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## LIST OF ABBREVIATIONS

API	Air Pollution Index (Hong Kong)
APS	Aerodynamic Particle Sizer
AQHI	Air Quality Health Index (Canada)
AQI	Air Quality Index (US EPA, Thailand and Asian)
ASCII	American Standard Code for Information Interchange: (Character-encoding)
BAM	Beta Attenuation Monitor
CAG	Combustion Aerosol Generator
CAI	Comprehensive Air-quality Index (South Korea)
CAMMS	A Continuous Ambient Mass Monitor System
CAQI	Common Air Quality Index (Europe)
CFR	Code of Federal Regulations
CNC	Condensation Nuclei Counter
CO	Carbon Monoxide
COMEAP	Committee on Medical Effects of Air Pollutants (UK)
CPC	Condensation Particle Counter
DC	Direct Current
DMPS	Differential Mobility Particle Sizer
DMT	DMT Diffusion Dryer from Droplet Measurement Technologies
DNA	Deoxyribonucleic Acid
DRM	Direct Reading Monitor
EAA	Electrical Aerosol Analyzer
E-analyzer	the DAM for classifying the particle size of EAS
EAS	Electrical Aerosol Spectrometer
E-BAM	Beta Attenuation from Met One Instruments Inc
ELPI	Electrical Low Pressure Impactor
EMA	Electrical Mobility Analyzers
EPA	Environmental Protection Agency

FEM	Federal Equivalence Method
FRM	Federal Reference Method
HI	Harvard-Marple Impactor
IMECAs	El Indice Metropolitano de la Calidad del Aire (Mexico)
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LIDAR	Light Detection and Ranging
MAR	Major Axis Line
MSB	Most Significant Bit
NAAQS	National Ambient Air Quality Standards
NH <sub>3</sub>	ammonia
NO	Nitric Oxide
NO <sub>2</sub>	Nitrogen Dioxide
O <sub>3</sub>	Ozone
OPC	Optical Particle Counters
PCD	Pollution Control Department (Thailand)
PDE	Partial Differential Equation
PM	Particulate Matter
PSAP	Particle Soot/Absorption Photometer
PSI	Pollutant Standards Index (Singapore)
RH	Relative Humidity
SEM	Scanning Electron Microscope
SMPS	Scanning Mobility Particle Sizer
SO <sub>2</sub>	Sulfur Dioxide
TEM	Transmission Electron Microscope
TEOM	Taper Element Oscillating Microbalance
TSP	Total Suspended Particulate or PM100
US EPA	United State Environmental Protection Agency
WHO	World Health Organization

## LIST OF SYMBOLS

$\alpha$	The solidity
$\sigma$	The electrical conductivity (S/m)
$\gamma$	The auxiliary variable for calculated $\beta_4$
$\gamma$	The surface tension of the droplet liquid
$\lambda_i$	Ion mean free path (m)
$\lambda$	The mean free path ( $\mu\text{m}$ )
$\chi$	The dynamic shape factor (for irregular particle)
$\beta_1, \beta_2, \beta_3, \beta_4$	The auxiliary variable for calculated the linear regression analysis
$\rho$	Density ( $\text{kg}/\text{m}^3$ ); The incoming charged particles; The electric charge density ( $\text{C}/\text{m}^3$ )
$\mu$	The deposition parameter; Micron ( $10^{-6}$ m)
$\varepsilon$	Dielectric constant of particles
$\eta$	The dynamic viscosity (Pa.s); Charge efficiency
$\Delta T_1, \Delta T_2$	Differential of temperature (Kelvin)
$R_{e_p}$	Particle Reynolds number
$\varepsilon$	The permittivity of particl (F/m
$\vec{u}$	The velocity vector (m/s)
$\pi$	Pi (3.1415926)
$\sigma(r)$	The path integrated extinction
$A$	The area ( $\text{m}^2$ ); Constant value in the power regression model
$B$	Magnetic flux ( $\text{Wb}/\text{m}^2$ ); Constant value (Power regression); Particle mobility (m/N.s)
$c, C$	The constant value
$\bar{c}$	The mean thermal speed of the ions ( $2.4 \times 10^4$ cm/s)
$C_c$	Cunningham correction factor

$C_D$	The coefficient of drag
$C_{eq}$	Concentration of water vapor at saturation
$C_r$	Rotameter coefficient (about 0.6 – 0.8)
$D_j$	The impactor jet diameter
$d_{50}$	Particle cutoff diameter
$d_a$	The aerodynamic diameter (m)
$d_c$	Particle velocity that gravity force; Cylinder diameter
$d_m$	The collision diameter of the molecule
$d_e$	The equivalent volume diameter (m)
$d_p$	Nozzle diameter; Particle diameter
$d_s$	Stoke diameter (m)
$e$	The elementary unit of charge ( $1.6 \times 10^{-19}$ C)
$E$	The electric field strength or electric field intensity (V/m)
$E_c$	The Collection Efficiency
$F$	Particle trajectories force; Force; Volume force field
$F_D$	The drag force of the air on the particle (N)
$F_G$	The gravity force (N)
$F_E$	Magnitude of the force (N)
$g$	Acceleration due to gravity
$I$	Discharge current (A); Transmitted flux (Wb/m <sup>2</sup> )
$I_e$	The electrometer current signal (A)
$I_p$	Charging current (A)
$J$	The current density (A/m <sup>2</sup> )
$J_e$	The externally generated current density (A/m <sup>2</sup> )
$J_R$	The parameter function of $R_{dl}$
$k$	Boltzmann's constant ( $1.38 \times 10^{-16}$ dyn cm/K)
$K_E$	Constant of proportionality ( $9 \times 10^9$ N.m <sup>2</sup> /C <sup>2</sup> )
$K_n$	Knudsen number
$L_l$	The length of needle electrode (the corona needle-cone charger)
$m$	The particle mass (kg)
$m_f$	The float mass (kg)

$m_p$	The particle mass concentration ( $\mu\text{g}/\text{m}^3$ )
$n$	The number of charge
$n_c$	The number of charge in combined chargers
$n_d$	The number of charge in diffusion charging
$n_f$	The number of charge in field charging
$n_{ion}$	The ion number concentration ( $\text{ions}/\text{m}^3$ )
$n_p$	The average number of elementary charge
$n_{pi}$	The mean of particle probability
$n_s$	Saturation charge
$N$	The number of air exchanges per day
$N_i$	The ion concentration ( $\text{ion}/\text{cm}^3$ )
$N_p$	The particle number concentration ( $\text{particles}/\text{m}^3$ )
$p$	Pressure (Pa or Pascal)
$P_r$	The pressure at standard temperature or NTP (101.3 kPa)
$P_p$	The particle penetration of the charger
$P_t$	Penetration of the inlet concentration
$P_{STP}$	The pressure at standard condition
$q$	The charge on the particle (coulomb)
$Q$	The air flow rate ( $\text{m}^3/\text{s}$ )
$Q_a$	The fluid flow rate ( $\text{m}^3/\text{s}$ )
$Q_{kg}$	The mass of silica gel (kg)
$Q_{STP}$	The flow rate at standard condition
$Q_j$	The boundary current source ( $\text{A}/\text{m}^2$ )
$r$	The radius or distance (m)
$r_p$	Particle radius
$R$	Correlation coefficient
$R^2$	Correlation coefficient of determination
$Re$	Raynold number
$Re_p$	The particle Reynolds number
$Re_0$	The Reynold number of the particle at the initial velocity

$R_f$	Feedback resistor
$R_i$	Acceptable concentration range ( $\mu\text{g}/\text{m}^3$ )
$s$	The ratio of stop distance
$S$	The Sutherland interpolation constant; Stopping distance
$S_{tk}$	Stokes number
$S_{tk50}$	Stoke number at $d_{50}$
$t$	The charging time (s)
$\tau$	The relaxation time (s)
$T$	The absolute temperature (Kelvin)
$T_r$	The standard condition (20°C or 293.15 K)
$\bar{u}_p$	The particle velocity vector (m/s)
$v, V, U$	The velocity (m/s)
$V_{out}$	The output voltage (V)
$V_p$	The particle velocity (m/s)
$V_{TE}$	The terminal electrostatic velocity, m/s
$V_{TS}$	The terminal settling velocity, m/s
$x$	The mass thickness of the sample, $\text{g}/\text{cm}^2$
$x(y)$	$x$ on $y$ in the Linear Regression Analysis
$y(x)$	$y$ on $x$ in the Linear Regression Analysis
$y_1(x)$	$y_1$ on $x$ in the Linear Regression Analysis
$y_2(x)$	$y_2$ on $x$ in the Linear Regression Analysis
$Z_i$ or $Z_{ion}$	Electrical mobility of ion
$Z_i^+$	The electrical mobility of positive ion $1.15 \times 10^{-4} \text{ m}^2/\text{V s}$
$Z_i^-$	The electrical mobility of positive ion $1.425 \times 10^{-4} \text{ m}^2/\text{V s}$

## GLOSSARY

22D1180	Diaphragm Vacuum Pump from GAST
5014i	The continuous PM monitor model 5014i Beta Ray
ADAM-4017	Analog to Digital 8 channel input 16 bit data
ADD	ADD Diffusion Drying
APS3320	An aerodynamic particle sizer model 3320 from TSI Company
Arduino UNO	Arduino Microcontroller Module
ATM 226	Aerosol Generator from TOPAS Company
BAM 1020	Beta Attenuation Monitor from Met One Instruments
D-analyzer	The DAM for classifying the particle size of EAS
DD250	Diffusion Dryer model DD250 of ATI Company
DDU570	Diffusion Dryer model DDU570 of TOPAS Company
DIAL	Differential Absorption LIDAR
DM-870A	Digital Voltmeter
DRX8533	Continuous PM Monitor from DUSTTRAK
DustDETEC	Electrostatic Sensor for Measuring Airborne Particulate Matter
Dusttrak8520	The continuous PM monitor model DustTrak8520
Dusttrak8533	The continuous PM monitor model DustTrak8533
DustTrak™	The continuous PM monitor model DustTrak™
E-Sample	The continuous PM monitor model E-Sample
FH62C14	The continuous PM monitor model FH62C14 Beta Ray
FH62I-N	Beta Attenuation Ambient Particulate Monitor

GDS-1052-U	Digital Oscilloscope from GW-INSTEX
GFC-1111	Dwyer Mass Flow Controller series GFC 0-15 L/min
GFC-1144	Dwyer Mass Flow Controller series GFC 0-100 L/min
GK2.05 KTL	Respirable/Thoracic Cyclone
GRIMM180	The continuous PM monitor model GRIMM180
JSM-5910LV	Scanning Electron Microscope (SEM) from JEOL
Kimoto180	The beta gauge sampler
MD™ Series	Nafion Dryer
MiniVol	The Air Sampler
Model289	True RMS Digital Multimeter from Fluke
Model2025	PM2.5 Sequential Air Sampler from Partisol-Plus
Model3081	Scanning Mobility Particle Sizer from TSI
Model3321s	the aerodynamic particle sizer from TSI Company
Model3775	the condensation particle counter from TSI Company
Model3776	Condensation Particle Counter from TSI Company
Model521721	DC High Voltage Power Supply from Leybold Didactic
Model6517A	Electrometer from Keithley
Model80K-40	High Voltage Probe from Fluke
Partisol-Plus	The Sequential Air Sampler
PD™ Series	Nafion Dryer
PQ2000	The FRM air sampler from BGI Company
TE-EDM 180	The continuous PM monitor model TE-EDM 180
TEOM1400	The continuous PM monitor model TEOM

## ข้อความแห่งการริเริ่ม

- ๑) ระบบควบคุมและฐานข้อมูลอัลกอริทึมใหม่ ใช้ระบบฐานข้อมูลแบบคลาวด์และการควบคุมระยะไกลสำหรับการวัดพีเอ็มในชุมชนนิพนธ์นี้เป็นอัลกอริทึมใหม่ ในขณะที่เครื่องวัดพีเอ็มแบบอื่นทั่วไปใช้การบันทึกข้อมูลลงในหน่วยความจำภายในเครื่อง เครื่องวัดที่พัฒนาขึ้นนี้ใช้ซอฟต์แวร์แลปวิวในการบันทึกข้อมูลการวัดพีเอ็มลงในไฟล์เซอเวียในเครื่องคอมพิวเตอร์ (พีซี) และมีการส่งข้อมูลการวัดนี้ไปยังระบบคลาวด์ด้วยซอฟต์แวร์ครอบป้อง โดยมีความจำเป็นต้องเชื่อมต่อเครื่องคอมพิวเตอร์กับระบบอินเทอร์เน็ต (ไวไฟ หรือ โมเด็มจีเอสเอ็ม) สำหรับส่งข้อมูลการวัดไปยังระบบคลาวด์โดยอัตโนมัติ ระบบนี้สามารถแสดงผลการวัดแบบเวลาจริง และสามารถควบคุมระยะไกลจากเครื่องคอมพิวเตอร์เครื่องอื่นหรือสมาร์ตโฟนได้
- ๒) ส่วนการให้ประจุนุภาคและชุดดักจับอนุภาคแบบ ๒ ใน ๑ เป็นชุดเดียวกัน ชุดให้ประจุนุภาคแบบยูนิโพลาร์ส่วนใหญ่เป็นการให้ประจุแบบโคโรนาดีสชาร์จ (โดยเฉพาะขั้วอิเล็กโทรดแบบเข็ม) สำหรับสร้างไอออนให้กับอนุภาคละอองลอย ชุดให้ประจุบางแบบอาจใช้ตะแกรงตัวนำและแรงดันขับหรือแผ่นแรงดันสูงสำหรับผลักให้อีออนไปยังพื้นที่ให้ประจุ ในขณะที่ชุดให้ประจุบางแบบใช้อากาศสะอาดนำไอออนไปผสมกับอนุภาคละอองลอยในพื้นที่ให้ประจุ สำหรับชุดให้ประจุแบบโคโรนาเข็ม-กรวย จำเป็นที่จะต้องมิชุดดักจับไอออนหลังจากกระบวนการให้ประจุ ส่วนการให้ประจุนุภาคในชุมชนนิพนธ์นี้ เป็นการรวมระหว่างชุดให้ประจุแบบยูนิโพลาร์โคโรนาและชุดดักจับไอออนเข้าไว้ด้วยกัน ซึ่งสามารถลดผลกระทบจากไอออนหลังจากกระบวนการให้ประจุได้ (เช่นการให้ประจุชั้นนอกพื้นที่การให้ประจุ)
- ๓) ชุดคัดแยกขนาดอนุภาค ชุดด้วยฟาราเดย์และวงจรรีเล็กโทรมิเตอร์แบบ ๓ ใน ๑ เป็นชุดเดียวกัน อุปกรณ์วัดพีเอ็มในอากาศที่ใช้หลักการทางไฟฟ้าทั่วไปมีการแยกส่วนระหว่างชุดคัดแยกขนาดอนุภาค กับชุดตรวจวัดสัญญาณอนุภาค หรือมีการแยกแหว่งด้วยฟาราเดย์และวงจรรีเล็กโทรมิเตอร์ ทำให้มีการสูญเสียที่อนุภาคและที่สัญญาณไฟฟ้า ระหว่างอุปกรณ์ที่แยกกันนี้ การสูญเสียอนุภาคมักเกิดกับท่ออากาศชนิดที่ไม่เป็นตัวนำไฟฟ้า ในขณะที่สัญญาณไฟฟ้าระดับต่ำจะสูญเสียที่จุดเชื่อมต่อไฟฟ้า และจากสัญญาณรบกวนภายนอก การรวมชุดคัดแยกขนาดอนุภาค ชุดด้วยฟาราเดย์และวงจรรีเล็กโทรมิเตอร์เข้าไว้ด้วยกัน ทำให้การ

ไหลอนุภาคภายในมีระยะที่สั้น และสามารถลดการสูญเสียในท่อได้ นอกจากนี้วงจรถือเล็กโพรมิเตอร์ที่อยู่ใต้ชุดถ้วยฟาราเดย์จะมีเสถียรภาพสูง และมีความเหมาะสมต่อการวัดสัญญาณระดับต่ำถึง  $10^{-5}$  (เฟมโต)

- ๔) การหาค่าสหสัมพันธ์ระหว่างความหนาแน่นมวลกับประจุ ตามที่ ยูเอส อีพีเอ กำหนดการวัดเปรียบเทียบของเครื่องมือวัดที่จะยื่นขอการรับรองมาตรฐาน ระบุว่าการวัดพีเอ็ม ๑๐ จะต้องวัดในช่วงที่ต่ำกว่าและสูงกว่า ๖๐ ไมโครกรัมต่อลูกบาศก์เมตร สำหรับค่าเฉลี่ยราย ๒๔ ชั่วโมง และในช่วงที่ต่ำกว่าและสูงกว่า ๓๐ ไมโครกรัมต่อลูกบาศก์เมตร สำหรับค่าเฉลี่ยราย ๒๔ ชั่วโมงของพีเอ็ม ๒.๕ ตามที่แสดงในตารางที่ ๒.๓ งานวิจัยการเปรียบเทียบการวัดส่วนใหญ่เป็นการทดสอบเปรียบเทียบในช่วงเวลาที่สั้น และบางงานทดสอบวัดกับฝุ่นที่มีความเข้มข้นน้อย สำหรับการทดสอบวัดเปรียบเทียบในชุมชนนี้ ได้ทำการเปรียบเทียบกับเครื่องมือมาตรฐานแบบที่ออม เบต้าเรย์ และเครื่องวัดเทคนิคทางแสงในระยะเวลาสั้น สำหรับการวัดพีเอ็ม ๑๐ พีเอ็ม ๒.๕ และ พีเอ็ม ๑.๐ ค่าสหสัมพันธ์แบบกำลังของพีเอ็ม ๑๐ ระหว่างเครื่องพีเอ็ม อี๊กกับเครื่องมือวัดมาตรฐานถูกคำนวณจากข้อมูลค่าเฉลี่ยราย ๒๔ ชั่วโมงของการวัดเปรียบเทียบในช่วง ๑๑.๑๕/๒๗.๖๗ ไมโครกรัมต่อลูกบาศก์เมตร ในช่วง ๒๘.๓๔/๑๕๕.๗๒ ไมโครกรัมต่อลูกบาศก์เมตร ในช่วง ๑๓.๗๔/๘๒.๐๗ ไมโครกรัมต่อลูกบาศก์เมตร และในช่วง ๒๐.๕๕/๖๕.๕๘ ไมโครกรัมต่อลูกบาศก์เมตร ในขณะที่ค่าสหสัมพันธ์แบบกำลังของพีเอ็ม ๒.๕ คำนวณจากข้อมูลค่าเฉลี่ยราย ๒๔ ชั่วโมงของการวัดเปรียบเทียบในช่วง ๗.๖๒/๓๖.๘๘ ไมโครกรัมต่อลูกบาศก์เมตร และค่าสหสัมพันธ์แบบกำลังของพีเอ็ม ๑.๐ คำนวณจากข้อมูลค่าเฉลี่ยรายชั่วโมงของการวัดเปรียบเทียบในช่วง ๓๑.๖๓/๕๘.๕๘ ไมโครกรัมต่อลูกบาศก์เมตร

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่  
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## STATEMENTS OF ORIGINALITY

- 1) **New Algorithm for Database and Control System:** The cloud database and remote control system of this thesis is a new PM measurement algorithm. Other PM detectors based on internal data logger. This detector used Labview software for write the PM measuring data into CSV file at the personal computer (PC) and upload data to cloud system by Dropbox software. This PC was needed connect to internet system (Wi-Fi, or GSM modem) for upload the data to the cloud system automatically. This system can be real-time monitor and remote control from anywhere by other PC or smart phone.
- 2) **Two-in-One Particle Charging Section:** Most unipolar chargers that use corona discharge (especially a needle electrode type) for generating the ion charges to aerosol particle has high concentration ion that does not stick with the ion. Some prototypes use a conductive mesh and a driving voltage or high voltage plate for getting an ion in to the charging zone, while some prototypes use the sheath air to get the ion into the charging zone. (Intra and Tippayawong 2009; Kimoto *et al.* 2010; Intra and Tippayawong 2011; Li and Chen 2011; Qi *et al.* 2007; Alguacil and Alonso 2006; Kruis and Fissan 2001; Intra *et al.* 2013). For the needle-cone types of corona charger, the ion trap is needed after charging process (Intra and Tippayawong 2011; Intra *et al.* 2014). The particle charging section of this thesis was a combination between the unipolar corona charger and the ion trap together, which can reduce effect from the ion after the charging process (such as the net charge distribution was charged).
- 3) **Three-in-One of a PM Classifier, Faraday Cup and Electrometer:** Conventional electrical analyzers for measuring PM in the air have separate units for particle size classifier and sensor (Shimada *et al.* 2000; Intra and Tippayawong 2015; He *et al.* 2007) or Faraday cup and electrometer circuit (Intra and Tippayawong 2008; Laitinen *et al.* 1996; Marjamaki *et al.* 2000; Jarvinen *et al.* 2014; Yao and Yoon 2000). The particle loss and the electrical loss between these components can be

high. The particle loss may be on the nonconductive air tube, while an ultra-low measuring signal may loss in a connector and has the interference signal. The combination of three parts resulted in a short path for aerosol flow and particle loss on the tube can be reduced. In addition, the electrometer circuit under the Faraday cup was stable (Amin *et al.* 2006) and appropriate for measuring ultra-low current signal in  $10^{-15}$  (Femto) levels.

- 4) Regression between Mass Concentration and Charge Concentration: According to US EPA for comparison between a candidate instrument for certification. Acceptable sample sets for PM<sub>10</sub> must be under/over  $60 \mu\text{g}/\text{m}^3$  in 24-h average, and under/over  $30 \mu\text{g}/\text{m}^3$  in 24-h average for PM<sub>2.5</sub>, as shown in Table 2.3. Most research studies involved a short comparison test and low concentration (Mohtar *et al.* 2013; Lopez *et al.* 2012; Chung *et al.* 2001; Wanjura *et al.* 2008; Zhu *et al.* 2007; Huang 2007; Venkatachari *et al.* 2006; Yanoskey *et al.* 2002; Yanosky and MacIntosh 2001; Cyrus *et al.* 2001; Ramachandran *et al.* 2000; Tsai and Cheng 1996). In this thesis, the detector was compared with the standard detectors including TEOM, Beta, and light scattering technique for a long time for PM<sub>10</sub>, PM<sub>2.5</sub>, and PM<sub>1.0</sub>. The power regression of PM<sub>10</sub> between the detector and the standard detectors was calculated from the comparative data with 11.15/27.67  $\mu\text{g}/\text{m}^3$ , 28.34/195.72  $\mu\text{g}/\text{m}^3$ , 13.74/82.07  $\mu\text{g}/\text{m}^3$ , and 20.99/69.98  $\mu\text{g}/\text{m}^3$  in min/max range of 24- h average. While, the power regression relation of PM<sub>2.5</sub> was calculated from the comparative data with 7.62/36.88  $\mu\text{g}/\text{m}^3$  in min/ max range of 24- h average. The power regression relation of PM<sub>1.0</sub> had 31.63/58.58  $\mu\text{g}/\text{m}^3$  in min/max range of an hour average.