are the derived emission factors on the dry weight basis.

- Grilling shrimp had the highest emission factors of CO, PM_{10}, CO_2 and CH_4 (3,682.62±335.91, 0.060±0.017, 46,871.34±6,525.10 and 184.49± 65.24 g/kg of fuel, respectively).

- Grilling chicken had the highest emission factor of NO_x, 2.55±1.85 g/kg of fuel.
- Grilling ruby fish showed the highest emission factor of CO and CO_2 (10,732.75±2,324.95 and 136,303.61±33,537.60 g/kg of meat, respectively).
- Grilling chicken wing had the highest emission factor of NO_x, 9.67± 2.31 g/kg of meat.
- Grilling shrimp had the highest emission factor of PM_{10} and CH_4, (0.166±0.048 and 507.54±168.11 g/kg of meat, respectively).
- Grilling shrimp had the highest emission factors of CO, PM_{10}, CO_2 and CH_4 (2,707.67±235.08, 0.044±0.012, 35,878.81±5,886.92 and 134.84± 46.21 g/kg of material, respectively).
- Grilling the chicken had the highest emission factor of NO_x, 1.95±1.39 g/kg of material.
- All of meat grilling activities was unable to detected SO_2 since sulfur is negligible in both fuel and meats used in the experiments.

Developed emission factors from meat grilling were differed from foreign data, especially PM_{10} had more discrepancy with literature, possibly due to the sampling device used in this study. The eight-stage impactor was not the ideal instrument for PM_{10} measurements in the stack. With repeated measurements and real-time data, the emission factors from this study are suitable for estimating the emissions of charcoal meat grilling in Thailand with the exception of PM_{10}. Fuel is a very important factor in meat grilling for estimate the emissions.

5.2 Recommendations

This study provides appropriate results and method for emission factors development. However, issues during the investigation indicates that further recommendations may provide improvement and refine the results for situation in the future. The recommendations are as follows.

- Investigates other types of charcoal used in grilling activity.
- Measures meat with marinade and spice as common ingredient.
- Uses appropriate in-stack measurement of particulate matter.
- SO_2 can be excluded if fuel has low sulphur content.

REFERENCES

REFERENCES

Air Sciences Inc, ASI. (2003). **Final Report: Cereal grain crop open field burning emissions study project 152-02.**

Andreae, MO., and Merlet, P. (2001). Emission of trace gases and aerosol from biomass burning. **Global Biogeochemical Cycles.** 15: 955-956.

AOAC. (2000). **Determination of moisture content**. In Official methods of analysis (17th ed.). Gaithersburg, Maryland.

ASTM. D 5373 – 02 (2004). **Standard test methods for instrumental determination of carbon, hydrogen and nitrogen in laboratory samples of coal and coke**. West Conshohocken, Pennsylvania, United States.

ASTM. D 5865-02 (2004). **Standard test method for gross calorific value of coal and coke**. West Conshohocken, Pennsylvania, United States.

Aykan, K. (2006). Evaluation of the potential air pollution from fuel combustion in industrial boilers in Kocaeli, Turkey. **Fuel**. 85: 1894–1903.

Bardh, N., and Ahling, B. (1983). **Emissions from oil-fired domestic furnaces**. Report No. 149, Swedish Water and Air Pollution Research Institute.

Besire, C., Mehush, A., and Tahir, M. (2010). Measurements of emission of gases SO_2, NO_x, CO and CO_2 from the burning process in the furnaces of power plant “Kosova B”. **Environmental Application & Science**. 5: 172-174.

Bhattacharya, S.C., Albina, D.O., and Salum, A. (2002). Emission factors of wood and charcoal-fired cookstoves. **Biomass and Bioenergy**. 23: 453-469.

Bromley, R. (2000). Street vending and public policy: A global review. **International Journal of Sociology and Social Policy.** 20: 1-28.

Brich, M.E., and Cary, R.A. (1996). Elemental carbon–based method for monitoring occupational exposures to particulate diesel exhaust. **Aerosol Science and Technology**. 25: 221-244.

Breum, N.O. (2000). The dust holding capacity of porous plastic foam used in particle size-selective sampling. **Journal of Aerosol Science**. 31: 379-385.

Burnet, P.G., Edmisten, N.G., Tiegs, P.E., Houck, J.E., and Yoder, R.A. (1986). Particulate, carbon monoxide, and acid emission factors for residential wood burning stoves. **Journal of the Air Pollution Control Association**. 36: 1012-1018.

Chang, M., Kim, S., and Sioutas, C. (1999). Experimental studies on particle impaction and bounce: Effects of substrate design and material. **Atmospheric Environment**. 33: 2313-2322.

Clean Air Strategic Alliance (2006). **Hydrocarbons** [On-line]. Available: http://www.casadataorg/pollutants/hydrocarbons.asp.

Cooper, C.D., and Alley, F.C., (1994). **Air pollution control: A design approach**. Wave land press. Inc, Illinois. 330-331.

Daisey, J.M., Spengler, J. D., and Kaarakka, P. (1989). A comparison of the organic composition of indoor aerosols during wood burning and nonwood burning periods. **Environment International**. 15: 435-442.

Darley, E. F. (1977). **Emission factors from burning agricultural waste collected in California.** CAL/ARB project 4-011, Final Report.

Darley, E. F. (1979). **Hydrocarbon characterization of agricultural waste burning.** CAL/ARB project A7-068-30, Final Report.

Derudi, M., Gelosa, S., Sliepcevich, A., Cattaneo, A., Rota, R., Cavallo, D., and Nano, G. (2012). Emission of air pollutants from scented candles burning in a test chamber. **Atmospheric Environment**. 55: 257-262.

Dhammapala, R., Claiborna, C., Corkill, J., and Gulett, B., (2006). Particulate emissions from wheat and Kentucky bluegrass stubble burning in eastern Washington and northern Idaho. **Atmospheric Environment**. 40: 1007-1015.

Duan, FK., Lu, YQ., and DI, YA. (2001). Influence of straw burning on the air quality in Beijing. **Environmental Monitoring in China**. 17: 8-11.

Ehsanul, K., Ki-Hyum, K., and Yoon., HO. (2011). Trace metal contents in barbeque (BBQ) charcoal products. **Journal of Hazardous Materials**. 185: 1418-1424.

Fan, C., and Zhang, J., (2001). Characterization of emissions from portable household combustion devices: particle size distributions, emission rates and factors, and potential exposures. **Atmospheric Environment**. 35: 1281-1290.

Fine, P.M., Cass, G.R., and Simoneit, B.R.T., (1999). Characterization of fine particle emissions from burning church candles. **Environmental Science and Technology**. 33: 2352-2362.

Gelosa, S., Derudi, M., Sliepcevich, A., Gelosa, D., Nano, G., and Rota, R. (2007). **Characterization of pollutants emissions from burning candles**. In: 30th Meeting of the Italian Section of the Combustion Institute Ischia, Italy.

Gouliang, C., Xiaoye, Z., Sunling, G., and Fangcheng, Z. (2008). Investigation on emission factors of particulate matter and gaseous pollutants from crop residue burning. **Journal of Environmental Sciences.** 20: 50-55.

Guofeng, S., Siye, W., Wen, W., Yanyan, Z., Yujia, M., Bin, W., Rong, W., Wei, L., Huizhong, S., Ye, H., Yifeng, Y., Wei, W., Xilong, W., Xuejun, W., and Shu, T. (2012). Emission factors, size distributions, and emission inventories of carbonaceous particulate matter from residential wood combustion in rural China. **Environmental Science and Technology**. 46: 4207-4214.

Hall, J., Bealey, B., and Wadsworth, R. (2006)**. Assessing the risks of air pollution impacts to the condition of areas/sites of special scientific interest in the UK**. JNCC Report No. 387.

Hildemann, L.M., Markowski, G.R., Jones, M.C., and Cass, G.R. (1991). Chemical composition of emissions from urban sources of fine organic aerosol. **Environmental Science and Technology.** 25: 744-759.

Hildemann, L.M., Markowski, G.R., Jones, M.C., and Cass, G.R. (1991). Submicrometer aerosol mass distributions of emissions from boilers, fireplaces, automobiles, diesel trucks, and meat-cooking operations. **Aerosol Science Technology**. 14: 138-152.

Huntzicker, J.J., Heyerdahl, E.K., Madow, S.R., Rau, J.A., Griest, W.H., and MacDougall, C.S., (1986). Combustion as the principal source of carbonaceous aerosol in the Ohio river valley. **Journal of the Air Pollution Control Association**. 36: 705-709.

Hurst, D.F., Griffith, D.W., and Cook, G.D. (1994). Trace gas emissions from biomass burning in tropical Australian savannas. **Journal of Geophysical Research.** 99: 16441–16456.

IPCC (2001). **Third assessment report climate change 2001. The scientific basis.** Cambridge University Press.

Jack, C. (2000). **Hazardous gas monitors: A practical guide to selection, operation and applications.** McGraw-Hill**.**

Jenkins, B.M., Turn, S.Q., Williams, R.B., Goronea, M., Abd-al-Fatah, H., and Mehlschau, J. (1996). **Atmospheric pollutant emission factors from open burning of agricultural and forest biomass by wind tunnel simulations.** Volume 1. California State Air Resources Board (NTIS PB97-133037).

Joe, S. (2009). **EarthTalk: Expert answers to everyday questions about the environment**. Penguin group. USA.

Johansson, L.S. (2002). **Characterisation of particle emissions from small-scale biomass combustion.** Department of Energy Technology, Chalmers University of Technology. Sweden.

Joshi, V., Venkataraman, C., and Ahuja, D.R., (1989). Emissions from burning biofuels in metal cookstoves. **Environmental Management**. 13: 763-772.

Lan, Q., Chapman, RS., Schreinemachers, DM., Tian, LW., and He, XZ. (2002). Household stove improvement and risk of lung cancer in Xuanwei, China. **Journal of the National Cancer Institute**. 94: 826-835.

Lee, S.C., and Wang, B. (2006). Characteristics of emissions of air pollutants from mosquito coils and candles burning in a large environmental chamber. **Atmospheric Environment**. 40: 2128-2138.

Levine, J.S. (1996). **In: Biomass burning and global change**. MIT Press, Cambridge, MA, USA.

Li, X., Wang, S., Duan, L., Hao, J., Li, C., Chen, Y., and Yang, L. (2007). Particulate and trace gas emissions from open burning of wheat straw and corn stover in China. **Environmental Sciences Technology**. 41: 6052-6058.

Mantananont, N., Garivait, S., and Patumsawad, S. Emission factors of particulate matter emitted from co-combustion of Thai lignite and agricultural residues in fixed bed combustor. **Proceedings of the 2nd International Conference on Environmental Science and Technology** 2011 (pp 235-240). Singapore.

McDonald, J.D., Zielinska, B., Fujita, E.M., Sagebiel, J.C., Chow, J.C., and Watson, J.G. (2003). Emissions from charbroiling and grilling of chicken and beef. **Journal of the Air & Waste Management Association.** 53: 185-194.

Melo, G., and Murcia, J.C. (2013). Analysis and measurement of NO_x emissions in port auxiliary vessels. **International Journal on Marine Navigation and Safety of Sea Transportation.** 7: 421-429.

Mitra, A.P., Lidia, M., Chhemendra, S., and Jim, Z. (2002). Chapter two: methodologies for characterization of combustion sources and for quantification of their emissions. **Chemosphere**. 49: 903-922.

National Research Council, NRC. (2010). **Advancing the science of climate change** [On-line]. Available: http://www.epa.gov/climatechange/ghgemissions/gases/co2.html

New Star NV Manual, (2004). **Instruction manual 8 stage non-viable cascade impactor.**

Norbeck, J. (1997). **Standardized test kitchen and screening tools evaluation for south coast air quality management** District Proposed Rule 1138; Prepared under Contract No. S- C95073 for the South Coast Air Quality Management District, Del Monte, CA, by CE-CERT: University of California, Riverside, CA.

Nordica, M., Damon, M., Dean, S., Tami, B., and Christoph, R. (2008). A laboratory comparison of the global warming impact of five major types of biomass cooking stoves. **Energy for Sustainable Development**. 12: 56-65.

Nussbaumer, T., Nussbaume, C., Klippel, N., Johansson, L., and Tullin, C. (2008). **Particulate emissions from biomass combustion in IEA countries.** International Energy Agency (IEA) Bioenergy Task 32, Swiss Federal Office of Energy.

Oanh, N., Reutergardh, L., and Dung, N. (1999). Emission of polycyclic aromatic hydrocarbons and particulate matter from domestic combustion of selected fuels. **Environmental Science and Technology**. 33: 2703-2709.

Pandey, S.K., Kim, K.H., Kang, C.H., Jung, M.C., and Yoon, H. (2009). BBQ charcoal as an important source of mercury emission. **Journal of Hazardous Materials**. 162: 536-538.

Pechan, E.H. (2003). **Method for developing a national emission inventory for commercial cooking**. U.S. Environmental Protection Agency Research Triangle Park, NC.

Pennise, D.M., Smith, K.R., Kithinji, J.P., Rezende, M.E., Raad, T.J., Zhang, J., and Fan, C. (2001). Emissions of greenhouse gases and other airborne pollutants from charcoal making in Kenya and Brazil. **Journal of Geophysical Research-Atmosphere**. 16: 24143-24155.

Philip, C.W., Christopher, Y.H., Wang, J.H., Cheung, C.W., and Kendall, G. (2007). Co-combustion performance of coal with rice husks and bamboo. **Atmospheric Environment**. 41: 7462–7472.

Pilat, M.J., Ensor, D.S., and Bosch, J.C. (1970). Source test cascade impactor. **Atmospheric Environment**. 4: 671-679.

Pima Country Government Arizona, Pima. Gov. (2012). **Volatile organic compounds** [On-line]. Available: http://www.pima.gov/deq/educ/LighterFluidhtml

Rangjob, K., and Nathapindhu, G. (2012). Size distribution of particles generated from grilling process. **KKU Journal for Public Health Research**. 5: 11-19.

Robert, E. (2005). **Using electrochemical sensors for toxic gas measurement.** AET Buyers' Guide 2005.

Rogge, W. F., Hildemann, L. M., Mazurek, M. A., Cass, G. R., and Simonelt, B. R. T. (1991). Sources of fine organic aerosol. 1. Charbroilers and meat cooking. **Environmental Science.** 25: 1112-1125.

Schare, S., and Smith, K.R. (1995). Particulate emission rates of simple kerosene lamps. **Energy for Sustainable Development**. 2: 32-35.

Smith, K.R., Uma, R., Kishore, V.V.N., Zhang, J., Joshi, V., and Khalil, M.A.K. (2000). Greenhouse implications of household stoves: an analysis for India. **Annual Review of Energy and the Environment.** 25: 741-776.

Stephen, M. (2010). **Improved emissions inventories for NO_x and particulate matter from small combustion installations in Ireland.** Presentation from U.S. Environmental Protection Agency Transboundary Research Workshop, Galway, 8th and 9th September.

Sung, B., Kim, YS., and Perry, R. (1997). Indoor air quality in homes, offices and restaurants in Korean urban areas-indoor/ outdoor relationship. **Atmospheric Environment**. 31: 529-544.

SEWPaC. (1999). **Emission estimation technique manual for petroleum refining**. National Pollutant Inventory. Australia.

Thomas, N., Claudia, C., Norbert, K., Linda, J., and Claes, T. (2008). **Particulate emissions from biomass combustion from IEA countries**. International Energy Agency (IEA) Bioenergy Task 32. Swiss Federal Office of Energy.

Tremeer G, J. (1996). Comparison of five rural, wood-burning cooking devices: efficiencies and emissions. **Biomass and Bioenergy.** 11: 419–430.

TSI Incorporated. (2004). **Combustion analysis basics**. United States.

U.S.EPA. (1995). **Particulate matter (PM-10)** [On-line]. Available: http://www.epa.gov/airtrends/aqtrnd95/pm10.html

U.S.EPA. (1996). **Emission factor documentation for AP-42 section 1.10 residential wood stoves**. Washington, DC: U.S. Environmental Protection Agency.

U.S.EPA. (1996). **Introduction to emission factors** [On-line]. Available: http://www.ehso.com/Air_AP_42.htm

U.S.EPA. (1997). **Procedures for preparing emission factor documents.** Washington, DC: U.S. Environmental Protection Agency.

U.S.EPA. (1999). **U.S. Environmental Protection Agency, Emissions from street vendor cooking devices (Charcoal Grilling)**. Washington, DC: U.S. Environmental Protection Agency.

U.S.EPA. (2003). **40 CFR Appendix B to part 50, Reference method for the determination of suspended particulate matter in the atmosphere (High-volume method)**. U.S. Environmental Protection Agency.

Vladimir, V., and Mirko, S. (2012). NO_x and SO_2 emission factors for serbian lignite kolubara. **Thermal Science**. 16: 1213-1228**.**

Wang, B., Lee, S.C., and Ho, K.F. (2006). Chemical composition of fine particles from incense burning in a large environmental chamber. **Atmospheric Environment**. 40: 7858–7868.

Ward, D.E., Susott, R.A., Kauffman, J.B., Babbitt, R.E., Cummings, D.L., and Dias, B. (1992). Smoke and fire characteristics for cerrado and deforestation burns in Brazil: BASE-B experiment. **Journal of Geophysical Research**. 97: 14601–14619.

Ward, D.E., Hoa, W.M., Susott, R.A., and Babbitt, R.E. (1996). Effect of fuel composition on combustion efficiency and emission factors for African savanna ecosystems. **Journal of Geophysical Research.** 101: 23569-23576.

Western Cape Government. (2005). **A Guide to reporting and estimating emissions for the integrated pollutant and waste information.**

Westerholm, R. N., Almen, J., Li, H., Rannug, U., Egebaick, K.E., and Graigg, K. (1991). Chemical and biological characterization of particulate, semivolatile, and gas phase associated compounds in diluted heavy-duty diesel exhausts; a comparison of three different semivolatile-phase samplers. **Environmental Science & Technology**. 25: 332-338.

Westerholm, R., Almen, J., Li, H., Rannug, U., and Rosen, A. (1992). Exhaust emissions from gasoline fuelled fight duty vehicles operated in different driving conditions: a chemical and biological characterization. **Atmospheric Environmental**. 26: 79-90.

WBEA. (2013). **Procedures for operating continuous total hydrocarbon (THC) analyzers.** Wood Buffalo Environmental Association. Canada.

Zhang, J., Smith, K.R., Ma, Y., YE, S., Jiang, F., Qi, W., Liu, P., Khalil, M.A.K.., Rasmussen, R.A., and Thorneloe, S.A. (2000). Greenhouse gases and other pollutants from household stoves in China: a database for emission factors. **Atmospheric Environment**. 34: 4537-4549.

Zhang, J., and Morawska, L. (2002). Combustion sources of particles: 2 Emission factors and measurement methods. **Chemosphere.** 49: 1059-1074.

APPENDICES

APPENDIX A

CALCULATIONS OF MAXIMUM PERCENTAGE OF CO_2

Table A.1 Percent of carbon, hydrogen, nitrogen, sulfur, and oxygen in charcoal produced from eucalyptus woods.

Experiment	% Carbon	% Hydrogen	% Nitrogen	% Sulfur	% Oxygen
1	81.123	1.808	0.408	0.013	9.882
2	82.076	1.847	0.380	0.009	9.833
3	82.174	1.869	0.400	0.011	8.869
4	83.397	1.882	0.389	0.015	9.089
5	83.618	1.895	0.341	0.013	8.997
6	84.340	1.897	0.373	0.019	9.220
7	84.508	1.909	0.388	0.017	8.448
8	84.770	1.917	0.349	0.010	9.631
9	85.440	1.946	0.374	0.009	9.473
10	85.796	1.965	0.321	-	9.854
Mean	83.724	1.894	0.372	0.013	9.330
S.D.	1.539	0.046	0.027	0.004	0.485
Min	81.123	1.808	0.321	0.009	8.448
Max	85.796	1.965	0.408	0.019	9.882
Median	83.979	1.896	0.377	0.013	9.347

Table A.2 Percent of carbon, hydrogen, nitrogen, sulfur, and oxygen in charcoal produced from jackfruit woods.

Experiment	**% Carbon**	**% Hydrogen**	**% Nitrogen**	**% Sulfur**	**% Oxygen**
1	84.336	1.782	0.713	0.038	9.927
2	84.521	1.801	0.695	0.037	9.331
3	84.684	1.879	0.704	0.033	10.260
4	85.187	1.836	0.704	0.036	8.655
5	85.645	1.720	0.706	0.034	8.427
6	85.819	1.708	0.616	0.039	9.391
7	85.881	1.694	0.644	0.036	9.833
8	85.979	1.706	0.703	0.037	9.308
9	86.510	1.706	0.703	0.037	9.014
10	86.619	1.778	0.839	0.036	9.355
Mean	85.518	1.761	0.703	0.036	9.350
S.D.	0.806	0.064	0.057	0.085	0.562
Min	84.336	1.694	0.616	0.033	8.427
Max	86.619	1.879	0.839	0.306	10.260
Median	85.732	1.749	0.704	0.037	9.343

Step 1: Convert the percentage of carbon, hydrogen, nitrogen, sulfur, and oxygen to moles

Each element was converted the percentage of carbon, hydrogen, nitrogen, sulfur, and oxygen to moles. Charcoal produced from eucalyptus woods had sulfur content lower than other elements. Therefore, sulfur content of 0.0004 was used to normalize the relative amount of mole to equal an integer. Then, 2500 was used as multiplier. For charcoal derived from jackfruit woods, mole of sulfur was 0.002 and yielded the multiplier of 500, more information in Tables A.3 and A.4.

The general flowchart for solving empirical formulas from known mass percentages is:

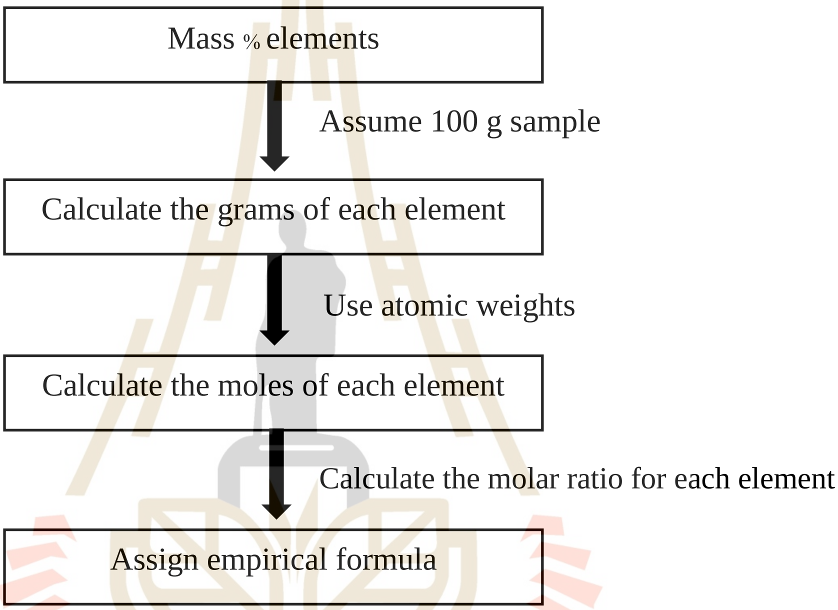


Figure A.1 Flowchart for solving empirical formulas from known mass percentages.

Table A.3 Shows mole of carbon, hydrogen, nitrogen, sulfur, and oxygen for charcoal produced from eucalyptus.

Element	Percent of element	Conversion formula	Amount of moles in each element	Normalized mole ratios
Carbon	83.724	mol = (mass %)/mw	$\frac{83.724}{12} = 6.977$	17,442.5
Hydrogen	1.894	mol = (mass %)/mw	$\frac{1.894}{1} = 1.894$	4,735
Nitrogen	0.372	mol = (mass %)/mw	$\frac{0.372}{14} = 0.027$	67.5
Sulfur	0.013	mol = (mass %)/mw	$\frac{0.013}{32} = 0.0004$	1
Oxygen	9.330	mol = (mass %)/mw	$\frac{9.330}{16} = 0.583$	1,457.5

Table A.4 Shows mole of carbon, hydrogen, nitrogen, sulfur, and oxygen for charcoal produced from jackfruit.

Element	Percent of element	Conversion formula	Amount of moles in each element	Normalized mole ratios
Carbon	85.518	mol = (mass %)/mw	$\frac{85.518}{12} = 7.127$	3,563
Hydrogen	1.761	mol = (mass %)/mw	$\frac{1.761}{1} = 1.761$	880
Nitrogen	0.703	mol = (mass %)/mw	$\frac{0.703}{14} = 0.050$	25
Sulfur	0.063	mol = (mass %)/mw	$\frac{0.063}{32} = 0.002$	1
Oxygen	9.350	mol = (mass %)/mw	$\frac{9.350}{16} = 0.584$	292

Step 2: Add moles of each element to the balance chemical equation for charcoal combustion.

The chemical formulas without nitrogen and sulfur are:

- Charcoal produced from eucalyptus: $C_{17443}H_{4735}O_{1458}$
- Charcoal produced from jackfruit: $C_{3563}H_{880}O_{292}$

The chemical formulas without sulfur are:

- Charcoal produced from eucalyptus: $C_{17443}H_{4735}N_{68}O_{1458}$
- Charcoal produced from jackfruit: $C_{3563}H_{880}N_{25}O_{292}$

The chemical formulas with all values are:

- Charcoal produced from eucalyptus: $C_{17443}H_{4735}N_{68}SO_{1458}$
- Charcoal produced from jackfruit: $C_{3563}H_{880}N_{25}SO_{292}$

Step 3: Calculating maximum CO_2 from balanced chemical equation

A general equation for the combustion of a simple hydrocarbon in air

$$C_xH_y + \frac{(4x+y)O_2}{4} \Rightarrow xCO_2 + \left(\frac{y}{2}\right)H_2O$$

where: x and y are the number of atoms of carbon and hydrogen in the fuel.

Complete combustion of a simple hydrocarbon C_xH_y produces a fixed amount of carbon dioxide. If the theoretical air is used (i.e. excess air is zero) the concentration of CO_2 in the exhaust is at the maximum concentration. To calculate the maximum CO_2 concentration assumes water condenses out leaving only CO_2 and N_2 (from the air) as gases in the exhaust stream by using the equation below for a simple hydrocarbon. The maximum CO_2 calculated from balanced chemical equation is showed in Tables A.5 and A.6.

$$\%CO_2max = \frac{molesCO_2}{(molesCO_2 + molesN_2)} \times 100$$

$$molesCO_2 = xmoles$$

$$molesN_2 = \frac{(4x + y) \times 3.76}{4}$$

Table A.5 Calculating CO_2 max from the carbon content (Eucalyptus)**.**

Equation			$\%CO_2$ max
$C_xH_y + \frac{(4x+y)O_2}{4} \Rightarrow xCO_2 + \left(\frac{y}{2}\right)H_2O$	$C_{17443}H_{4735} + 18626.75O_2 \Rightarrow 17443CO_2 + 2367.5H_2O$	$\%CO_2max = \frac{molesCO_2}{(molesCO_2 + molesN_2)} \times 100$ $molesCO_2 = xmoles$ $molesN_2 = \frac{(4x+y) \times 3.76}{4}$	**19.94**
$C_xH_y + z(O_2 + 3.76N_2) \Rightarrow xCO_2 + yH_2O + zN_2$	$C_{17443}H_{4735} + 18626.75(O_2 + 3.76N_2) \Rightarrow 17443CO_2 + 2367.5H_2O + 70036.58N_2$	$\%CO_2max = \frac{molesCO_2}{(molesCO_2 + molesN_2)} \times 100$ $molesCO_2 = xmoles$ $molesN_2 = \frac{(4x+y) \times 3.76}{4}$	**19.94**
$aC + bH_2 + cS + dO_2 + eN_2 + fO_2 + (3.76)gN_2 \Rightarrow hCO_2 + iSO_2 + jCO + kO_2 + lN_2 + mH_2O$	$17443C + 4735H_2 + S + 1458O_2 + 68N_2 + 13993.75O_2 + (3.76)N_2 \Rightarrow 8721.5CO_2 + SO_2 + 8721.5CO + O_2 + 71.76N_2 + 4735H_2O$	$\%CO_2max = \frac{molesCO_2}{(molesCO_2 + molesN_2)} \times 100$ $molesCO_2 = xmoles$ $molesN_2 = \frac{(4x+y) \times 3.76}{4}$	**11.07**

Table A.6 Calculating CO_2 max from the carbon content (Jackfruit).

Equation			%CO_2 max
$C_xH_y + \frac{(4x+y)O_2}{4} \Rightarrow xCO_2 + \left(\frac{y}{2}\right)H_2O$	$C_{3563}H_{880} + 3783O_2 \Rightarrow 3563CO_2 + 440H_2O$	$\%CO_2 max = \frac{molesCO_2}{(molesCO_2 + molesN_2)} \times 100$ $molesCO_2 = xmoles$ $molesN_2 = \frac{(4x+y) \times 3.76}{4}$	**20.03**
$C_xH_y + z(O_2 + 3.76N_2) \Rightarrow$ $xCO_2 + yH_2O + zN_2$	$C_{3563}H_{880} + 3783(O_2 + 3.76N_2) \Rightarrow$ $3563CO_2 + 440H_2O + 14224.08N_2$	$\%CO_2 max = \frac{molesCO_2}{(molesCO_2 + molesN_2)} \times 100$ $molesCO_2 = xmoles$ $molesN_2 = \frac{(4x+y) \times 3.76}{4}$	**20.03**
$aC + bH_2 + cS + dO_2 + eN_2 + fO_2 + (3.76)gN_2 \Rightarrow$ $hCO_2 + iSO_2 + jCO + kO_2 + lN_2 + mH_2O$	$3563C + 880H_2 + S + 292O_2 + 25N_2 + 2822.25O_2 + (3.76)N_2 \Rightarrow$ $1781.5CO_2 + SO_2 + 1781.5CO + O_2 + 28.76N_2 + 880H_2O$	$\%CO_2 max = \frac{molesCO_2}{(molesCO_2 + molesN_2)} \times 100$ $molesCO_2 = xmoles$ $molesN_2 = \frac{(4x+y) \times 3.76}{4}$	**11.13**

Step 4 and 5: Entering the value of maximum CO_2 and O_2 on Testo 350 and setting four difference charcoal coefficients.

Enter the value of maximum CO_2 and O_2 on Testo 350 for setting instrument prior to the experiment. Setting charcoal coefficients for charcoal produced from eucalyptus as shown in Table 7.A

Table 7.A Eucalyptus charcoal coefficients used with Testo® 350

Parameter	Charcoal coefficients
O_2	9.3
CO_2 max	19.93
VAG	-
Hu	-
VL_{min}	-
H_2O max	6.3
K_{gr}	-
K_{net}	-
K_1	-
Q_{gr}	-
Q_{net}	29.85
H	1.87

APPENDIX B

THE RATE OF EMISSIONS FOR DIFFERENT TYPES OF MEAT GRILLING

Table B.1 Descriptive statistics of the rate CO emissions of meat grilling.

Meat	Stage	Rate of CO emissions (ppm/sec)					
		N	**Mean**	**S.D.**	**Min**	**Max**	**Median**
Pork	Whole stage (0-20 min)	5	153.03	12.86	138.41	170.11	150.67
	Ignition stage (0-3 min)	5	74.34	40.27	33.67	127.97	86.12
	Smoldering stage (3-10 min)	5	146.45	18.93	115.89	167.02	147.66
	Flaming stage (10-20 min)	5	181.25	6.82	172.14	187.92	184.91
Chicken	Whole stage (0-20 min)	6	167.45	8.59	156.80	178.61	165.54
	Ignition stage (0-3 min)	6	93.49	10.64	81.01	111.19	93.72
	Smoldering stage (3-10 min)	6	154.18	13.05	136.46	167.44	157.62
	Flaming stage (10-20 min)	6	198.93	9.78	188.57	215.44	198.61
Chicken wing	Whole stage (0-20 min)	9	159.26	19.60	136.88	185.64	152.78
	Ignition stage (0-3 min)	9	85.78	17.61	49.13	104.14	92.97
	Smoldering stage (3-10 min)	9	145.69	26.58	103.60	185.59	142.38
	Flaming stage (10-20 min)	9	190.80	28.58	144.61	226.87	189.32
Chicken liver	Whole stage (0-20 min)	7	166.13	5.95	159.16	175.70	162.85
	Ignition stage (0-3 min)	7	94.47	40.41	32.76	150.83	97.21
	Smoldering stage (3-10 min)	7	172.84	17.98	155.54	201.98	169.51
	Flaming stage (10-20 min)	7	182.93	12.53	162.23	200.19	180.91

Table B.1 Descriptive statistics of the rate CO emissions of meat grilling (Continued).

Meat	Stage	Rate of CO emissions (ppm/sec)					
		N	**Mean**	**S.D.**	**Min**	**Max**	**Median**
Catfish	Whole stage (0-20 min)	7	126.40	10.32	117.26	141.76	120.54
	Ignition stage (0-3 min)	7	39.89	20.86	13.01	65.41	38.39
	Smoldering stage (3-10 min)	7	103.43	21.66	82.65	139.76	92.77
	Flaming stage (10-20 min)	7	168.43	6.19	155.75	173.49	170.51
Ruby fish	Whole stage (0-20 min)	8	130.96	9.83	120.37	144.79	128.48
	Ignition stage (0-3 min)	8	43.14	12.77	25.57	65.46	42.39
	Smoldering stage (3-10 min)	8	115.95	14.76	89.34	138.45	117.35
	Flaming stage (10-20 min)	8	167.81	17.74	146.96	188.56	163.53
Tilapia	Whole stage (0-20 min)	5	135.44	25.64	105.91	167.85	141.29
	Ignition stage (0-3 min)	5	33.03	11.60	18.76	46.23	34.63
	Smoldering stage (3-10 min)	5	112.62	40.18	56.86	167.32	115.22
	Flaming stage (10-20 min)	5	182.15	31.21	132.38	211.41	189.42
Shrimp	Whole stage (0-15 min)	7	170.02	15.36	146.05	188.90	178.26
	Ignition stage (0-3 min)	7	102.65	26.10	69.76	136.27	101.85
	Smoldering stage (3-10 min)	7	172.10	19.34	132.47	190.20	176.26
	Flaming stage (10-15 min)	7	207.54	10.98	196.48	227.54	208.69
Squid	Whole stage (0-15 min)	9	152.64	12.24	130.31	167.15	157.46
	Ignition stage (0-3 min)	9	86.50	39.39	26.27	160.25	96.16
	Smoldering stage (3-10 min)	9	155.73	16.59	123.43	179.99	153.70
	Flaming stage (10-15 min)	9	188.01	24.78	149.71	221.79	190.40
Thai sausage	Whole stage (0-20 min)	7	115.58	20.35	82.74	144.96	113.11
	Ignition stage (0-3 min)	7	29.54	14.46	9.42	48.17	29.54
	Smoldering stage (3-10 min)	7	98.53	29.07	63.71	148.85	99.91
	Flaming stage (10-20 min)	7	153.32	30.74	110.03	184.14	170.03

Table B.1 Descriptive statistics of the rate CO emissions of meat grilling (Continued).

Meat	Stage	Rate of CO emissions (ppm/sec)					
		N	Mean	S.D.	Min	Max	Median
Thai sour pork	Whole stage (0-20 min)	6	180.39	29.43	137.64	222.34	184.09
	Ignition stage (0-3 min)	6	112.22	16.37	90.96	130.43	111.91
	Smoldering stage (3-10 min)	6	174.41	21.56	158.32	208.30	162.33
	Flaming stage (10-20 min)	6	205.03	47.02	134.59	262.90	216.21
Meatball	Whole stage (0-15 min)	8	173.93	19.99	150.82	212.66	173.65
	Ignition stage (0-3 min)	8	125.33	29.96	90.71	184.89	115.41
	Smoldering stage (3-10 min)	8	173.69	22.42	145.04	216.66	171.19
	Flaming stage (10-15 min)	8	203.43	32.09	152.30	253.82	202.58
Pork ball	Whole stage (0-15 min)	9	157.97	23.88	132.79	200.09	164.05
	Ignition stage (0-3 min)	9	91.20	29.96	61.88	146.84	78.59
	Smoldering stage (3-10 min)	9	156.09	33.46	122.46	215.52	163.55
	Flaming stage (10-15 min)	9	200.68	13.18	181.12	223.98	202.88
Fish ball	Whole stage (0-15 min)	6	170.27	6.63	165.13	180.63	167.02
	Ignition stage (0-3 min)	6	103.37	12.67	89.47	119.83	101.43
	Smoldering stage (3-10 min)	6	168.68	5.06	163.05	177.69	168.37
	Flaming stage (10-15 min)	6	212.63	14.67	191.97	232.56	212.16
Chicken ball	Whole stage (0-15 min)	5	134.59	21.16	100.99	158.26	140.67
	Ignition stage (0-3 min)	5	64.94	30.90	33.37	112.37	66.20
	Smoldering stage (3-10 min)	5	128.03	16.24	103.86	143.79	133.43
	Flaming stage (10-15 min)	5	185.57	27.67	137.54	206.04	195.50

N = Sample size

Table B.2 Descriptive statistics of the rate NO_x emissions of meat grilling.

Meat	Stage	Rate of NO_x emissions (ppm/sec)					
		N	Mean	S.D.	Min	Max	Median
Pork	Whole stage (0-20 min)	4	0.261	0.192	0.059	0.501	0.241
	Ignition stage (0-3 min)	4	0.025	0.024	0.002	0.056	0.021
	Smoldering stage (3-10 min)	4	0.233	0.207	0.027	0.506	0.199
	Flaming stage (10-20 min)	4	0.351	0.232	0.098	0.631	0.337
Chicken	Whole stage (0-20 min)	7	0.345	0.193	0.126	0.537	0.193
	Ignition stage (0-3 min)	7	0.060	0.050	0.006	0.139	0.050
	Smoldering stage (3-10 min)	7	0.199	0.126	0.061	0.360	0.126
	Flaming stage (10-20 min)	7	0.533	0.295	0.208	0.821	0.295
Chicken wing	Whole stage (0-20 min)	8	0.248	0.091	0.094	0.364	0.239
	Ignition stage (0-3 min)	8	0.064	0.065	0.001	0.180	0.055
	Smoldering stage (3-10 min)	8	0.150	0.082	0.049	0.262	0.141
	Flaming stage (10-20 min)	8	0.372	0.137	0.142	0.563	0.351
Chicken liver	Whole stage (0-20 min)	6	0.190	0.188	0.037	0.551	0.137
	Ignition stage (0-3 min)	6	0.019	0.018	0.002	0.044	0.014
	Smoldering stage (3-10 min)	6	0.147	0.212	0.007	0.570	0.063
	Flaming stage (10-20 min)	6	0.272	0.239	0.069	0.689	0.208
Catfish	Whole stage (0-20 min)	5	0.038	0.026	0.003	0.071	0.040
	Ignition stage (0-3 min)	5	ND	ND	ND	ND	ND
	Smoldering stage (3-10 min)	5	ND	ND	ND	ND	ND
	Flaming stage (10-20 min)	5	0.075	0.051	0.006	0.143	0.080
Ruby fish	Whole stage (0-20 min)	4	0.020	0.014	0.003	0.035	0.021
	Ignition stage (0-3 min)	4	ND	ND	ND	ND	ND
	Smoldering stage (3-10 min)	4	ND	ND	ND	ND	ND
	Flaming stage (10-20 min)	4	0.040	0.027	0.005	0.071	0.042

Table B.2 Descriptive statistics of the rate NO_x emissions of meat grilling (Continued).

Meat	Stage	Rate of NO_x emissions (ppm/sec)					
		N	Mean	S.D.	Min	Max	Median
Tilapia	Whole stage (0-20 min)	4	0.051	0.025	0.028	0.078	0.050
	Ignition stage (0-3 min)	4	0.002	0.002	0.001	0.004	0.001
	Smoldering stage (3-10 min)	4	0.036	0.020	0.014	0.057	0.036
	Flaming stage (10-20 min)	4	0.077	0.036	0.046	0.116	0.073
Shrimp	Whole stage (0-15 min)	5	0.065	0.053	0.012	0.148	0.060
	Ignition stage (0-3 min)	5	ND	ND	ND	ND	ND
	Smoldering stage (3-10 min)	5	0.024	0.023	0.000	0.046	0.027
	Flaming stage (10-15 min)	5	0.161	0.143	0.036	0.379	0.115
Squid	Whole stage (0-15 min)	5	0.071	0.031	0.037	0.100	0.089
	Ignition stage (0-3 min)	5	0.005	0.006	0.001	0.016	0.003
	Smoldering stage (3-10 min)	5	0.055	0.021	0.029	0.084	0.055
	Flaming stage (10-15 min)	5	0.134	0.068	0.059	0.209	0.147
Thai sausage	Whole stage (0-20 min)	5	0.029	0.010	0.019	0.046	0.027
	Ignition stage (0-3 min)	5	ND	ND	ND	ND	ND
	Smoldering stage (3-10 min)	5	ND	ND	ND	ND	ND
	Flaming stage (10-20 min)	5	0.058	0.021	0.039	0.092	0.054
Thai sour pork	Whole stage (0-20 min)	4	0.119	0.063	0.035	0.177	0.133
	Ignition stage (0-3 min)	4	0.023	0.016	0.004	0.037	0.025
	Smoldering stage (3-10 min)	4	0.111	0.029	0.085	0.138	0.110
	Flaming stage (10-20 min)	4	0.155	0.106	0.005	0.249	0.182

Table B.2 Descriptive statistics of the rate NO_x emissions of meat grilling (Continued).

Meat	Stage	Rate of NO_x emissions (ppm/sec)					
		N	**Mean**	**S.D.**	**Min**	**Max**	**Median**
Meatball	Whole stage (0-15 min)	8	0.053	0.023	0.017	0.088	0.053
	Ignition stage (0-3 min)	8	ND	ND	ND	ND	ND
	Smoldering stage (3-10 min)	8	0.036	0.024	0.002	0.071	0.038
	Flaming stage (10-15 min)	8	0.109	0.050	0.048	0.179	0.107
Pork ball	Whole stage (0-15 min)	4	0.057	0.030	0.013	0.079	0.068
	Ignition stage (0-3 min)	4	0.006	0.003	0.003	0.009	0.006
	Smoldering stage (3-10 min)	4	0.044	0.028	0.003	0.065	0.054
	Flaming stage (10-15 min)	4	0.105	0.060	0.031	0.167	0.112
Fish ball	Whole stage (0-15 min)	4	0.035	0.015	0.019	0.049	0.035
	Ignition stage (0-3 min)	4	ND	ND	ND	ND	ND
	Smoldering stage (3-10 min)	4	0.014	0.012	0.003	0.029	0.012
	Flaming stage (10-15 min)	4	0.084	0.032	0.049	0.122	0.084
Chicken ball	Whole stage (0-15 min)	3	0.033	0.029	0.0004	0.057	0.042
	Ignition stage (0-3 min)	3	ND	ND	ND	ND	ND
	Smoldering stage (3-10 min)	3	0.012	0.010	0.0007	0.021	0.014
	Flaming stage (10-15 min)	3	0.084	0.074	0.0003	0.143	0.108

N = Sample size

$NO_x = NO + NO_2$

ND - none detected (<0.00 ppm NO_x)

Measurement range for NO of Testo 350 was 0 to 4000 ppm

Measurement range for NO_2 of Testo 350 was 0 to 500 ppm

Table B.3 Descriptive statistics of the rate CO_2 emissions of meat grilling.

Meat	Stage	Rate of CO_2 emissions (ppm/sec)					
		N	**Mean**	**S.D.**	**Min**	**Max**	**Median**
Pork	Whole stage (0-20 min)	7	1,519.06	324.86	996.50	1,927.08	1,469.33
	Ignition stage (0-3 min)	7	594.13	232.51	330.00	869.44	688.33
	Smoldering stage (3-10 min)	7	1,303.44	364.62	773.57	1,735.48	1,351.67
	Flaming stage (10-20 min)	7	1,947.48	357.78	1,339.17	2,410.67	1,893.50
Chicken	Whole stage (0-20 min)	5	1,569.63	101.34	1,415.08	1,681.83	1,604.25
	Ignition stage (0-3 min)	5	846.89	177.43	636.67	1,118.33	837.78
	Smoldering stage (3-10 min)	5	1,303.48	216.50	1,022.14	1,615.24	1,269.29
	Flaming stage (10-20 min)	5	1,972.77	78.81	1,897.50	2,089.33	1,937.00
Chicken wing	Whole stage (0-20 min)	8	1,370.44	141.85	1,141.25	1,538.92	1,378.83
	Ignition stage (0-3 min)	8	731.67	106.15	601.11	940.56	738.89
	Smoldering stage (3-10 min)	8	1,150.71	202.26	880.24	1,410.24	1,132.86
	Flaming stage (10-20 min)	8	1,715.88	199.98	1,440.50	2,075.50	1,722.67
Chicken liver	Whole stage (0-20 min)	6	1,392.46	12.66	1,378.17	1,410.42	1,393.25
	Ignition stage (0-3 min)	6	576.02	210.20	323.89	808.89	583.06
	Smoldering stage (3-10 min)	6	1,240.20	117.32	1,124.29	1,404.52	1,221.90
	Flaming stage (10-20 min)	6	1,743.97	69.68	1,644.67	1,824.00	1,732.33
Catfish	Whole stage (0-20 min)	8	1,120.22	165.37	908.00	1,333.25	1,181.17
	Ignition stage (0-3 min)	8	251.39	145.28	77.78	477.78	246.94
	Smoldering stage (3-10 min)	8	755.98	157.92	548.33	974.29	759.88
	Flaming stage (10-20 min)	8	1,635.83	222.89	1,290.83	1,855.50	1,730.75
Ruby fish	Whole stage (0-20 min)	7	1,095.76	137.86	864.75	1,282.58	1,098.08
	Ignition stage (0-3 min)	7	399.68	42.17	327.78	457.78	401.11
	Smoldering stage (3-10 min)	7	832.45	143.05	600.00	1,015.48	869.29
	Flaming stage (10-20 min)	7	1,488.90	201.87	1,192.00	1,774.50	1,512.50

Table B.3 Descriptive statistics of the rate CO_2 emissions of meat grilling (Continued).

Meat	Stage	Rate of CO_2 emissions (ppm/sec)					
		N	**Mean**	**S.D.**	**Min**	**Max**	**Median**
Tilapia	Whole stage (0-20 min)	5	1,217.95	169.76	986.33	1,436.67	1,227.42
	Ignition stage (0-3 min)	5	341.22	191.16	146.11	649.44	300.00
	Smoldering stage (3-10 min)	5	991.86	227.10	746.19	1,303.81	969.29
	Flaming stage (10-20 min)	5	1,639.23	202.57	1,360.33	1,889.00	1,590.83
Shrimp	Whole stage (0-15 min)	9	1,350.51	119.44	1,208.00	1,532.00	1,329.22
	Ignition stage (0-3 min)	9	744.51	122.96	565.56	929.44	758.33
	Smoldering stage (3-10 min)	9	1,289.15	117.31	1,120.00	1,485.71	1,253.57
	Flaming stage (10-15 min)	9	1,800.00	191.79	1,531.33	2,098.00	1,764.33
Squid	Whole stage (0-15 min)	8	1,316.44	135.16	1,134.67	1,551.56	1,319.17
	Ignition stage (0-3 min)	8	672.50	309.25	273.33	1,215.56	679.44
	Smoldering stage (3-10 min)	8	1,245.57	204.45	965.00	1,557.38	1,226.90
	Flaming stage (10-15 min)	8	1,802.04	121.08	1,641.33	2,005.33	1,784.50
Thai sausage	Whole stage (0-20 min)	8	1,065.08	190.91	788.75	1,586.83	1,075.08
	Ignition stage (0-3 min)	8	310.00	146.66	103.89	1,664.44	303.61
	Smoldering stage (3-10 min)	8	797.26	210.94	529.05	1,609.05	750.95
	Flaming stage (10-20 min)	8	1,479.08	235.89	1,127.33	1,761.00	1,554.42
Thai sour pork	Whole stage (0- 20min)	4	1,359.52	124.30	1,271.42	1,539.00	1,313.83
	Ignition stage (0-3 min)	4	680.14	49.20	611.11	727.78	690.83
	Smoldering stage (3-10 min)	4	1,170.77	136.10	1,045.48	1,341.90	1,147.86
	Flaming stage (10-20 min)	4	1,695.46	186.53	1,483.67	1,920.33	1,688.92
Meatball	Whole stage (0-15 min)	9	1,395.91	197.63	1,122.56	1,682.33	1,425.44
	Ignition stage (0-3 min)	9	785.99	172.65	510.56	1,058.33	785.00
	Smoldering stage (3-10 min)	9	1,341.88	218.84	1,069.76	1,738.33	1,275.71
	Flaming stage (10-15 min)	9	1,837.52	233.13	1,528.33	2,081.00	1,956.67

Table B.3 Descriptive statistics of the rate CO_2 emissions of meat grilling (Continued).

Meat	Stage	Rate of CO_2 emissions (ppm/sec)					
		N	Mean	S.D.	Min	Max	Median
Pork ball	Whole stage (0-15 min)	8	1,090.56	213.30	824.89	1,491.33	1,071.94
	Ignition stage (0-3 min)	8	593.68	185.17	427.78	951.11	501.94
	Smoldering stage (3-10 min)	8	1,020.21	239.87	756.67	1,508.33	997.86
	Flaming stage (10-15 min)	8	1,487.17	215.04	1,158.67	1,791.67	1,541.33
Fish ball	Whole stage (0-15 min)	9	1,316.62	212.76	981.56	1,605.56	1,241.33
	Ignition stage (0-3 min)	9	683.89	61.78	590.00	772.22	700.00
	Smoldering stage (3-10 min)	9	1,217.83	223.40	828.10	1,558.57	1,170.71
	Flaming stage (10-15 min)	9	1,834.56	307.14	1,431.33	2,281.00	1,760.00
Chicken ball	Whole stage (0-15 min)	5	841.31	195.94	569.89	1,092.00	851.00
	Ignition stage (0-3 min)	5	401.44	71.23	321.11	492.78	400.00
	Smoldering stage (3-10 min)	5	746.81	124.51	552.86	858.10	800.95
	Flaming stage (10-15 min)	5	1,237.53	441.50	695.67	1,911.67	1,162.33

N = Sample size

Table B.4 Descriptive statistics of the rate CH_4 emissions of meat grilling.

Meat	Stage	Rate of CH_4 emissions (ppm/sec)					
		N	Mean	S.D.	Min	Max	Median
Pork	Whole stage (0-20 min)	6	0.31	0.07	0.23	0.43	0.30
	Ignition stage (0-3 min)	6	0.87	0.40	0.48	1.41	0.84
	Smoldering stage (3-10 min)	6	0.25	0.04	0.20	0.31	0.25
	Flaming stage (10-20 min)	6	0.19	0.07	0.11	0.31	0.18

Table B.4 Descriptive statistics of the rate CH_4 emissions of meat grilling (Continued).

Meat	Stage	Rate of CH_4 emissions (ppm/sec)					
		N	Mean	S.D.	Min	Max	Median
Chicken	Whole stage (0-20 min)	5	0.25	0.03	0.23	0.29	0.24
	Ignition stage (0-3 min)	5	0.40	0.24	0.17	0.76	0.39
	Smoldering stage (3-10 min)	5	0.27	0.04	0.21	0.30	0.29
	Flaming stage (10-20 min)	5	0.20	0.02	0.18	0.22	0.20
Chicken wing	Whole stage (0-20 min)	9	0.26	0.07	0.14	0.38	0.24
	Ignition stage (0-3 min)	9	0.58	0.37	0.16	1.15	0.45
	Smoldering stage (3-10 min)	9	0.27	0.06	0.17	0.35	0.26
	Flaming stage (10-20 min)	9	0.17	0.05	0.12	0.24	0.14
Chicken liver	Whole stage (0-20 min)	6	0.42	0.03	0.38	0.46	0.41
	Ignition stage (0-3 min)	6	0.85	0.23	0.47	1.17	0.83
	Smoldering stage (3-10 min)	6	0.43	0.11	0.25	0.59	0.44
	Flaming stage (10-20 min)	6	0.28	0.05	0.23	0.37	0.26
Catfish	Whole stage (0-20 min)	7	0.23	0.17	0.04	0.34	0.31
	Ignition stage (0-3 min)	7	0.41	0.23	0.04	0.73	0.37
	Smoldering stage (3-10 min)	7	0.36	0.06	0.26	0.47	0.37
	Flaming stage (10-20 min)	7	0.33	0.06	0.24	0.39	0.33
Ruby fish	Whole stage (0-20 min)	6	0.30	0.03	0.26	0.33	0.32
	Ignition stage (0-3 min)	6	0.38	0.12	0.26	0.55	0.38
	Smoldering stage (3-10 min)	6	0.30	0.04	0.24	0.34	0.30
	Flaming stage (10-20 min)	6	0.29	0.06	0.20	0.38	0.28

Table B.4 Descriptive statistics of the rate CH_4 emissions of meat grilling (Continued).

Meat	Stage	Rate of CH_4 emissions (ppm/sec)					
		N	**Mean**	**S.D.**	**Min**	**Max**	**Median**
Tilapia	Whole stage (0-20 min)	6	0.30	0.06	0.24	0.39	0.30
	Ignition stage (0-3 min)	6	0.32	0.15	0.06	0.47	0.34
	Smoldering stage (3-10 min)	6	0.33	0.06	0.26	0.41	0.34
	Flaming stage (10-20 min)	6	0.28	0.06	0.19	0.39	0.27
Shrimp	Whole stage (0-15 min)	9	0.47	0.12	0.30	0.63	0.47
	Ignition stage (0-3 min)	9	0.93	0.28	0.57	1.37	1.02
	Smoldering stage (3-10 min)	9	0.38	0.13	0.20	0.53	0.38
	Flaming stage (10-15 min)	9	0.32	0.10	0.19	0.52	0.30
Squid	Whole stage (0-15 min)	9	0.45	0.14	0.24	0.62	0.45
	Ignition stage (0-3 min)	9	0.85	0.22	0.56	1.19	0.87
	Smoldering stage (3-10 min)	9	0.39	0.17	0.14	0.62	0.37
	Flaming stage (10-15 min)	9	0.29	0.12	0.12	0.52	0.26
Thai sausage	Whole stage (0-20 min)	5	0.34	0.005	0.33	0.34	0.34
	Ignition stage (0-3 min)	5	0.42	0.12	0.28	0.58	0.46
	Smoldering stage (3-10 min)	5	0.37	0.07	0.30	0.48	0.38
	Flaming stage (10-20 min)	5	0.29	0.05	0.25	0.38	0.27
Thai sour pork	Whole stage (0-20 min)	8	0.45	0.10	0.30	0.62	0.45
	Ignition stage (0-3 min)	8	0.97	0.48	0.43	1.69	0.94
	Smoldering stage (3-10 min)	8	0.39	0.11	0.26	0.61	0.40
	Flaming stage (10-20 min)	8	0.33	0.15	0.10	0.55	0.32

Table B.4 Descriptive statistics of the rate CH_4 emissions of meat grilling (Continued).

Meat	Stage	Rate of CH_4 emissions (ppm/sec)					
		N	Mean	S.D.	Min	Max	Median
Meatball	Whole stage (0-15 min)	8	0.47	0.11	0.25	0.62	0.47
	Ignition stage (0-3 min)	8	1.00	0.28	0.60	1.38	1.03
	Smoldering stage (3-10 min)	8	0.37	0.10	0.21	0.51	0.36
	Flaming stage (10-15 min)	8	0.29	0.13	0.10	0.51	0.31
Pork ball	Whole stage (0-15 min)	8	0.46	0.07	0.39	0.58	0.45
	Ignition stage (0-3 min)	8	0.76	0.17	0.53	1.05	0.79
	Smoldering stage (3-10 min)	8	0.38	0.08	0.28	0.49	0.38
	Flaming stage (10-15 min)	8	0.40	0.09	0.26	0.53	0.41
Fish ball	Whole stage (0-15 min)	6	0.46	0.05	0.38	0.52	0.47
	Ignition stage (0-3 min)	6	0.92	0.14	0.70	1.12	0.91
	Smoldering stage (3-10 min)	6	0.36	0.05	0.31	0.46	0.35
	Flaming stage (10-15 min)	6	0.33	0.08	0.28	0.49	0.30
Chicken ball	Whole stage (0-15 min)	7	0.40	0.08	0.29	0.50	0.42
	Ignition stage (0-3 min)	7	0.64	0.41	0.04	1.25	0.63
	Smoldering stage (3-10 min)	7	0.34	0.06	0.25	0.41	0.34
	Flaming stage (10-15 min)	7	0.35	0.16	0.15	0.54	0.40

N = Sample size

APPENDIX C

DESCRIPTIVE STATISTIC OF PARTICLE MASS CONCENTRATIONS OF MEAT GRILLING:

Table C.1 Descriptive statistics of particle mass concentrations of meat grilling.

Meat		**particle mass concentration (µm) (mg/m^3)**								
		9.0-10	**5.8-9.0**	**4.7-5.8**	**3.3-4.7**	**2.1-3.3**	**1.1-2.1**	**0.7-1.1**	**0.4-0.7**	**<0.4**
Pork	Median	3.58	2.53	2.34	2.61	2.56	2.52	3.76	6.23	2.98
	Max	3.87	3.04	2.87	2.82	2.58	2.74	6.06	14.15	5.10
	Min	3.01	2.31	1.11	2.33	1.84	2.40	2.72	5.83	2.11
	Mean	3.52	2.60	2.15	2.60	2.34	2.52	3.99	8.12	3.07
	SD	0.33	0.27	0.69	0.19	0.33	0.14	1.26	3.50	1.22
	N	5	5	5	5	5	5	5	5	5

Table C.1 Descriptive statistics of particle mass concentrations of meat grilling (Continued).

Meat		**particle mass concentration (µm) (mg/m³)**								
		9.0-10	**5.8-9.0**	**4.7-5.8**	**3.3-4.7**	**2.1-3.3**	**1.1-2.1**	**0.7-1.1**	**0.4-0.7**	**<0.4**
Chicken	Median	3.30	2.83	2.50	2.46	2.37	2.85	4.25	10.03	3.71
	Max	4.26	3.44	3.30	3.02	2.88	4.55	6.59	15.04	5.67
	Min	2.77	2.55	2.15	1.97	2.10	2.30	2.66	7.69	1.85
	Mean	3.44	2.86	2.61	2.43	2.46	3.10	4.64	10.93	3.72
	SD	0.53	0.33	0.40	0.39	0.27	0.82	1.53	2.94	1.97
	N	6	6	6	6	6	6	6	6	6
Chicken wing	Median	4.30	3.10	2.73	2.53	2.21	3.21	4.34	10.63	2.33
	Max	5.17	3.78	3.11	3.40	3.02	3.70	5.14	14.94	6.50
	Min	3.18	1.95	1.96	1.48	1.34	1.64	2.62	8.40	1.35
	Mean	4.21	3.06	2.65	2.57	2.26	2.99	4.20	11.22	3.18
	SD	0.62	0.62	0.45	0.64	0.64	0.69	0.86	2.26	2.08
	N	7	7	7	7	7	7	7	7	7

Table C.1 Descriptive statistics of particle mass concentrations of meat grilling (Continued).

Meat		particle mass concentration (µm) (mg/m^3)								
		9.0-10	**5.8-9.0**	**4.7-5.8**	**3.3-4.7**	**2.1-3.3**	**1.1-2.1**	**0.7-1.1**	**0.4-0.7**	**<0.4**
Chicken liver	Median	2.50	2.04	2.13	1.99	1.64	1.72	2.06	3.99	1.02
	Max	2.81	2.60	2.34	2.53	2.46	2.21	3.29	4.55	2.26
	Min	2.29	1.84	1.80	1.55	1.27	1.09	1.26	2.26	0.87
	Mean	2.51	2.16	2.11	1.97	1.70	1.67	2.14	3.69	1.28
	SD	0.19	0.32	0.20	0.34	0.43	0.38	0.74	0.86	0.56
	N	6	6	6	6	6	6	6	6	6
Catfish	Median	2.80	2.71	2.11	2.14	2.08	1.67	2.20	4.37	1.30
	Max	3.18	3.21	2.31	2.16	2.59	1.87	3.63	6.61	1.39
	Min	2.27	2.27	1.96	2.01	1.61	1.29	1.73	3.43	1.00
	Mean	2.75	2.69	2.11	2.11	2.03	1.63	2.49	4.67	1.21
	SD	0.36	0.35	0.14	0.06	0.40	0.22	0.76	1.28	0.18
	N	5	5	5	5	5	5	5	5	5

Table C.1 Descriptive statistics of particle mass concentrations of meat grilling (Continued).

Meat		particle mass concentration (µm) (mg/m^3)								
		9.0-10	**5.8-9.0**	**4.7-5.8**	**3.3-4.7**	**2.1-3.3**	**1.1-2.1**	**0.7-1.1**	**0.4-0.7**	**<0.4**
Ruby fish	Median	2.02	1.53	1.20	1.18	1.13	1.24	2.03	3.51	0.64
	Max	2.22	1.97	1.60	1.72	1.36	1.71	4.34	5.06	1.11
	Min	1.43	1.44	1.00	1.02	0.60	0.81	0.84	1.53	0.05
	Mean	1.94	1.64	1.27	1.26	1.08	1.26	2.28	3.49	0.65
	SD	0.32	0.23	0.22	0.27	0.27	0.35	1.26	1.56	0.38
	N	6	6	6	6	6	6	6	6	6
Tilapia	Median	2.45	2.11	2.02	1.77	1.41	1.90	2.41	5.27	0.68
	Max	2.94	2.77	2.48	2.08	1.93	3.45	3.52	6.59	0.80
	Min	2.11	1.11	1.69	1.17	0.96	0.76	1.25	2.50	0.46
	Mean	2.50	2.05	2.05	1.70	1.45	1.85	2.39	4.90	0.66
	SD	0.36	0.61	0.29	0.35	0.37	0.94	0.81	1.65	0.11
	N	6	6	6	6	6	6	6	6	6

Table C.1 Descriptive statistics of particle mass concentrations of meat grilling (Continued).

Meat		particle mass concentration (µm) (mg/m^3)								
		9.0-10	**5.8-9.0**	**4.7-5.8**	**3.3-4.7**	**2.1-3.3**	**1.1-2.1**	**0.7-1.1**	**0.4-0.7**	**<0.4**
Shrimp	Median	4.08	2.22	3.38	2.83	2.62	1.46	1.82	3.06	1.11
	Max	4.57	4.19	4.30	3.40	3.68	2.77	2.76	5.48	2.48
	Min	2.41	1.89	1.99	1.58	0.66	0.57	1.35	1.34	0.77
	Mean	3.72	2.69	3.01	2.65	2.49	1.59	1.96	3.04	1.27
	SD	0.81	0.97	0.90	0.75	0.95	0.86	0.49	1.40	0.59
	N	7	7	7	7	7	7	7	7	7
Squid	Median	2.47	3.11	2.23	2.75	1.74	1.13	1.28	2.44	1.30
	Max	5.18	4.91	4.78	5.87	3.96	3.74	3.56	4.29	2.46
	Min	1.82	1.70	1.12	0.93	0.75	0.75	0.54	1.42	0.43
	Mean	3.11	3.05	2.59	2.99	2.12	1.92	1.84	2.70	1.37
	SD	1.36	1.29	1.43	1.67	1.31	1.18	1.05	0.90	0.68
	N	9	9	9	9	9	9	9	9	9

Table C.1 Descriptive statistics of particle mass concentrations of meat grilling (Continued).

Meat		particle mass concentration (µm) (mg/m^3)								
		9.0-10	**5.8-9.0**	**4.7-5.8**	**3.3-4.7**	**2.1-3.3**	**1.1-2.1**	**0.7-1.1**	**0.4-0.7**	**<0.4**
Thai sausage	Median	3.51	3.47	2.93	2.85	2.37	2.45	3.04	5.58	1.58
	Max	4.52	4.15	3.28	3.68	2.72	2.62	4.68	6.45	2.05
	Min	2.00	1.57	1.45	0.46	0.48	1.56	2.09	2.58	0.07
	Mean	3.33	3.02	2.56	2.34	2.01	2.27	3.12	5.04	1.25
	SD	0.94	1.06	0.76	1.21	0.87	0.39	1.05	1.50	0.86
	N	6	6	6	6	6	6	6	6	6
Thai sour pork	Median	3.54	2.94	2.22	2.32	2.39	3.09	4.43	7.21	1.33
	Max	5.13	4.26	2.43	3.43	3.13	4.08	5.77	9.54	1.39
	Min	2.95	2.43	1.68	1.37	1.67	1.86	2.27	4.18	0.88
	Mean	3.71	3.22	2.15	2.36	2.34	3.09	4.10	7.03	1.25
	SD	0.81	0.71	0.29	0.69	0.53	0.78	1.27	1.86	0.19
	N	7	7	7	7	7	7	7	7	7

Table C.1 Descriptive statistics of particle mass concentrations of meat grilling (Continued).

Meat		particle mass concentration (µm) (mg/m^3)								
		9.0-10	**5.8-9.0**	**4.7-5.8**	**3.3-4.7**	**2.1-3.3**	**1.1-2.1**	**0.7-1.1**	**0.4-0.7**	**<0.4**
Meatball	Median	2.65	2.12	1.81	1.95	1.79	1.54	1.09	1.76	0.79
	Max	2.91	3.19	2.76	2.85	2.36	3.33	1.71	2.09	1.32
	Min	1.35	1.06	1.16	1.00	0.86	0.82	0.59	1.19	0.20
	Mean	2.28	2.04	1.91	1.87	1.60	1.71	1.15	1.75	0.78
	SD	0.70	0.80	0.65	0.71	0.62	0.89	0.39	0.31	0.41
	N	7	7	7	7	7	7	7	7	7
Pork ball	Median	2.14	2.09	1.50	1.34	1.49	1.14	1.62	2.22	0.53
	Max	2.40	2.39	2.11	1.96	1.82	1.53	2.53	3.35	1.03
	Min	1.26	1.18	1.16	0.86	0.81	0.78	1.20	1.18	0.30
	Mean	1.96	1.87	1.63	1.47	1.44	1.21	1.66	2.23	0.61
	SD	0.46	0.43	0.32	0.40	0.34	0.26	0.41	0.73	0.23
	N	9	9	9	9	9	9	9	9	9

Table C.1 Descriptive statistics of particle mass concentrations of meat grilling (Continued).

Meat		particle mass concentration (µm) (mg/m^3)								
		9.0-10	**5.8-9.0**	**4.7-5.8**	**3.3-4.7**	**2.1-3.3**	**1.1-2.1**	**0.7-1.1**	**0.4-0.7**	**<0.4**
Fish ball	Median	2.06	1.55	1.34	1.26	1.10	1.10	1.40	2.36	0.49
	Max	2.41	2.31	2.11	1.81	2.27	1.59	2.30	3.86	0.79
	Min	1.75	0.67	0.96	0.98	0.48	0.59	0.96	1.29	0.26
	Mean	2.06	1.54	1.38	1.28	1.13	1.08	1.44	2.44	0.47
	SD	0.25	0.49	0.38	0.28	0.57	0.36	0.45	0.89	0.19
	N	7	7	7	7	7	7	7	7	7
Chicken ball	Median	1.84	1.55	1.12	1.19	0.88	0.87	1.38	1.58	0.30
	Max	2.19	2.11	1.50	1.79	1.29	1.27	1.65	3.06	0.71
	Min	1.21	1.06	0.72	0.59	0.54	0.58	1.06	1.41	0.03
	Mean	1.73	1.57	1.14	1.18	0.89	0.89	1.35	1.97	0.31
	SD	0.41	0.37	0.27	0.44	0.35	0.29	0.25	0.73	0.23
	N	6	6	6	6	6	6	6	6	6

N = Sample size

APPENDIX D

PARTICLE SIZE DISTRIBUTION FROM MEAT GRILLING ACTIVITIES :

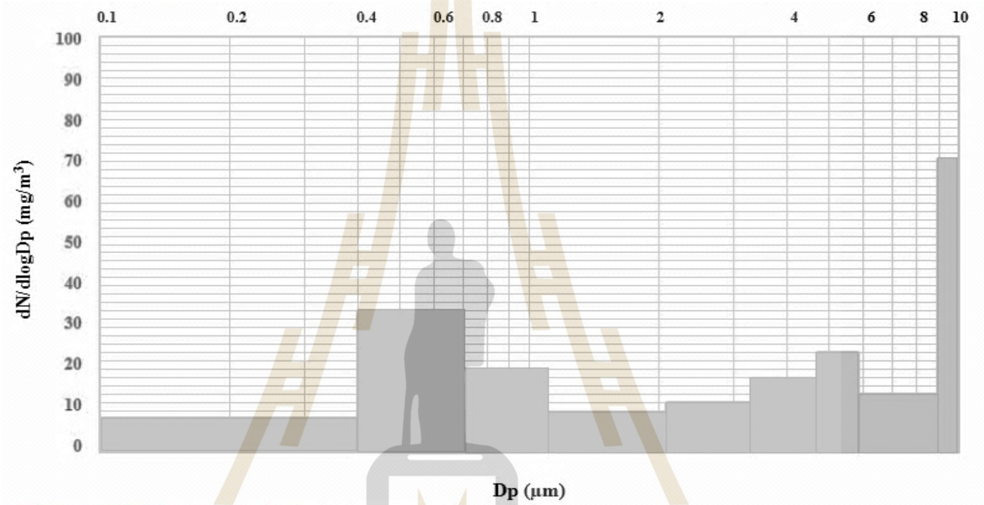


Figure D.1 Particle size distribution emitted from pork grilling.

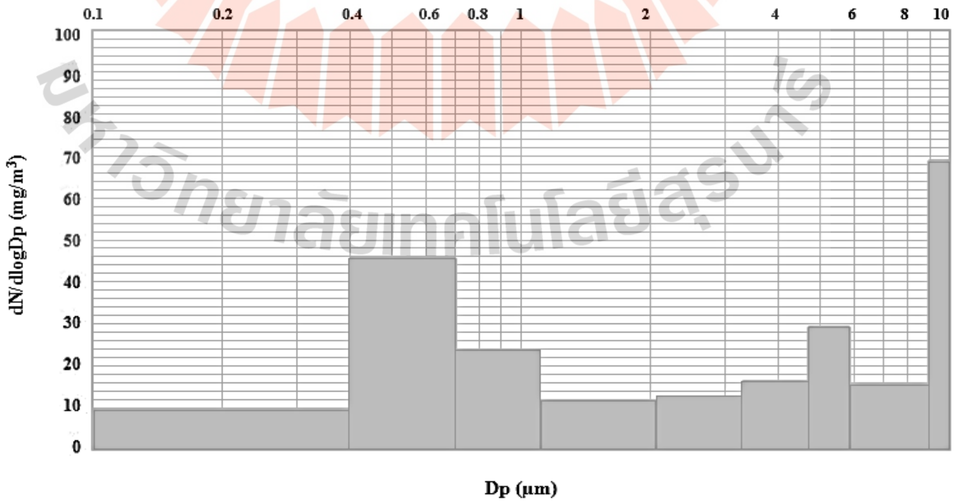


Figure D.2 Particle size distribution emitted from chicken grilling.

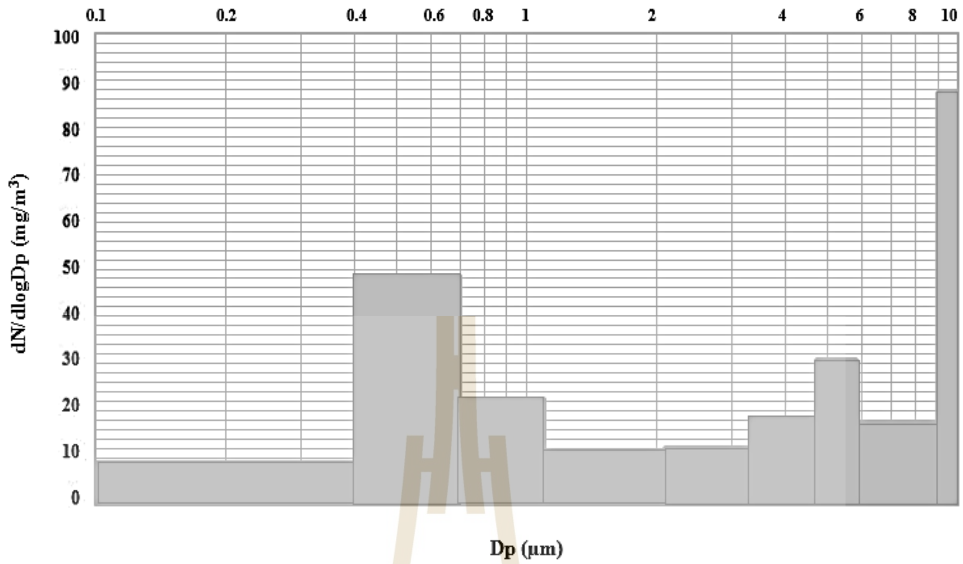


Figure D.3 Particle size distribution emitted from chicken wing grilling.

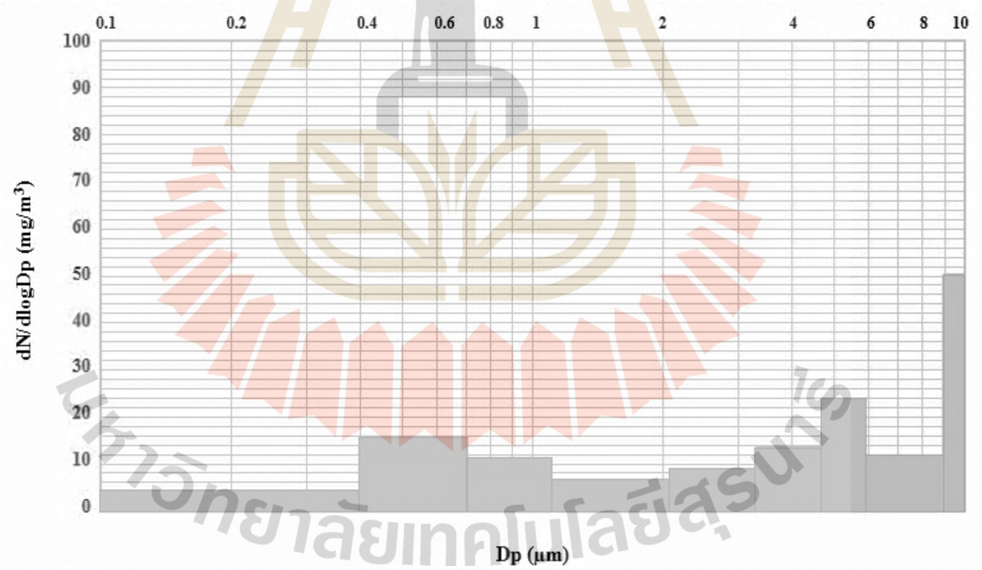


Figure D.4 Particle size distribution emitted from chicken liver grilling.

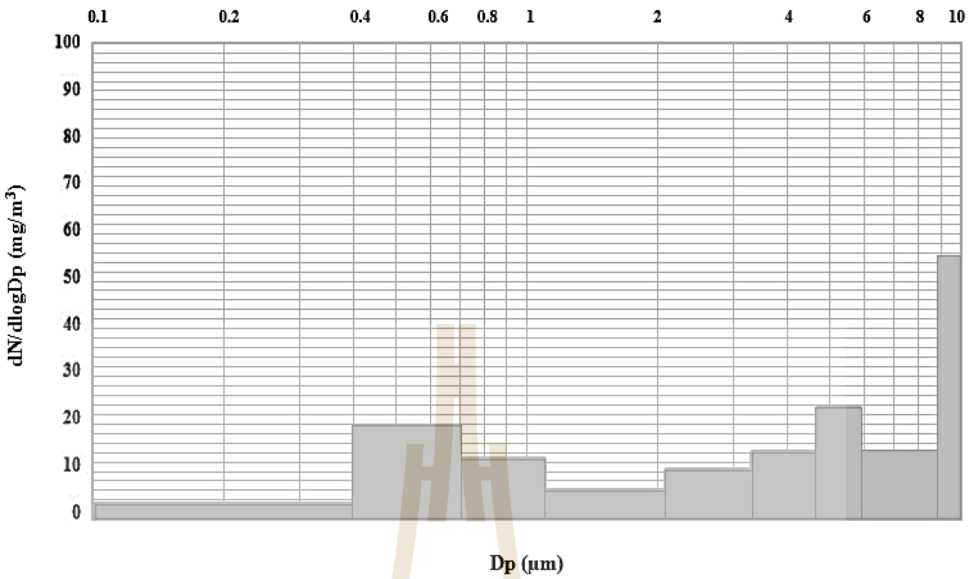


Figure D.5 Particle size distribution emitted from catfish grilling.

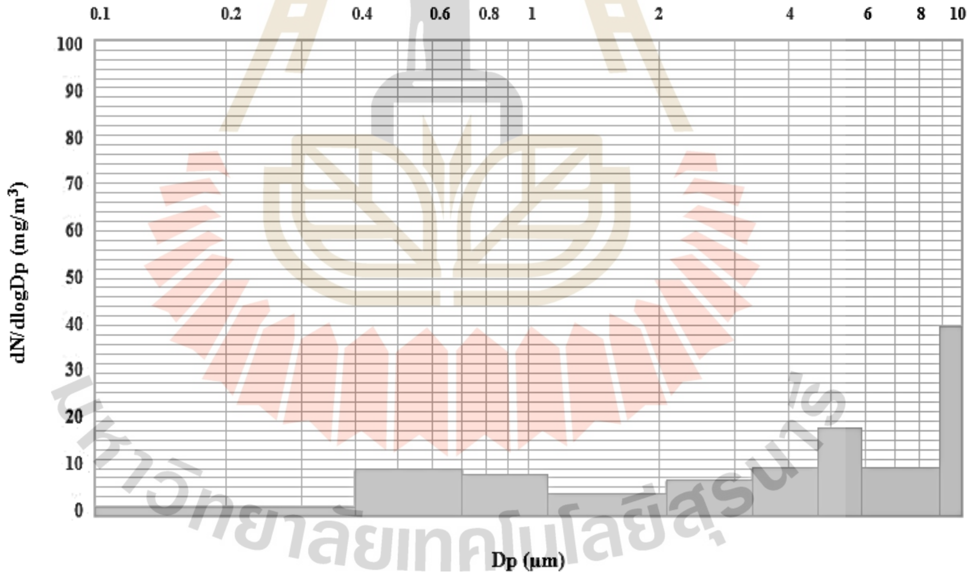


Figure D.6 Particle size distribution emitted from ruby fish grilling.

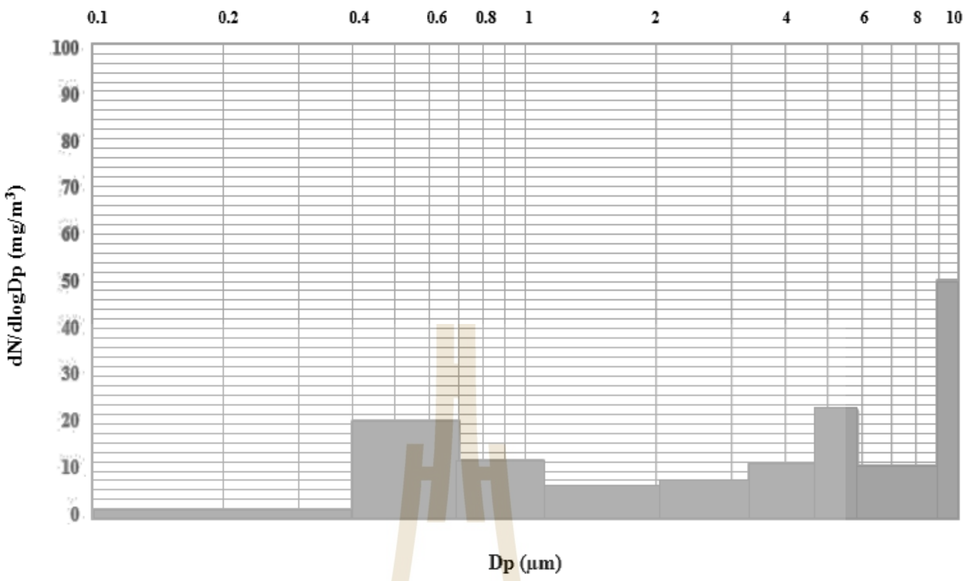


Figure D.7 Particle size distribution emitted from tilapia grilling.

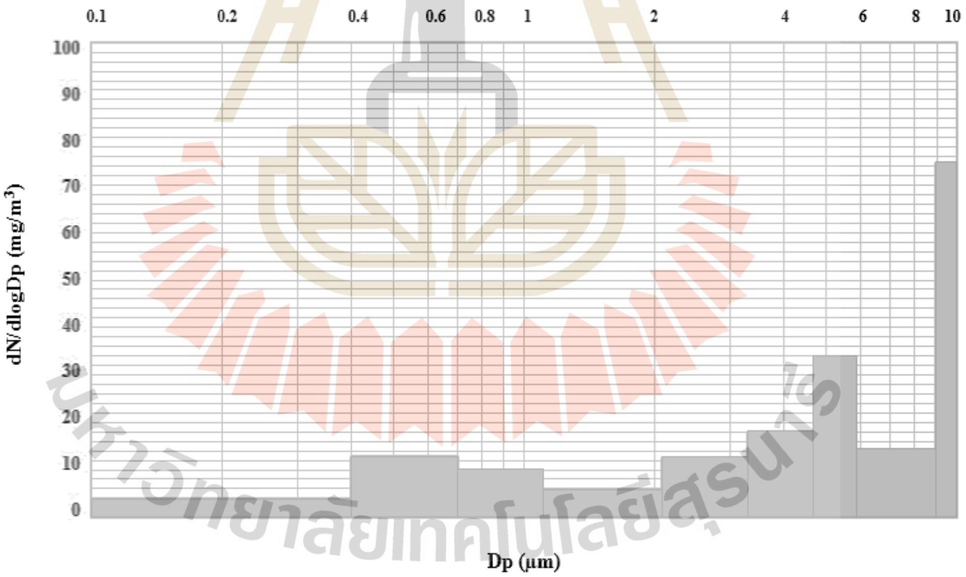


Figure D.8 Particle size distribution emitted from shrimp grilling.

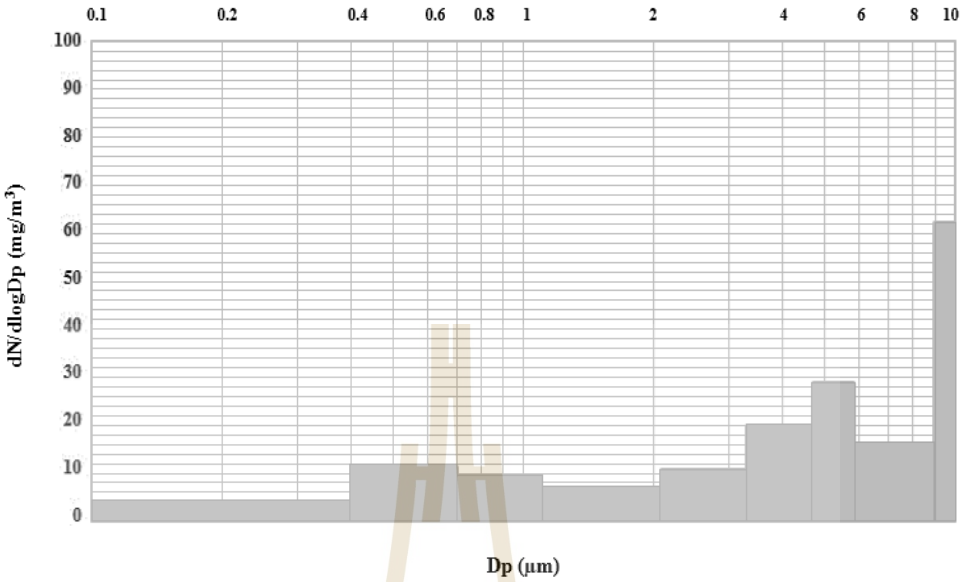


Figure D.9 Particle size distribution emitted from squid grilling.

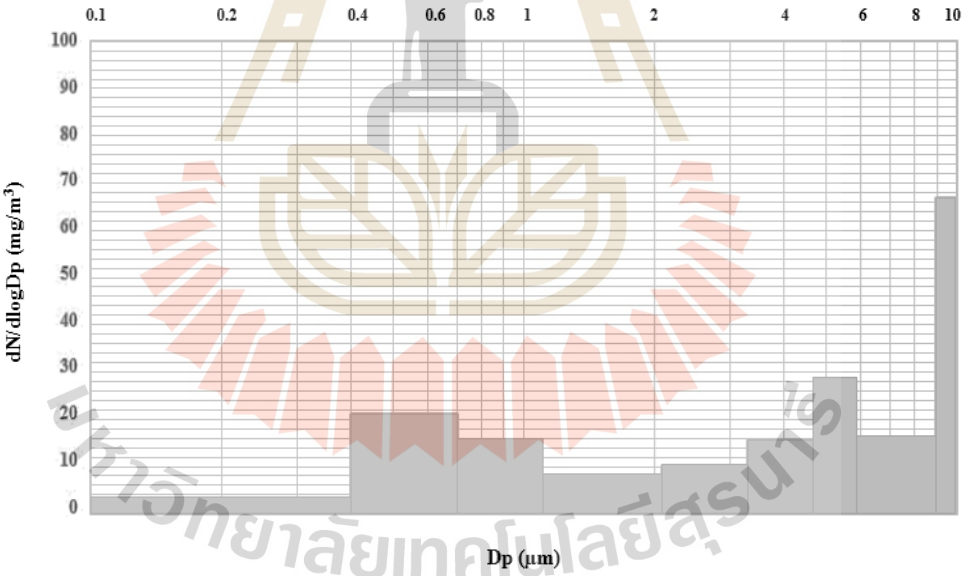


Figure D.10 Particle size distribution emitted from Thai sausage grilling.

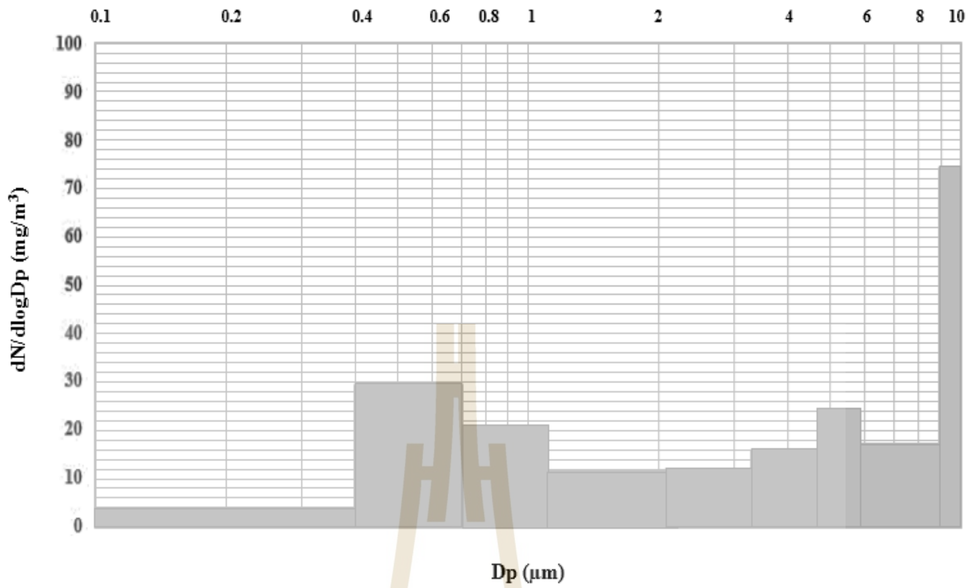


Figure D.11 Particle size distribution emitted from Thai sour pork grilling.

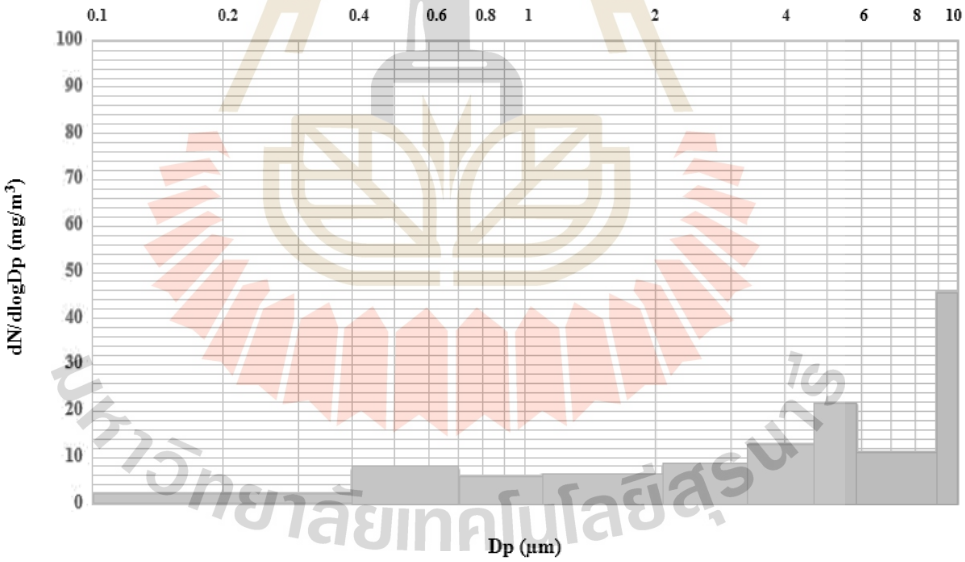


Figure D.12 Particle size distribution emitted from meatball grilling.

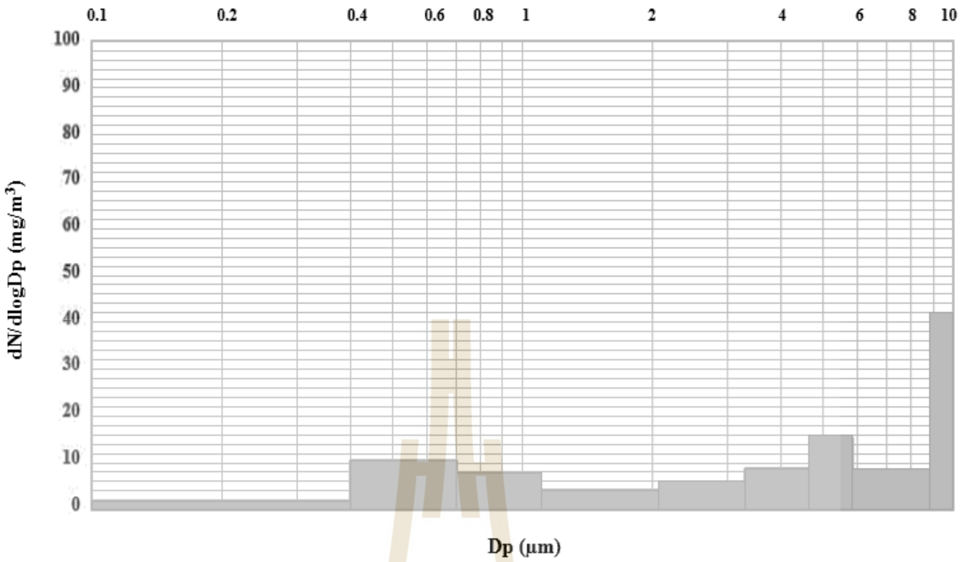


Figure D.13 Particle size distribution emitted from pork ball grilling.

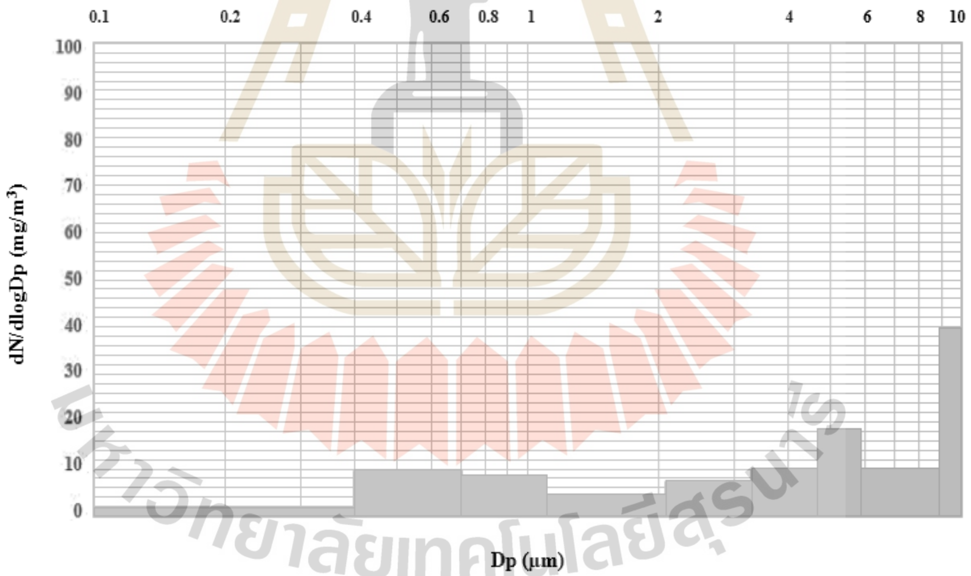


Figure D.14 Particle size distribution emitted from fish ball grilling.

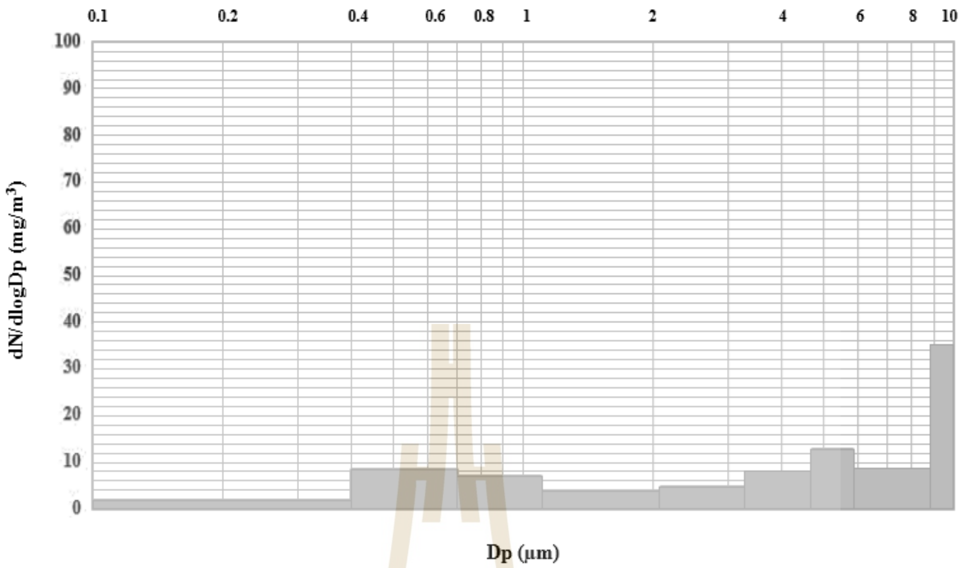


Figure D.15 Particle size distribution emitted from chicken ball grilling.

APPENDIX E

REAL-TIME CORRELATION OF EMISSIONS, FLAME TEMPERATURE, AND GRILLING TIME DURING MEAT GRILLING ACTIVITIES:

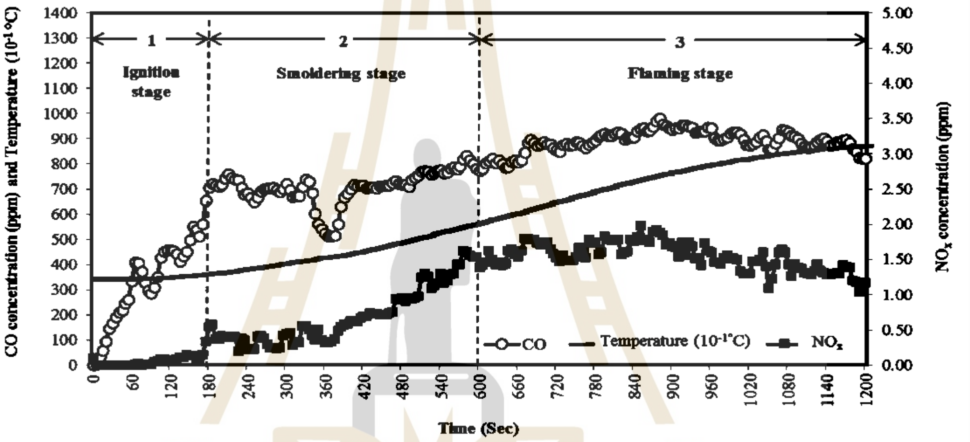


Figure E.1 Real-time correlation of mean CO, NO_x concentrations and flame temperature during pork grilling.

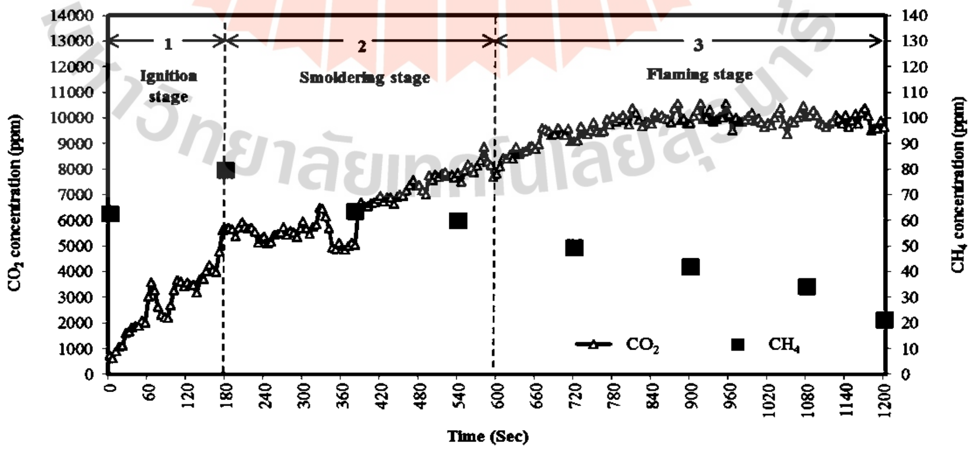


Figure E.2 Real-time correlation of two greenhouse gases (mean CO_2 and CH_4 concentrations) during pork grilling.

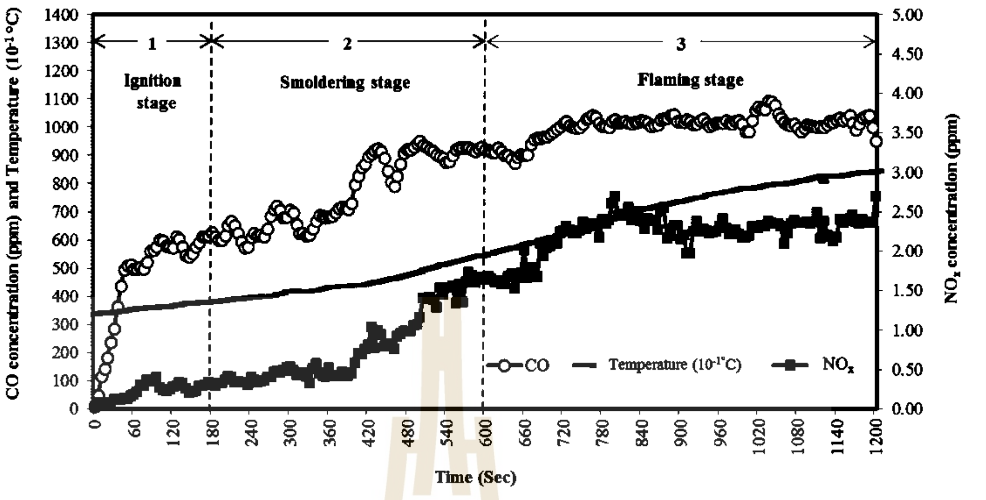


Figure E.3 Real-time correlation of mean CO, NO_x concentrations and flame temperature during chicken grilling.

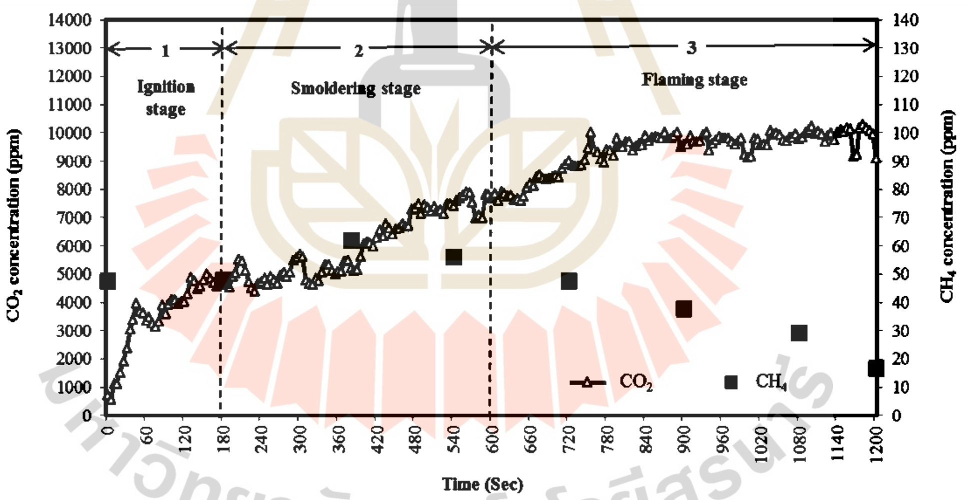


Figure E.4 Real-time correlation of two greenhouse gases (mean CO_2 and CH_4 concentrations) during chicken grilling.

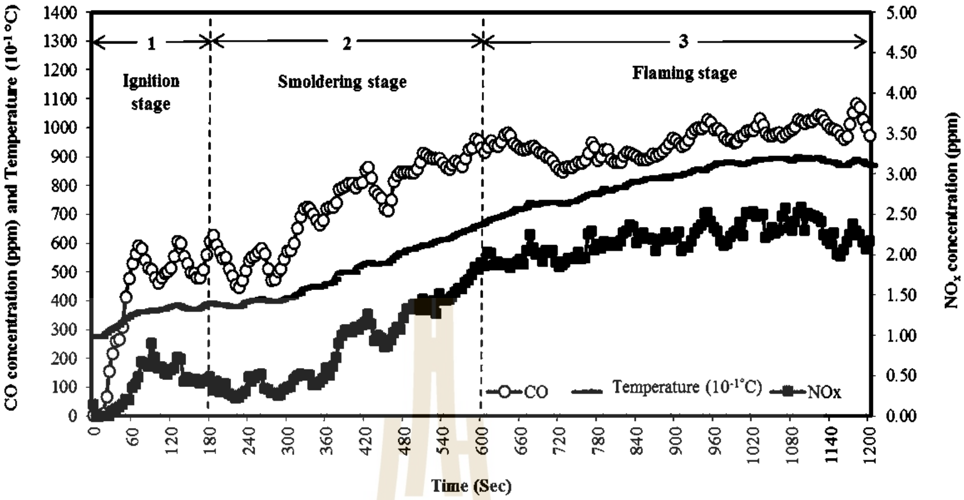


Figure E.5 Real-time correlation of mean CO, NO_x concentrations and flame temperature during chicken wing grilling.

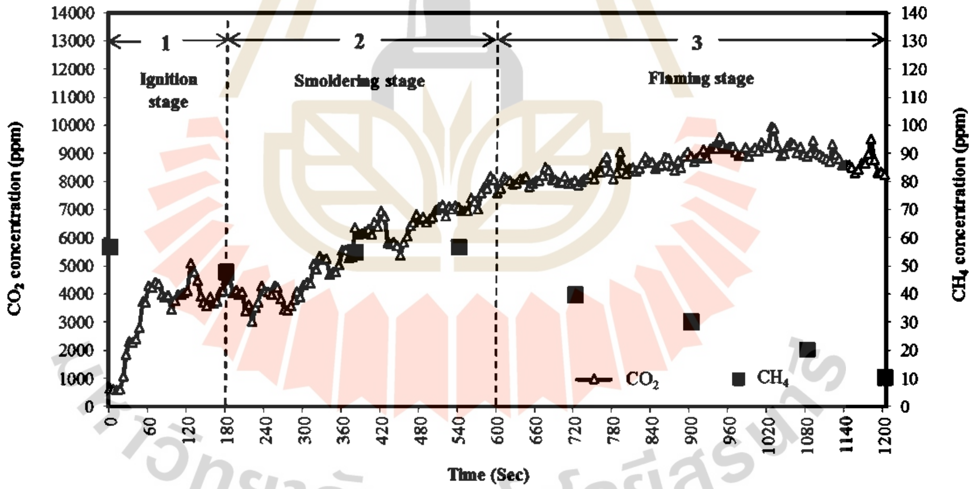


Figure E.6 Real-time correlation of two greenhouse gases (mean CO_2 and CH_4 concentrations) during chicken wing grilling.

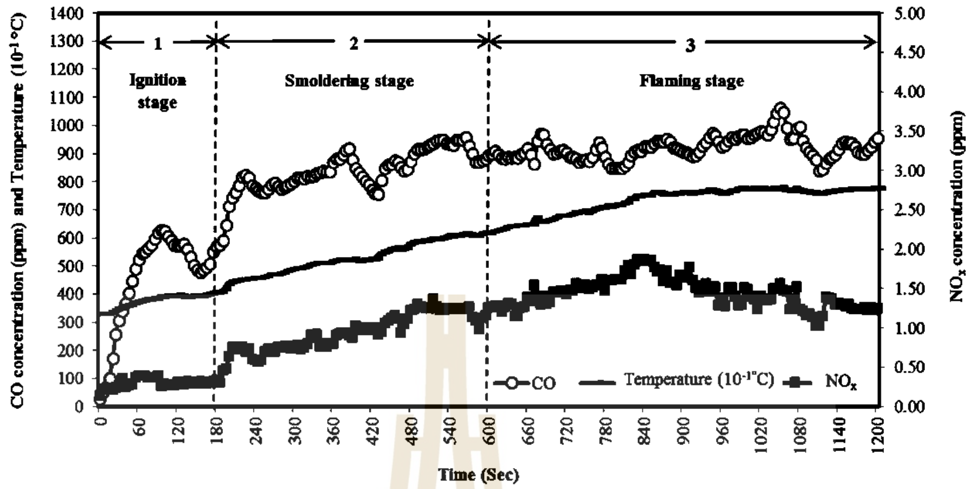


Figure E.7 Real-time correlation of mean CO, NO_x concentrations and flame temperature during chicken liver grilling.

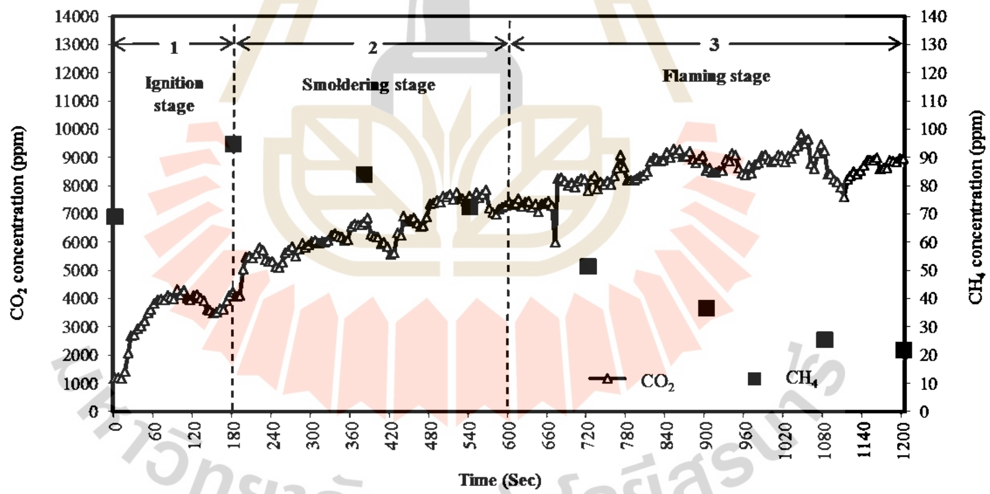


Figure E.8 Real-time correlation of two greenhouse gases (mean CO_2 and CH_4 concentrations) during chicken liver grilling.

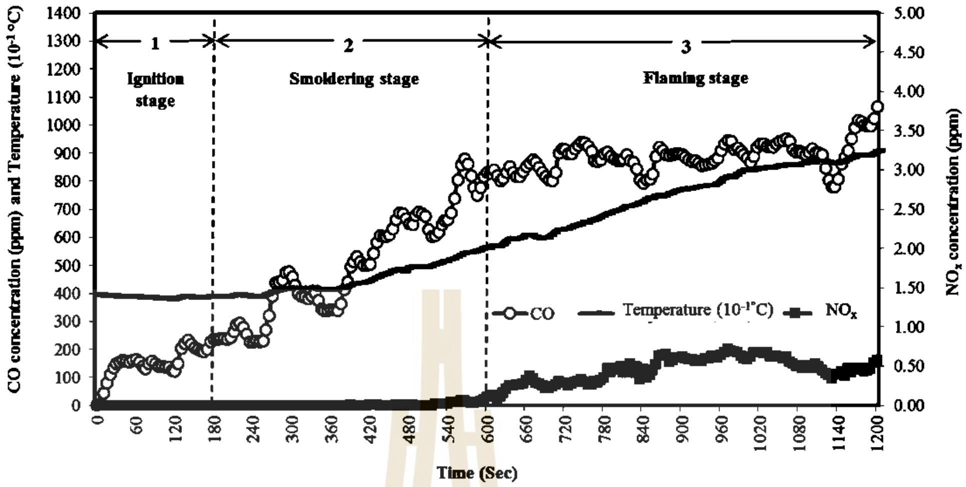


Figure E.9 Real-time correlation of mean CO, NO_x concentrations and flame temperature during catfish grilling.

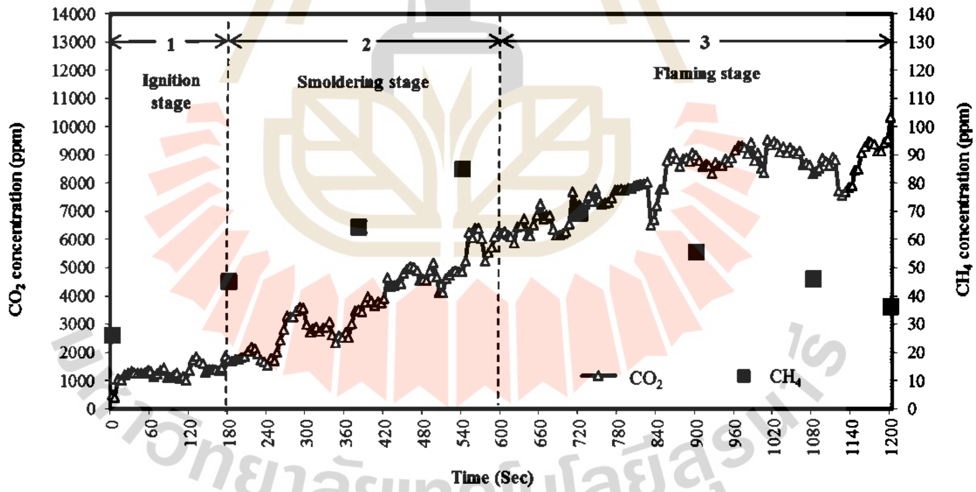


Figure E.10 Real-time correlation of two greenhouse gases (mean CO_2 and CH_4 concentrations) during catfish grilling.

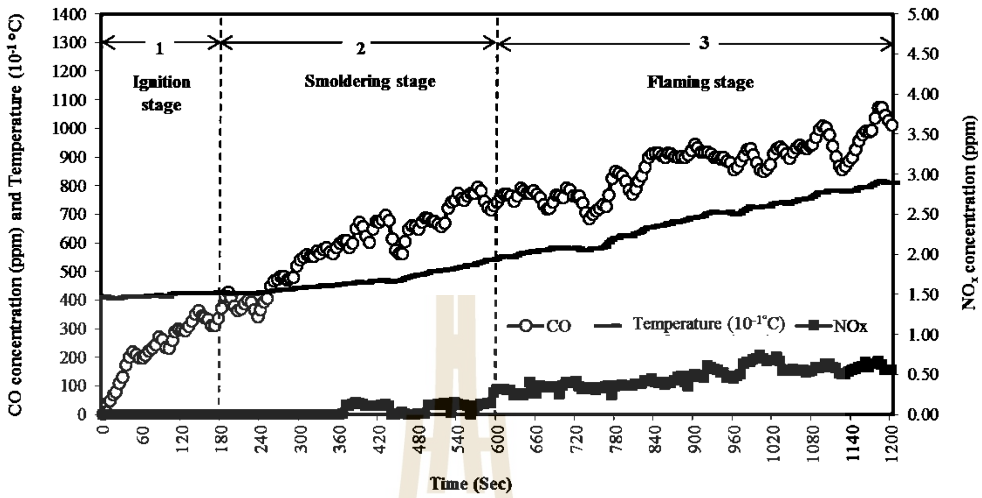


Figure E.11 Real-time correlation of mean CO, NO_x concentrations and flame temperature during ruby fish grilling.

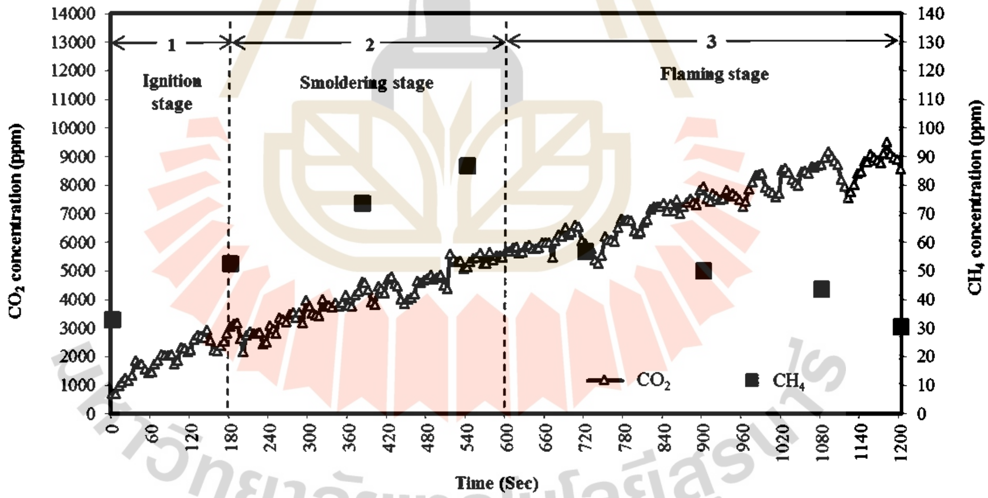


Figure E.12 Real-time correlation of two greenhouse gases (mean CO_2 and CH_4 concentrations) during ruby fish grilling.

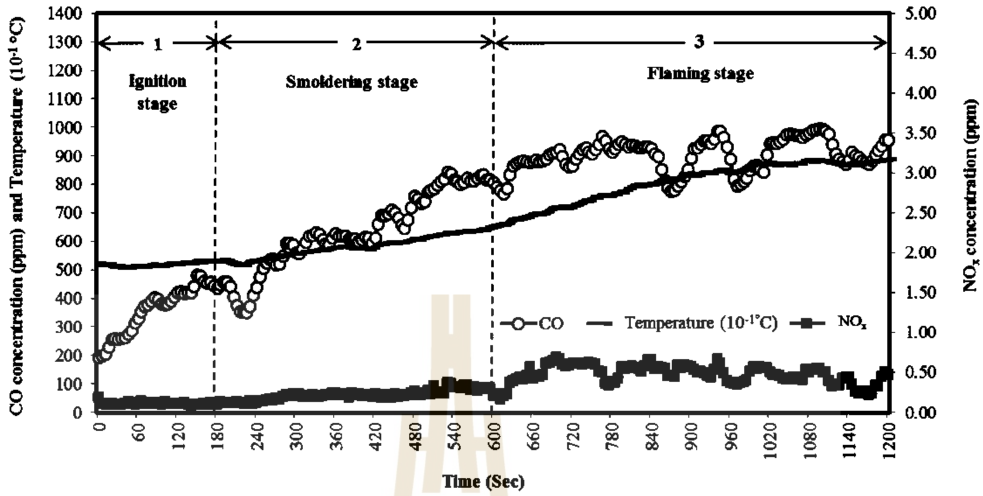


Figure E.13 Real-time correlation of mean CO, NO_x concentrations and flame temperature during tilapia grilling.

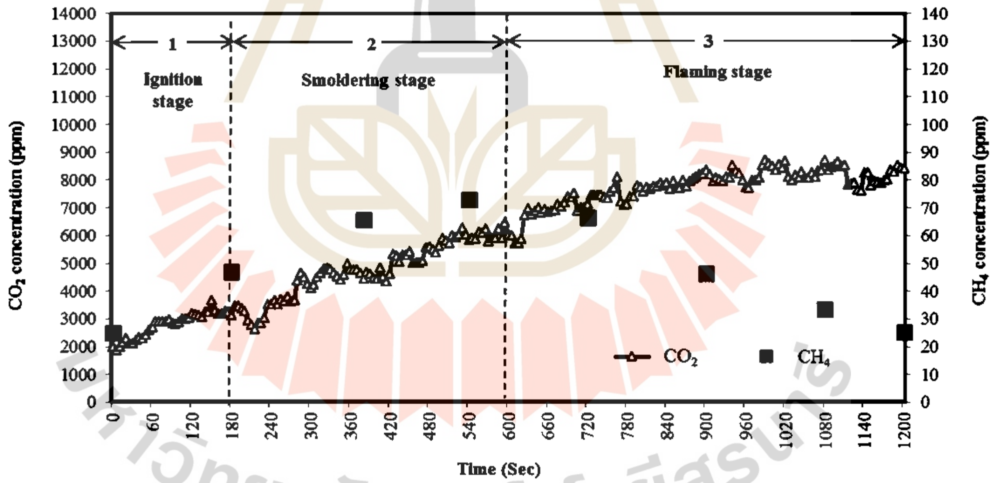


Figure E.14 Real-time correlation of two greenhouse gases (mean CO_2 and CH_4 concentrations) during tilapia grilling.

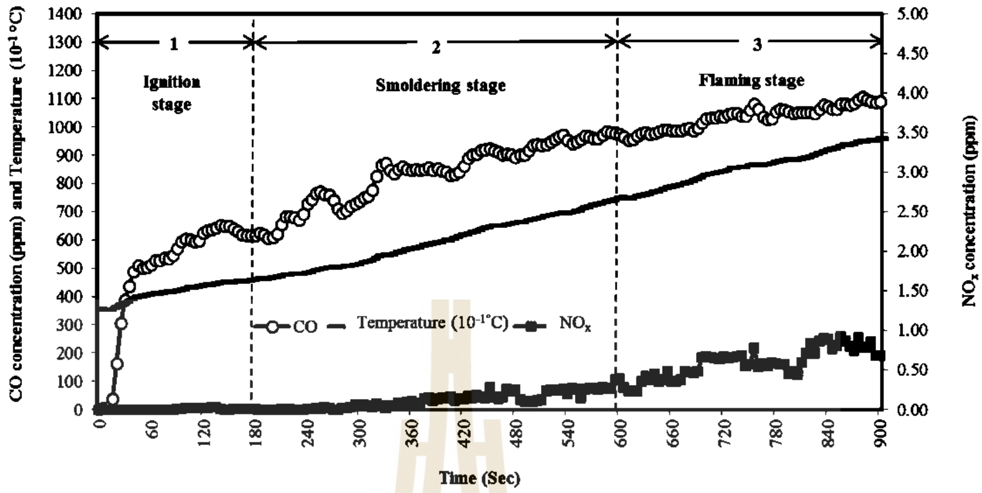


Figure E.15 Real-time correlation of mean CO, NO_x concentrations and flame temperature during shrimp grilling.

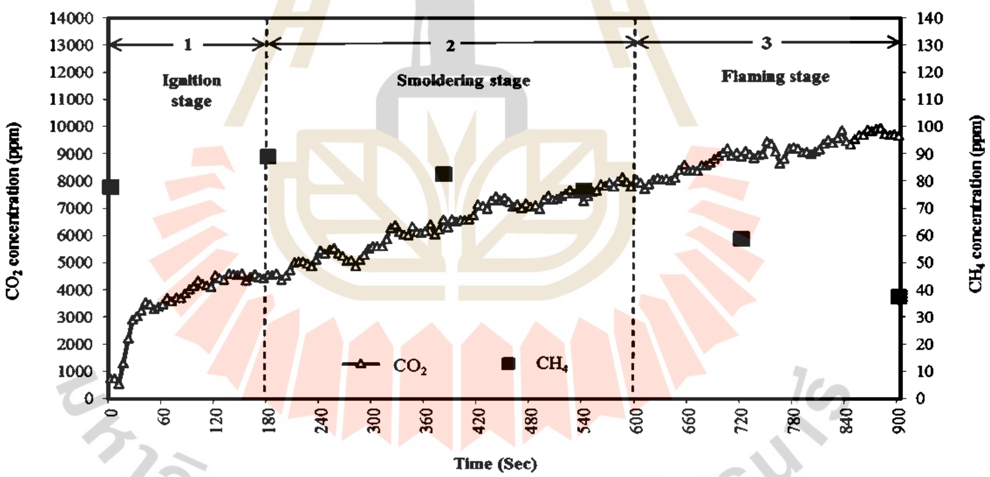


Figure E.16 Real-time correlation of two greenhouse gases (mean CO_2 and CH_4 concentrations) during shrimp grilling.

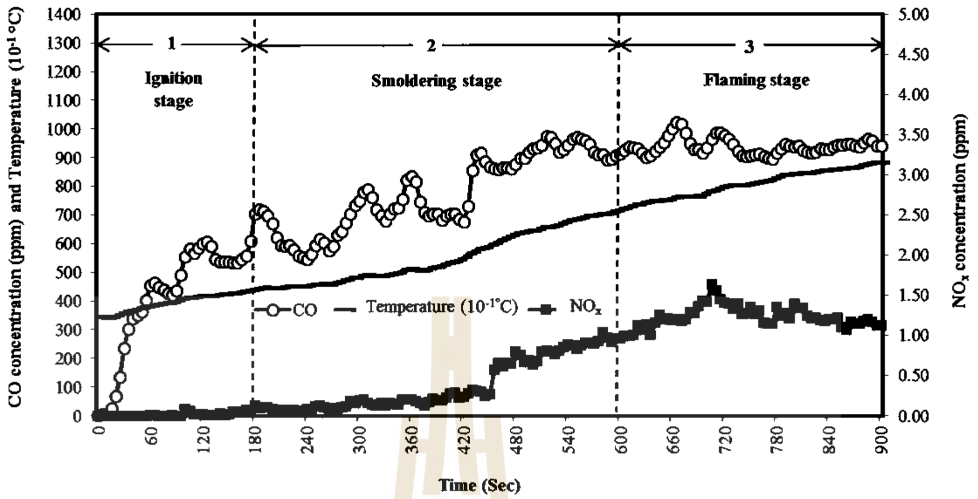


Figure E.17 Real-time correlation of mean CO, NO_x concentrations and flame temperature during squid grilling.

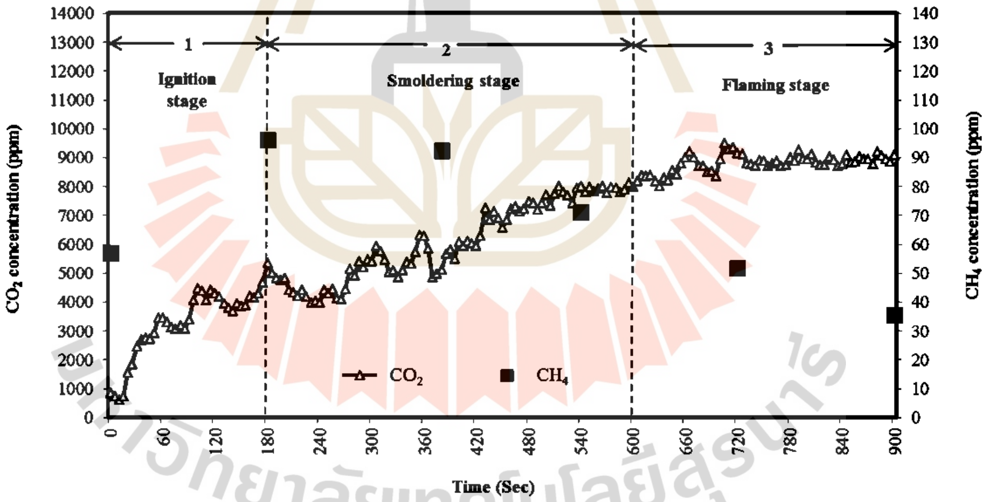


Figure E.18 Real-time correlation of two greenhouse gases (mean CO_2 and CH_4 concentrations) during squid grilling.

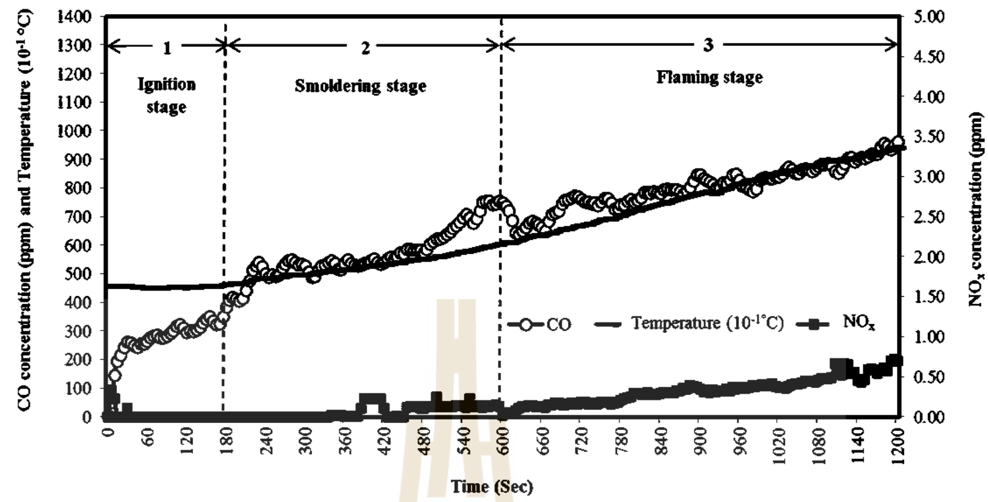


Figure E.19 Real-time correlation of mean CO, NO_x concentrations and flame temperature during Thai sausage grilling.

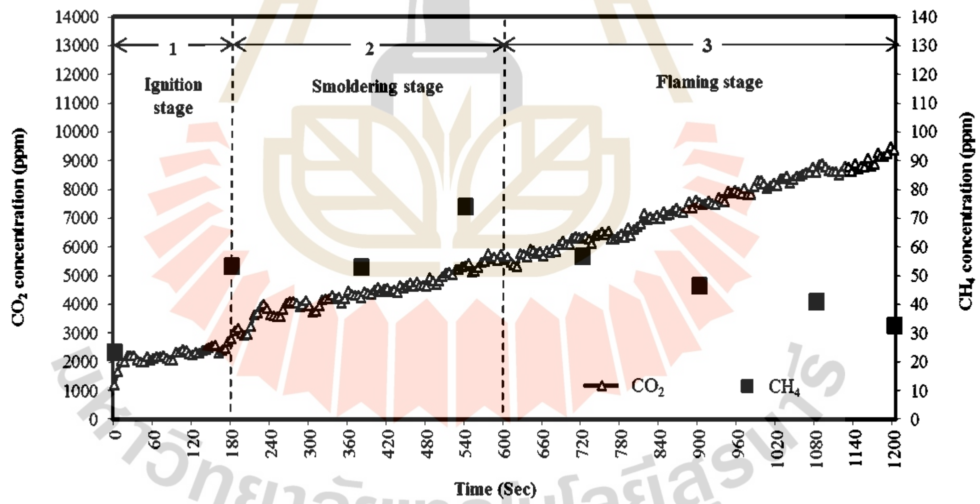


Figure E.20 Real-time correlation of two greenhouse gases (mean CO_2 and CH_4 concentrations) during Thai sausage grilling.

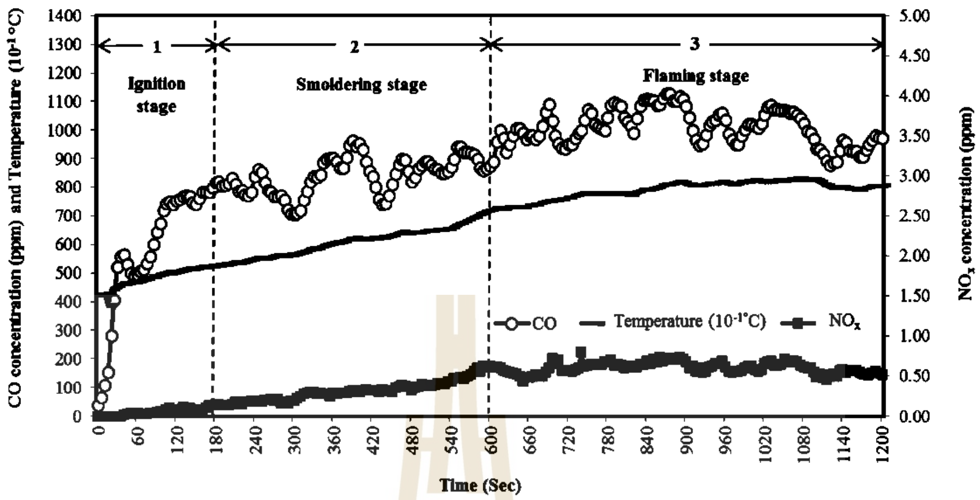


Figure E.21 Real-time correlation of mean CO, NO_x concentrations and flame temperature during Thai sour pork grilling.

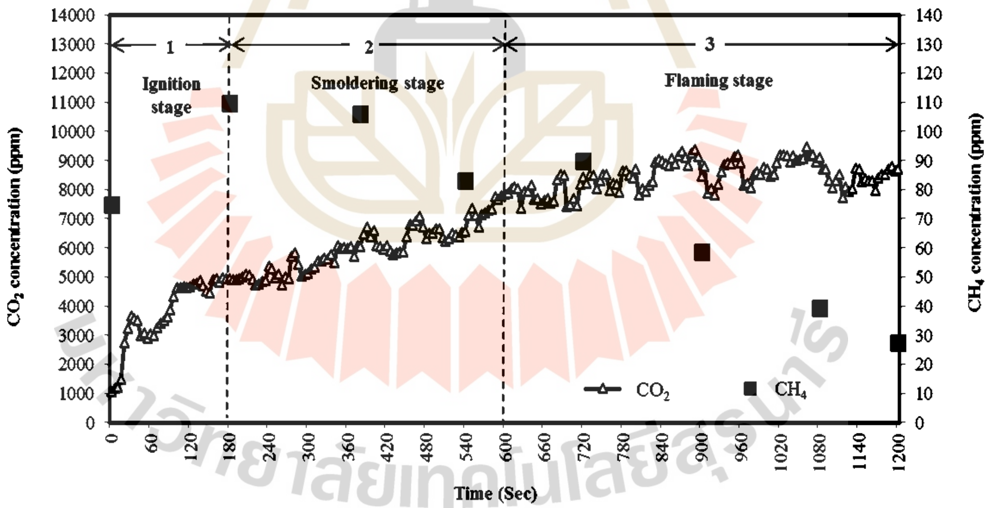


Figure E.22 Real-time correlation of two greenhouse gases (mean CO_2 and CH_4 concentrations) during Thai sour pork grilling.

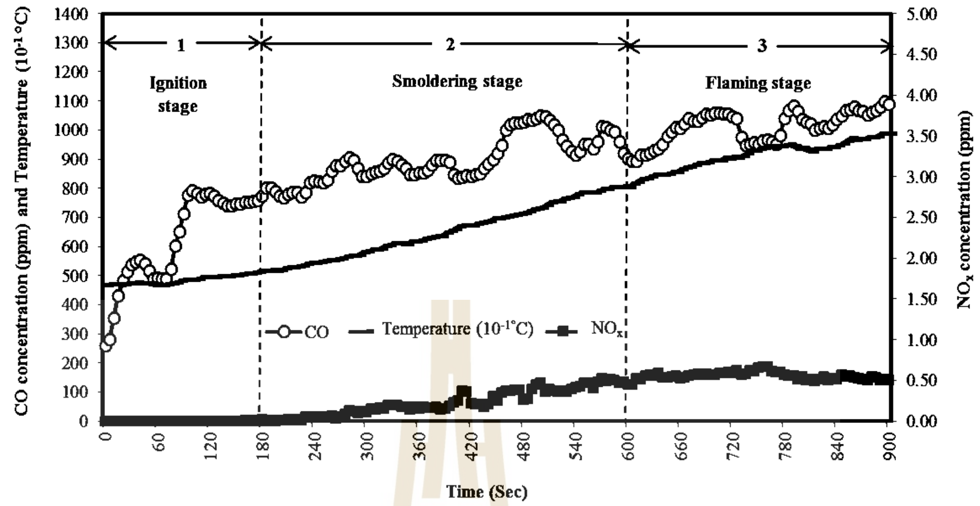


Figure E.23 Real-time correlation of mean CO, NO_x concentrations and flame temperature during meatball grilling.

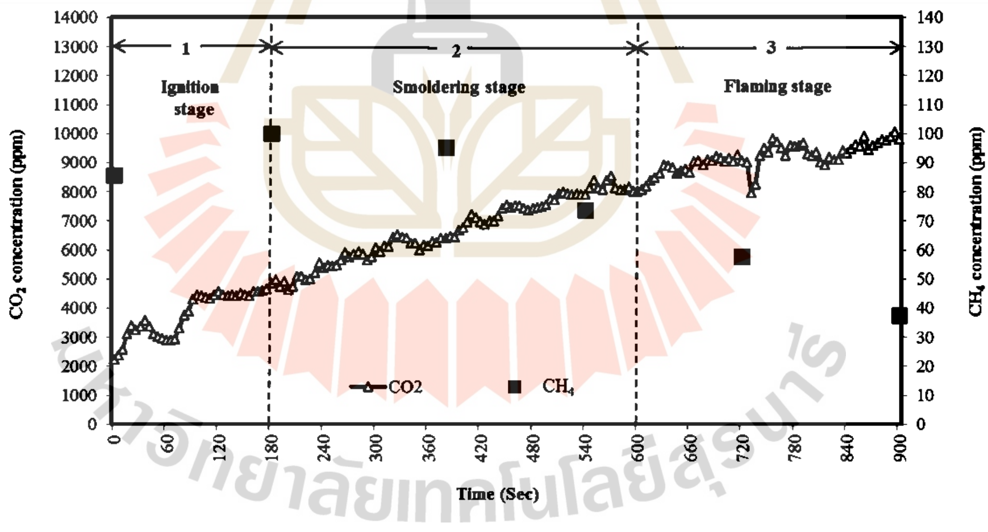


Figure E.24 Real-time correlation of two greenhouse gases (mean CO_2 and CH_4 concentrations) during meatball grilling.

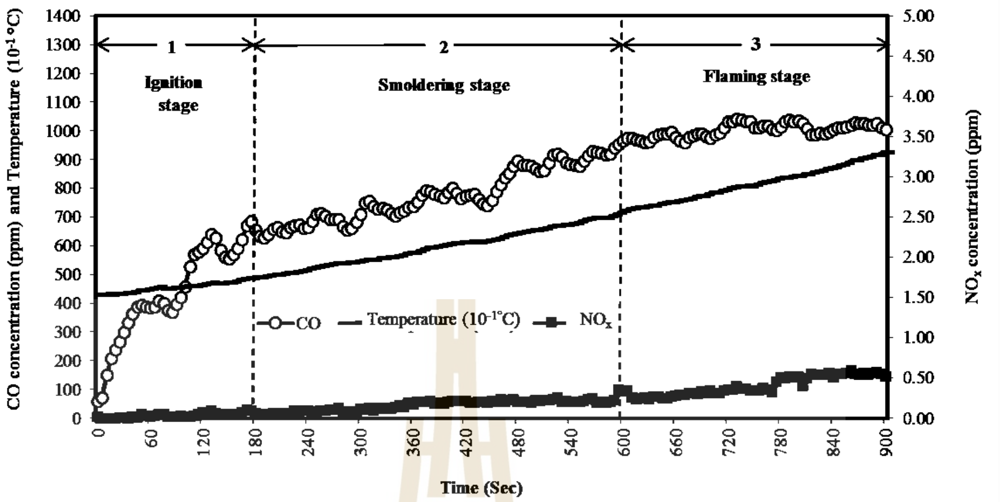


Figure E.25 Real-time correlation of mean CO, NO_x concentrations and flame temperature during pork ball grilling.

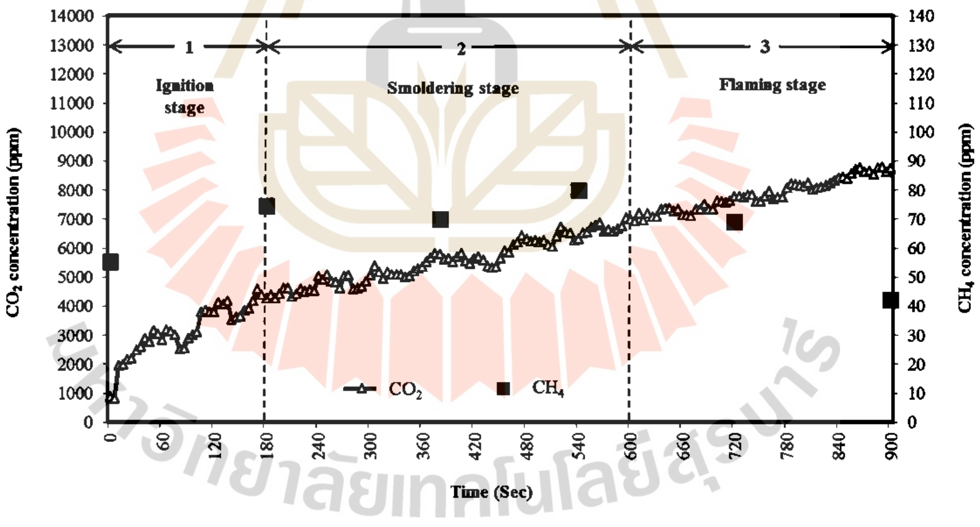


Figure E.26 Real-time correlation of two greenhouse gases (mean CO_2 and CH_4 concentrations) during pork ball grilling.

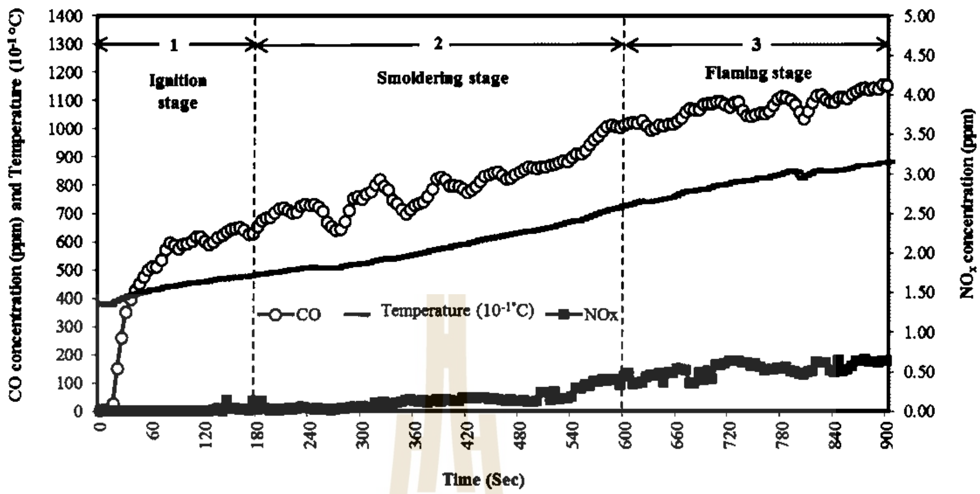


Figure E.27 Real-time correlation of mean CO, NO_x concentrations and flame temperature during fish ball grilling.

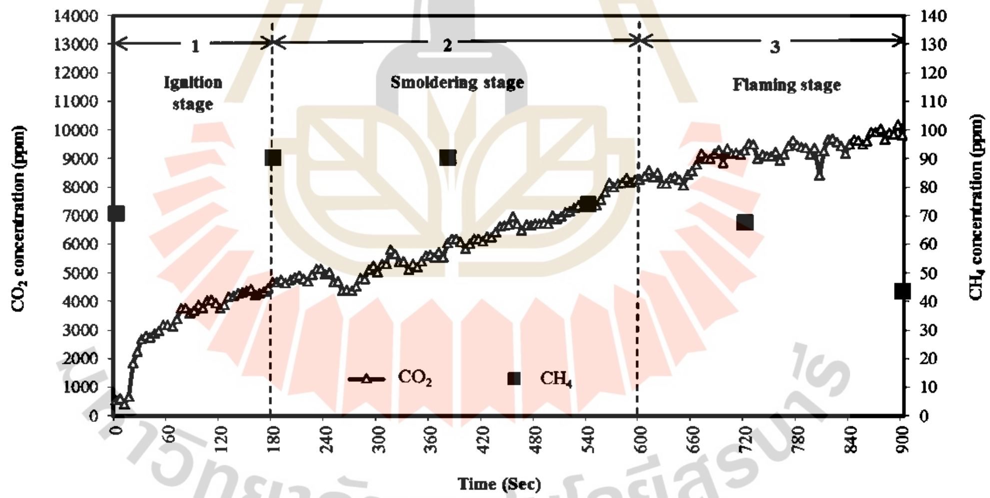


Figure E.28 Real-time correlation of two greenhouse gases (mean CO_2 and CH_4 concentrations) during fish ball grilling.

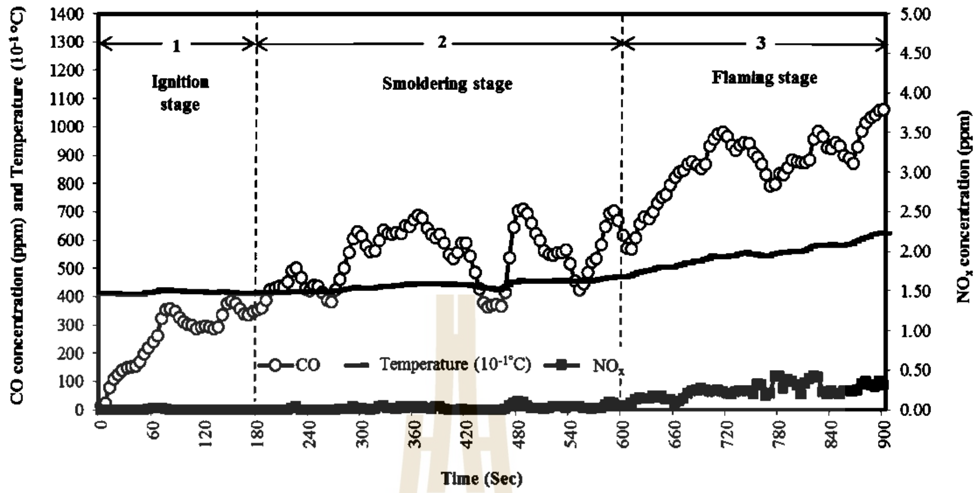


Figure E.29 Real-time correlation of mean CO, NO_x concentrations and flame temperature during chicken ball grilling.

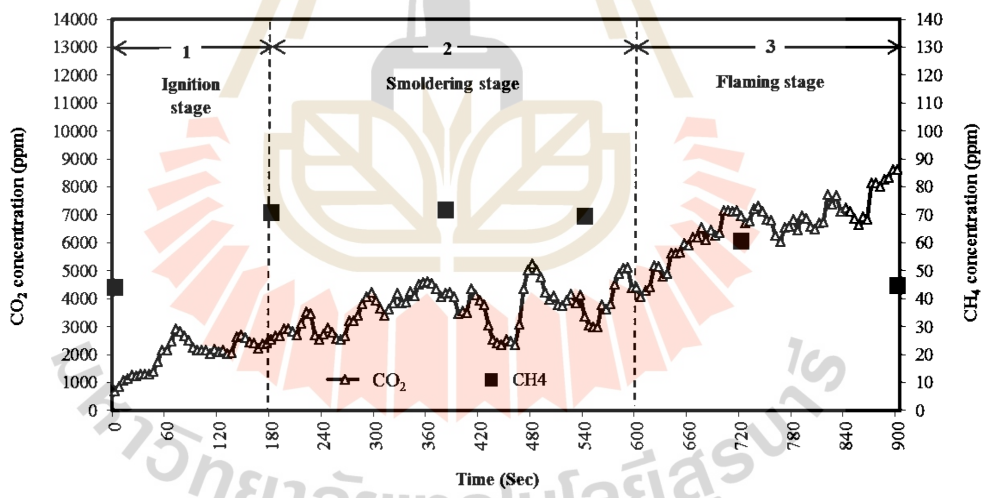


Figure E.30 Real-time correlation of two greenhouse gases (mean CO_2 and CH_4 concentrations) during chicken ball grilling.

APPENDIX F

PUBLICATION

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Estimating Emission Factors Of Fifteen Categories Of Meats From Thai-Style Barbeque Activities

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Abstract**:** *This study aims to determine air emission factors from meats grilling activity commonly found in Thailand. The major air pollutants included CO, NO_x, SO_2, particulate matter (PM_{10}) and two greenhouse gases (CO_2 and CH_4). 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 CH_4 were collected and subsequently analyzed in the laboratory. CH_4 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 NO_x, 0.009-0.042 g/kg of meat for PM_{10}, 10,587.62-47,236.79 g/kg of meat for CO_2 and 30.39-171.12 g/kg of meat for CH_4. SO_2 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.*

1. 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 (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), 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, NO_x 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 CO_2, 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.

2. 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 0.03 m^2. 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, CO_2, SO_2, and NO_x, were performed by a Testo 350 (Testo AG, Germany), while CH_4 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, CO_2, SO_2, and NO_x. 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 CH_4 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.

2.1. Computing Method

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

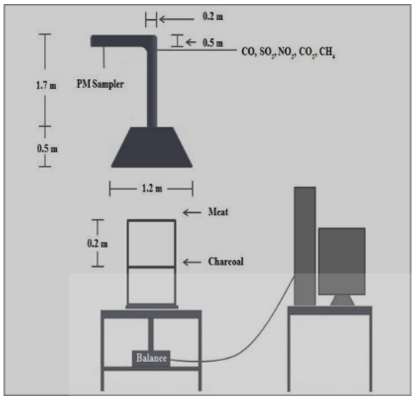
$$E_i = \frac{10^{-3}}{m_{fd}} \int_{t_0}^{t_f} A_s \, u \, C_i \, \frac{w_i}{22.4} \tag{1}$$

where: E_i is the emission factor of gas i (g/kg), m_{fd} is the mass of burned material (g), t_0 is the initial time of burn (s), t_f is the final time of burn (s), A_s is the surface area of the stack (m^2), u is the velocity of gas in the stack (m/s), C_i 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:

$$EF_{PM} = \frac{M_i}{M_{fuel}} \tag{2}$$

where: EF_{PM} is the emission factor of particulate matter (mg/kg or g/kg), M_i is the mass of emitted particles on a filter (mg or g), and M_{fuel} is the mass of fuel consumed (g or kg).



(a) **(b)**

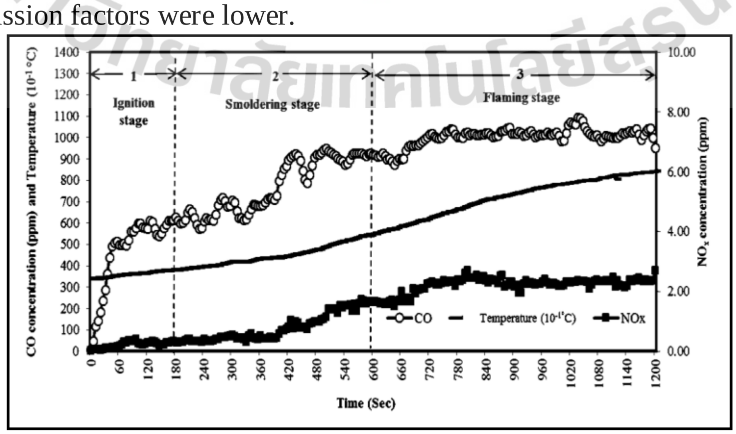
Fig. 1: **(a)** Illustrative drawing of combustion testing equipment and **(b)** Combustion testing equipment, the chimney and aluminum mesh screen and aluminum rectangular box for collecting ash on top of the balance.

3. Results and Discussion

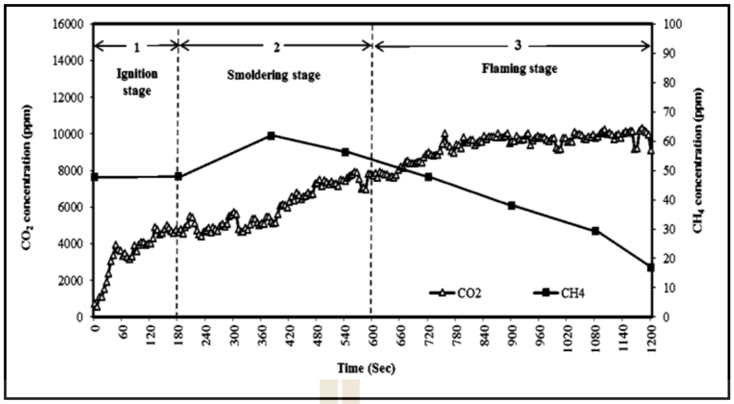
Each grilling took about 15-20 minutes. Gas emissions during ignition stage increased rapidly. A large quantity of PM, CO, NO_x, and CO_2 were generated during smoldering stage and further increased during the flaming stage (Fig. 2). In contrast, CH_4 concentrations were slowly increase during ignition stage and higher in smoldering stage. CH_4 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 NO_x 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 NO_x emissions. SO_2 was not detected in all samples. When meat fat dripped onto the flamed charcoal, rapid increased and high concentrations of CO and NO_x were observed. Meats with high fat contents showed high potential of releasing more CO and NO_x 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 NO_x 0.4-3.6 g/kg of meat. PM_{10} 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 CO_2 was 10,587.6-47,236.8 g/kg of meat while CH_4 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, NO_x, and PM_{10}, respectively [3]. The CO emission factor from this study was higher than the values reported in the literature while NO_x and PM_{10} 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

TABLE I: Emission factors of particulate matter and gaseous from charcoal meat grilling.

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

4. Conclusions

Among fifteen meats, grilling catfish showed the highest emission factor of CO and CH_4 (3,343.91 and 171.12 g/kg of meat, respectively) while grilling the chicken wing had the highest emission factor of NO_x, 3.58 g/kg of meat. Grilling shrimp showed the highest emission factor of PM_{10}, 0.042 g/kg of meat, and Thai sausage had the highest emission factor of CO_2 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 PM_{10} 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 SO_2 since sulfur is negligible in both fuel and meats used in the experiments. Future measurements may exclude SO_2 from the similar experiments.

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6. References

[1] S. Haryono, T. Susumu, and C. Renqiu, "Indoor $PM_{2.5}$ 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.

http://doi: 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.

http://dx.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.

http://dx.doi.org/10.1016/S0973-0826(08)60429-9

[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. http://dx.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. http://dx.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. http://doi: 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.

[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. http://dx.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.

[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.

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