CHAPTER 1

Introduction

This Chapter serves as an introduction to the thesis and the objectives of the current work. First Section of the Chapter presents the current state and significance of knowledge on the main source of air pollution that generate from the energy activities, illness from air pollution, and measuring devices for aerosols using the electric principle. The second Section presents literature reviews of the already existing impact of air pollution from energy use, health effect from particulate matter (PM), and the airborne PM measuring devices, including the working principle of each device, the impactor technique for selection of particle size, the field test and compare a measuring device, and patent for fast measuring the airborne PM. The aims, benefits, and scope of the current study are also presented in the last Section of the Chapter.

1.1 Historical Background

The main source of air pollution is generated from energy consumption in four major economic sectors including power generation, transportation, industry and other economic sectors (EPPO 2015). Since 2012, diesel exhaust emission was classified as carcinogenic and considered the primary source (WHO 2010, 2016). David (2000) studied the measurement of engine exhaust particle size and presented at the University of California, Davis on February 2000. Figure 1.1 shows the typical diesel particle size distribution. A significant fraction is nanoparticles (Intra and Tippayawong 2007). There are special concerns about Nanoparticle and health such as increasing deep lung deposition, increasing the number and surface area at the same mass exposure and particles that are non-toxic in the mm size range but may be toxic in the nm range (Seaton *et al.* 1995).

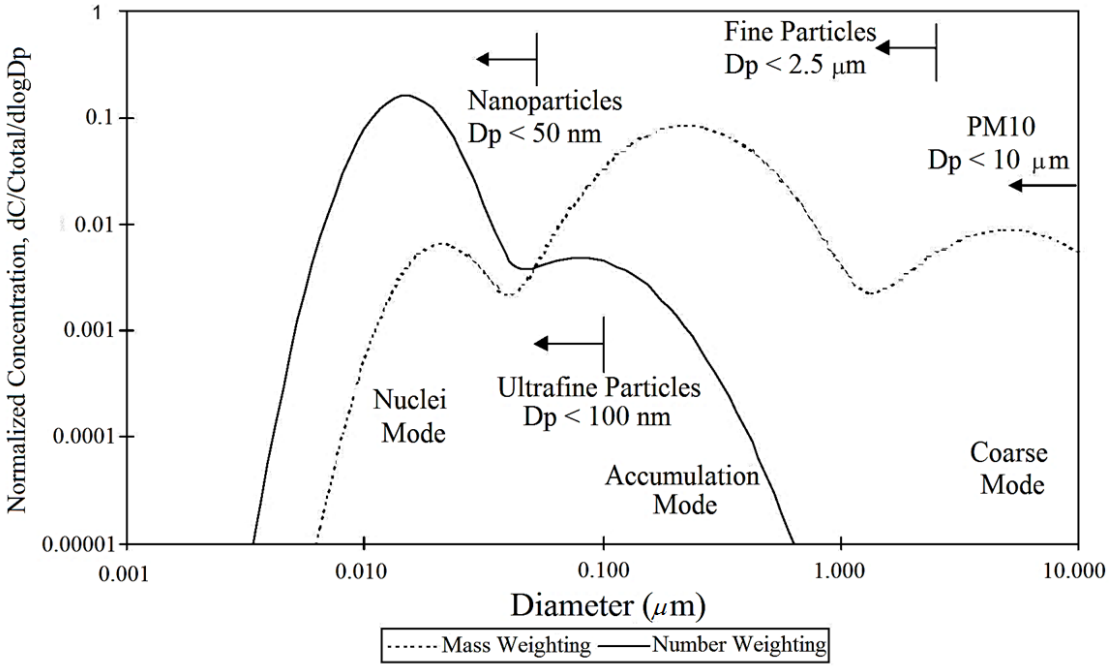


Figure 1.1 The typical diesel particle size distribution (David 2000).

Engine exhaust, especially diesel PM is the cause of the cancer risk as shown in Figure 1.2 (Kurt *et al.* 2013). Small particles can penetrate the human respiratory system deep into the smallest airways and parts of the lungs (Tippayawong 2001; Tippayawong and Damrongsak 2003). Many reports indicate that values of dust are related to human illness and death from respiratory disease (Sopajaree and Pengchai 2007). In addition, a medical report indicates that the smaller dust is a cause of health problems, due to the fact that it can pass into the pulmonary alveoli and accumulate forever. The death from respiratory disease is increased due to air pollution. The disorder occurs when breathing the smaller dust into the lung and dust is eaten by the macrophage cells, causing an increase of the oxidative stress condition in the lung alveoli. If antioxidants can protect or inhibit the oxidative stress condition, this condition causes inflammation and cell death or destroy DNA, which is an important cause for the respiratory disease (Vinitketkumnuen *et al.* 2007). Ambient PM received increased interest due to the consequence of epidemiological studies which shows relationships of a PM concentration and size with significant health effects. There are considerable interests in health effects not only for the regulatory authorities, but also quality management departments, physicians, researchers and peoples (Buonanno *et al.* 2009; Tiwari *et al.* 2012). General air quality standards are defined by the mass of a PM which less than 10 μm (PM10) and

2.5 µm (PM2.5) in aerodynamic diameter, following Part 50 of Chapter I in Title 40 of the CFR (US GPO 2016). While, PM1.0 less than 1 µm in aerodynamic diameter is interesting, due to large volume of scholarly articles, scientific studies, published, newspaper reports and government warnings for the negative health effects which link to a fine particle and concentration (WHO 2010, 2016). When inhaled a PM including PM1.0, PM2.5, and PM10 into body in different ways, it was accumulated and trapped in the lung and cause respiratory disease. At worst, it can be contributed to deadly diseases such as lung cancer, emphysema, edema, emphysema, dementia, heart attacks, other serious disease and link to premature death. In addition, it has an effect to environment, travel, and economy (Vijitwatakarn *et al.* 2004).

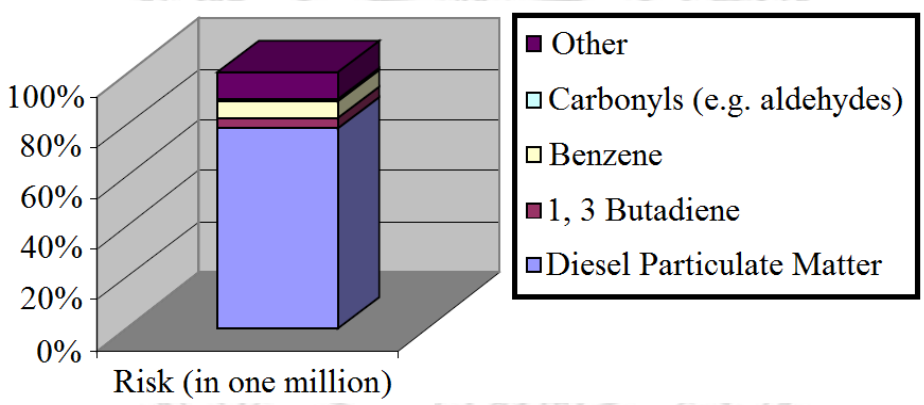


Figure 1.2 The cancer risks from all sources in air ambient (Kurt *et al.* 2013).

The air pollution problem occurs around the world. The United States as the world's leaders recognizes the importance of air pollution by establishing the Environmental Protection Agency or US EPA. US EPA is committed to protecting human health and safeguarding the natural environment, including air, water and soil. In addition, "Protection of Environment" (Title 40) was specified in "Code of Federal Regulations" (CFR) and National Ambient Air Quality Standards (NAAQS) which both standards are applied throughout the world. The air pollution report is in terms of Air Quality Index (AQI), although in some countries it is reported as an Air Quality Health Index (AQHI) or Air Pollution Index (API) for easy understanding to the public. All indexes are calculated from small dust particles in the air, which shows that the airborne PM is an important variable (AQI 2016; CFR 2016; PSI 2016; US EPA 2016). Ambient PM measuring tools according to US EPA announced are separated into reference method and equivalence

method (US EPA 2016). The reference method is based on filtering technique and needs a weighting machine for finding a net mass of a PM. This technique requires a long time and complex procedure. In addition, the measuring tools have many limitations. They cannot report immediately for the reference method. This method is highly reliable but cannot report the PM data in real time. Meanwhile the equivalent method that is a continuous monitor method, including a piezoelectric aerosol mass monitor, beta attenuation mass monitor, light scattering aerosol photometer and aerosol electrometer (CFR 2016; Willeke and Baron 1993). Thailand Pollution Control Depart-ment (PCD) is responsible for configuration of airborne PM tools, characteristics and measurements, calculating, comparing, reporting and measurement of dust in the air. Current continuous monitor devices approved by PCD are a Taper Element Oscillating Microbalance (TEOM) and beta gauge attenuation, or other equivalence method devices that meet requirements according to EPA (PCD 2016). Both continuous devices are high price and must be imported from abroad. A continuous monitor method can get a real data that used for source characterization, evaluation of dangerous air pollution source, and emergency report to peoples (Stephens 1996).

PM is the cause for respiratory diseases. So it is needed to measure the PM, and report PM data in real time to plan and manage the PM source effectively. There are many techniques for fast measurement of PM. The electrical measurement is an interesting technique. Its principle is sample and noncomplex that can be designed and assemblied in Thailand. Electrical technique is a fast measurement method that is used widely to measure particles concentration and size distribution. An electrical aerosol instrument has the simplest form for measuring aerosol concentration that consists of an electrometer and a filter inside a Faraday cage. A filter accumulates a charged particle, sending current signal to the electrometer circuit (Willeke and Baron 1993). Electrical technique has the advantage of simplicity, fast measuring and high stability, popularly used to measure a dynamic aerosol. These include the Electrical Low Pressure Impactor (ELPI) for size range between 10 – 10,000 nm (Jarvinen *et al.* 2014; Keskinen *et al.* 1992; Marjamaki *et al.* 2000; Rostedt *et al.* 2009), the electrical aerosol spectrometer (EAS) of Tartu University for size range between 10 – 10,000 nm (Tammet *et al.* 1998, 2002), and an electrostatic sensor or DustDETEC (Intra and Yawootti 2012, Intra *et al.* 2013).

For general continuous PM monitor, these was a limit for a measurement range that does not cover between 10 nm to 10 µm in particle diameter. The airborne PM has a diameter between 1 nm to 100 µm such as these from the engine exhaust, smoke, dust storm, sea spray, and industrial PM. The PM between 0.01 to 10 µm are generated from accumulation of smoke, exhaust and steam, while particles between 0.4 to 0.9 µm affect light distribution and dusky sky. The PM that bigger size than 1 µm is caused by a combination of a smoke, ashes, a powdered metal from attrition, carpel, and an insect (Intra and Tippayawong 2008). The PM in air has wide size range. Only one of an existing device (continuous PM monitor) cannot be used to measure wide range. The system that is able to cover the wide range is generally complex, big, and needs more energy, and complex procedure and high costs. In addition, it is not suitable for outdoor operation, and field test. The time responses of the existing devices are rather slow and improper for measuring fast variation PM. Intra and Tippayawong (2008) developed an electrostatic sensor for detecting the number concentration of nm sizer aerosol particles (less than 0.1 µm in diameter). It consists of a size selective inlet, a corona charger, an ion trap, a Faraday cup, an electrometer, a signal conditioning and processing system, and an I/O control and personal computer interface. The Faraday cup electrometer can measure ultra-low current about 10^{-12} A which has output voltage of 10 mV per 1 pA of input signal current. At present, most of PM measuring devices are imported from abroad that are highly expensive, and limited for specific works such as the measurement for report to public, the public health research from air pollution, education and development on the combustion machine, control engine in industrial to reduce the exhaust, measurement and control of traffics.

The aim of this research is to develop a multi-channel airborne PM detector by electrical technique. This device should be able automatically measure PM10, PM2.5, and PM1.0 (both size and number or mass concentration). The PM data can be used to manage and plan the energy use (especially for diesel engine) for traffic, factory/industry, In addition, it should have high sensitivity, fast response, low energy use, and low cost. This research is to study behavior of particles in the inertial impactor, combined charger for three PM sizes, electrostatic sensor on the Faraday cage that can measure ultra-low current, and compare measurements with standard detectors. The effect of humidity,

pressure, flow rate and temperature are considered in this study. The performance is also evaluated long time by field test comparing with standard instruments.

1.2 Literature Reviews

1.2.1 Continuous Particle Measurement Methods. This Section describes continuous PM measurement methods used for measuring concentration of dynamic aerosol mass including a mass and mass equivalent (such as TEOM, Piezoelectric microbalance, BAM, and CAMMS), a visible light scattering (such as Nephelometer, OPC, CNC, APS, and LIDAR), a visible light absorption (such as Aethalometer, particle soot or absorption photometer), and electrical mobility (such as EAA and DMPS) (US EPA 1998).

1) Mass and Mass Equivalent. The particle mass is determined by the inertia, by the properties of electron attenuation, and by the decrease in pressure across small pores in a filter. Four different types of the continuous mass measurement monitors are discussed in the following subsections.

1.1) Tapered Element Oscillating Microbalance (TEOM). TEOM device is a direct mass measurement that collects mass on a vibrating collection substrate and changes frequency of oscillation. TEOM draws air through a hollow tapered tube (Figure 1.3), with the wide end of the tube fixed, while the narrow end oscillates in response to an applied electric field. Near a mass base plate the wide end of the tube is firmly mounted. A replaceable collection medium such as a filter or impaction plate is installed on the narrow end supports for oscillation. Aerosol particle is collected in a filter cartridge, but the filtered gas is then drawn through the hollow tube that controlled by an automatic mass flow controller. (John *et al.* 1998; Willeke and Baron 1993).

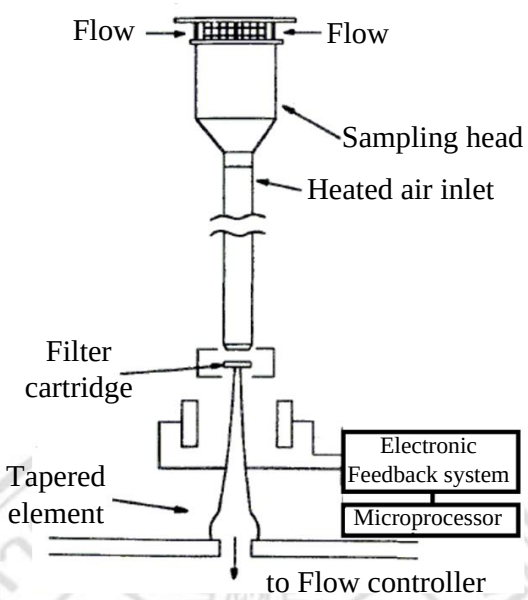


Figure 1.3 Schematic diagram of the TEOM ambient particulate monitor (Harvey and Erich 1991).

1.2) Beta Attenuation Monitor (BAM). The beta gauge method of mass measurement depends on the near exponential decay in the amount of beta particles transmitted through a thin sample as the density is increased. The beta particles are emitted as a continuous energy distributed by a radioisotope source, and their intensity is measured by a suitable electron counter. The method is automatic for large- scale applications and has the advantages of instrumental simplicity. The dynamic range of sensitivity is well matched to the mass range of interest in aerosol monitoring in which thin membrane filters are the substrates. The beta gauge instrument consists of a beta source, a filter for collecting a PM sample, and the detector, as shown in Figure 1.4. The measurement principle is about determining the total flux in a continuous beta particle spectrum emitted by the beta source and transmitted through the sample on filter. Under the proper experimental conditions, the transmitted flux (I) can be found from the relationship of the incident flux (I_o), the mass absorption coefficient for beta absorption (μ) in cm^2/g unit, and the mass thickness of the sample (x) in g/cm^2 unit. The mass absorption coefficient is normally determined through a calibration procedure involving the measurement of a series of known standards which bracket the mass range of interest. The incident flux (I_o) can either be derived during the same calibration procedure or, if

the interval between successive measurements is short, the value of the incident flux can be made to cancel by calculating the ratio between transmitted fluxes measured with and without the particle deposit. The latter case applies for certain beta gauge designs where continuous particle deposition is monitored. (Willeke and Baron 1993). The detector measures the attenuation of 0.01-0.1 MeV beta particles from a beta source through a particle-laden filter (McMurry 2000). Under proper conditions in the beta control chamber, the transmitted flux is corresponding to the sample mass on the filter. This technique has fast response. But, there may be error if a relative humidity (RH) of a sample is more than 80% RH. This error can be decreased by the having mild heating at an aerosol sample (Wilson *et al.* 2002).

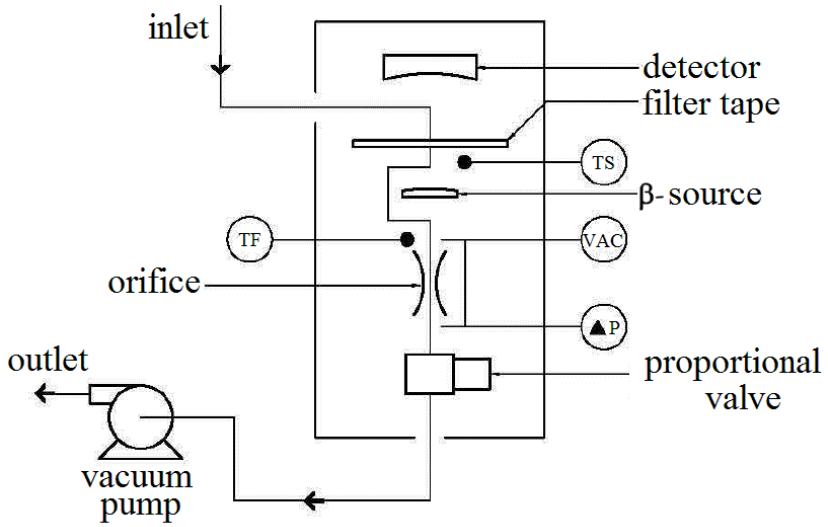


Figure 1.4 Flow schematic of model 5014i beta ray (Thermo Scientific 2016).

1.3) Piezoelectric Microbalance. Particle mass is measured by depositing the particle on the crystal surface, by impaction or electrostatic precipitation as shown in Figure 1.5. The collection efficiency has to be defined as a function of particle size for the quantitative measurements. Although, the mechanical coupling of large particles to the crystal is uncertain, but the quartz crystals have sensitivities of several hundred hertz per microgram. That is good for the sensitivity results because it can measure the typical mass concentration at about 100 μg/m^3 in less than one min (John *et al.* 1998).

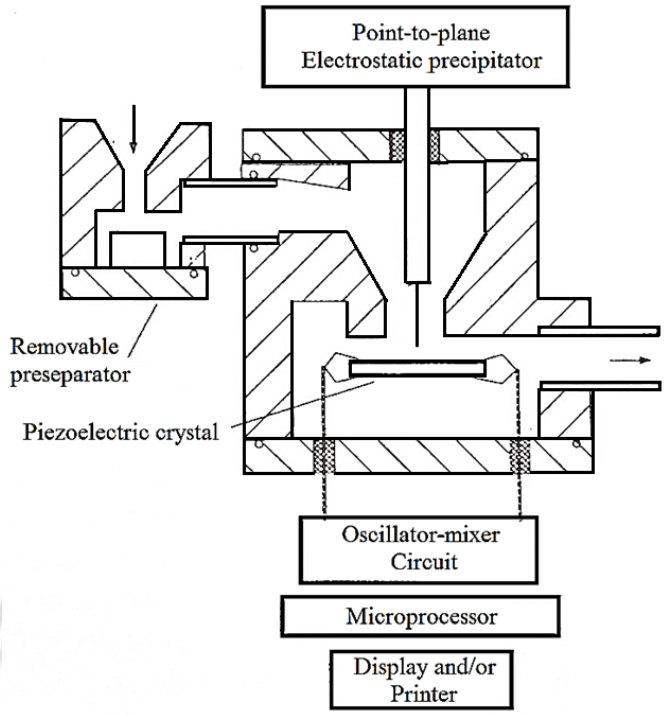


Figure 1.5 Schematic diagram of piezoelectric microbalance (Willeke and Baron 1993).

1.4) Pressure Drop Tape Sampler (CAMMS). The CAMMS is a continuous ambient mass monitor system that determines the fine particle mass. It is based on measuring the increase in pressure drop across a membrane filter during particle sampling which design and develop at Harvard University. The CAMMS reports the PM concentrations in mass per volume or micrograms per cubic meter of air ($\mu g/m^3$). The filter tape has rotated to new section every measurement period, allowing particles to remain in or close to equilibrium with the sample air during collection. The CAMMS consists of 4 main parts as shown in Figure 1.6, including (1) a Well Impactor Ninety Six, (2) two round nozzle virtual impactors that having 50% cut points of aerodynamic diameter at 1.0 and 0.40 mm, respectively, (3) the PM2.5 monitoring channel, and (4) a data acquisition and control system (John *et al.* 1998; Peter *et al.* 2000).

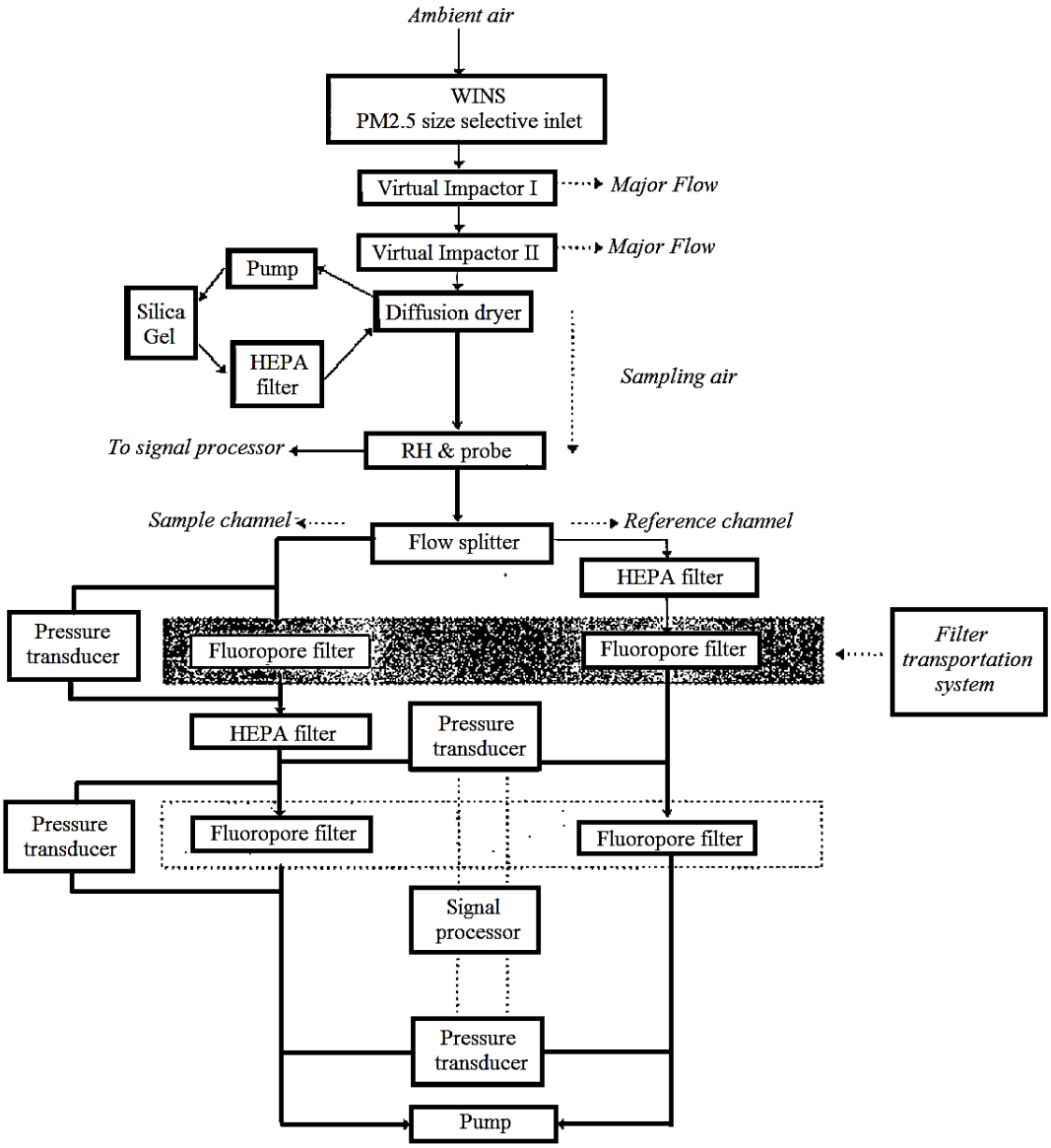


Figure 1.6 Schematic of the CAMM (Peter *et al.* 2000).

2) Visible Light Scattering. Particle light scattering is determined by illuminating particles, and measuring the scattered intensity at different orientations from the light source. The mass concentration from the intensity of the scattered light method is compared with a collocated filter measurement. Five different types of instruments in Particle light scattering Measurements are discussed in the following subsections.

2.1) Nephelometer. The original nephelometer was applied to quantify airport visibility during World War II. Beuttell and Brewer (1949) studied and designed a basic integrating nephelometer. The nephelometer was used for determination of aerosol size distributions. Nephelometer, needs the sensing chamber that have minimal

temperature charge. Internal ambient temperatures are controlled in such a way that allows ambient air to flow unmodified over a short distance. Closing the inlet door allows for the introduction of a calibration gas. This passive sampling scheme alters the temperature of the air sample by less than 0.5 °C. The light scattering method is highly sensitive to a RH exceeding 80% (John *et al.* 1998). Figure 1.7 shows a schematic diagram of a forward laser light scatter nephelometer system of E-Sample from MetOne instrument Company. Sample air is drawn into the instrument by a vacuum pump. The flow rate is controlled based on actual conditions for an accurate cut-points through sharp-cut cyclones, and to accurately determine the sampled volume. This sample air is drawn through the laser engine module, where an internal visible laser diode beam is collimated and directed through the sample air stream. The particulate in the sample air stream scatters the laser light through reflective and refractive properties. This scattered light is collected accumulate on a silicon photodiode detector at a near-forward angle, and has a continuous, real-time measurement of this electronic signal (Met One 2002).

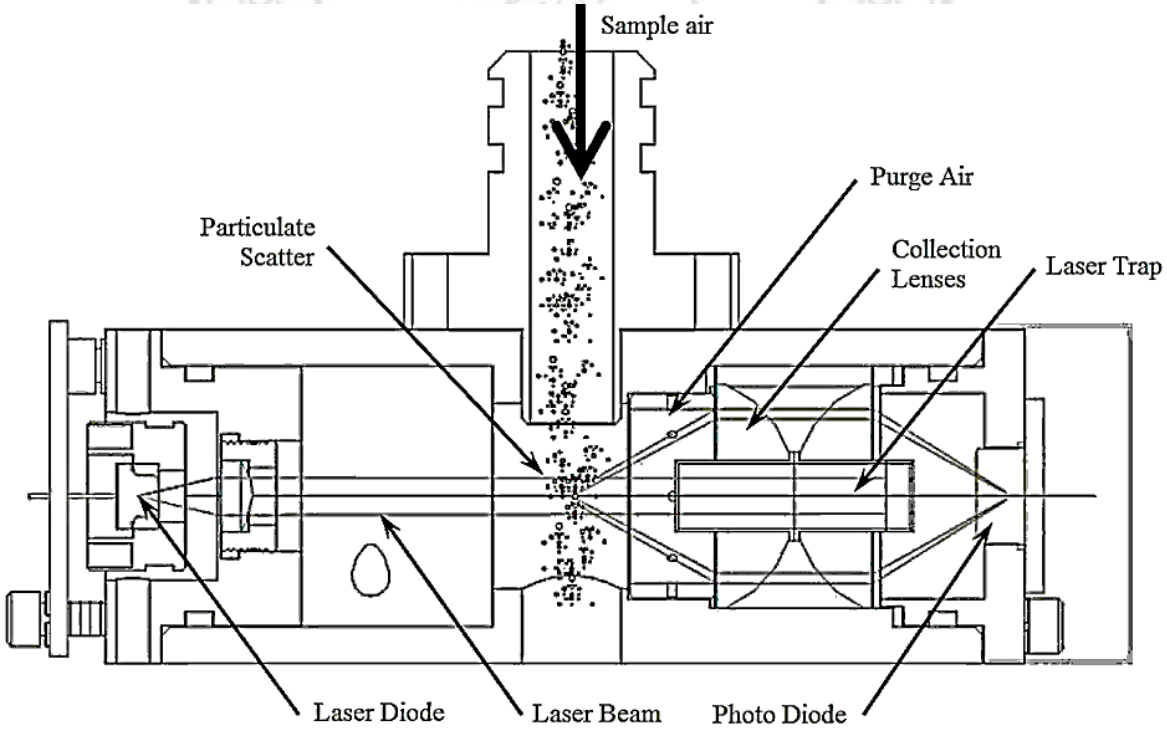


Figure 1.7 Schematic diagram of E-sampler from MetOne Company (Met One 2002).

2.2) Optical Particle Counter (OPC). Optical Particle Counters or OPC is one of a light scattering method that can detect the size and number of a sample

particles. DustTrak^{TM} 8250 from TSI is a commercial light scattering device. It is a portable PM monitor used for measuring particle concentrations corresponding to PM10, PM2.5, and PM1.0. It is a laser photometer which shows PM data on display and recording into data logger. Measuring range between 0.001 to 100 mg/m^3 and ±0.001 mg/m^3 in resolution or ±0.1% of reading. This automatic PM monitor device is popular and compared with reference method devices in several research (Chung *et al.* 2001; Kim *et al.* 2004; Ramachandran *et al.* 2000; Yanosky *et al.* 2002). While, DustTrak DRX8533 from TSI is new portable PM monitor that can simultaneously measure both mass and size fraction (TSI Company 2015). It operation diagram is shown in Figure 1.8. It can operate as light-scattering laser photometers and used for measuring PM1, PM2.5, PM10 and total PM fractions. Particle size range is between 0.1 to 15 µm in diameter and used 3.0 L/min of aerosol flow rate. It can operate under 95% RH without a condensing system.

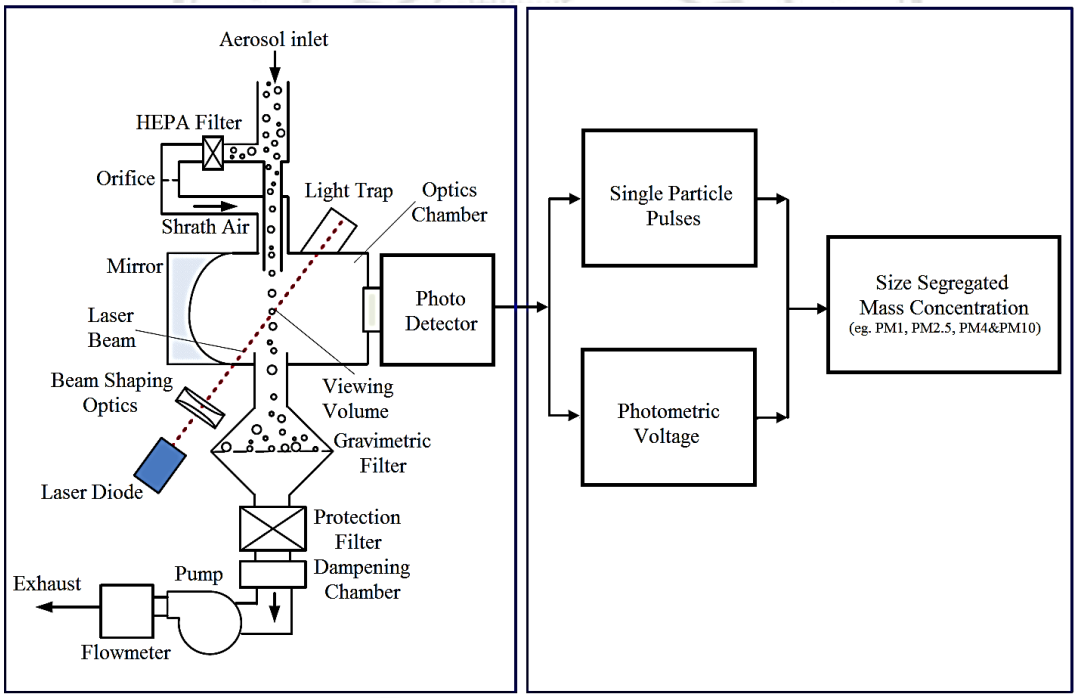


Figure 1.8 DUSTTRAK^{TM} DRX from TSI Company (TSI Company 2012).

2.3) Condensation Nuclei/Particle Counter (CNC/CPC). The CNC or CPC sense ultrafine particles by causing them to grow to a size that is efficiently detected. The CNC is the most practical instruments for determining ultrafine particle concentrations between 0.003 to 1 µm diameters. It is not as accurate as other continuous methods for determining PM2.5 or larger size (John *et al.* 1998). Figure 1.9 shows a

schematic diagram of the condensation particle counter. The aerosol sample flows through a heated saturator and is drawn into the CPC inlet by an internal vacuum pump. The inlet flow can be configured for high-flow mode operation at 1.5 L/min or low-flow mode operation at 0.3 L/min. Both flow modes, the sample aerosol flow passes through the sensor part, which consists of the saturator, condenser, and optics. The CPC uses a laser-diode light source and diode photodetector to collect scattered light from particles. A high resolution color Liquid Crystal Display (LCD) display shows real-time graphs of number concentration. The CPC has a critical flow pump for high accuracy volumetric flows. In addition, it can also be used with an external vacuum pump (TSI Company 2007).

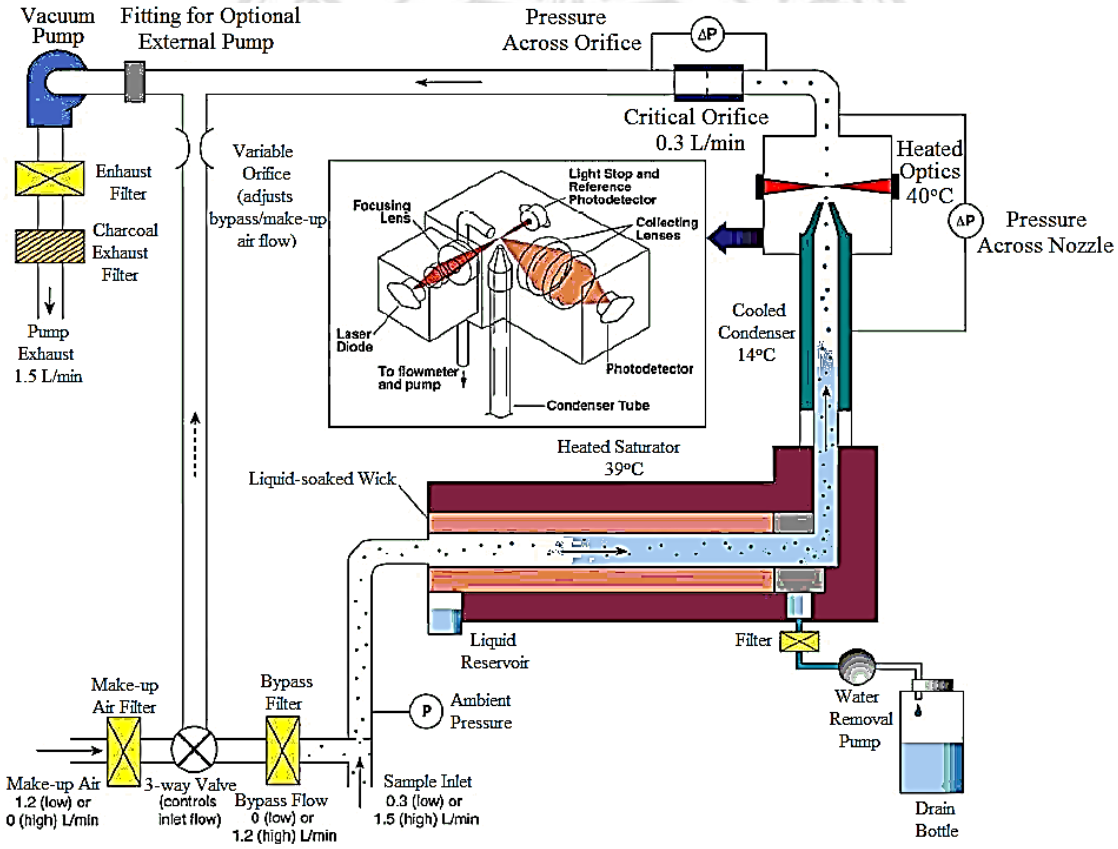


Figure 1.9 Schematic diagram of condensation particle counter (TSI Company 2007).

2.4) Aerodynamic Particle Sizer (APS). The APS uses light scattering principle as well as the time-of-flight of sampled particles. The measured aerodynamic diameter can be converted to mobility-equivalent diameter or volume-equivalent diameter. A converging nozzle of the APS has a function for accelerating the air stream.

Particles that have larger inertia than the gaseous component, and therefore lag in acceleration and speed behind the air stream. Particles with higher mass achieve lower velocities than those with lower mass. Each particle is detected by laser at the beginning and the end of a fixed path length to determine the time taken to traverse this path (time-of-flight). The APS measures particles between 0.5 to 30 μm in diameter (John *et al.* 1998). Figure 1.10 shows a schematic diagram of the aerodynamic particle sizer from TSI. Time-of-flight particle sizing technology involves measuring the acceleration of aerosol particles in response to the accelerated flow of the sample aerosol through a nozzle. The aerodynamic size of a particle determines its rate of acceleration, with larger particles accelerating more slowly due to increased inertia. As particles exit the nozzle, the time of flight between the Model3321s two laser beams is recorded and converted to aerodynamic diameter using a calibration curve. Previous time-of-flight spectrometers used two tightly focused laser beams, resulting in two distinct signals for each particle. The Model3321 also provides a light scattering measurement by examining each particle's side scatter signal intensity. This measurement produces a second distribution that can be plotted against aerodynamic size to gain additional information about the aerosol sample (TSI Company 2012).

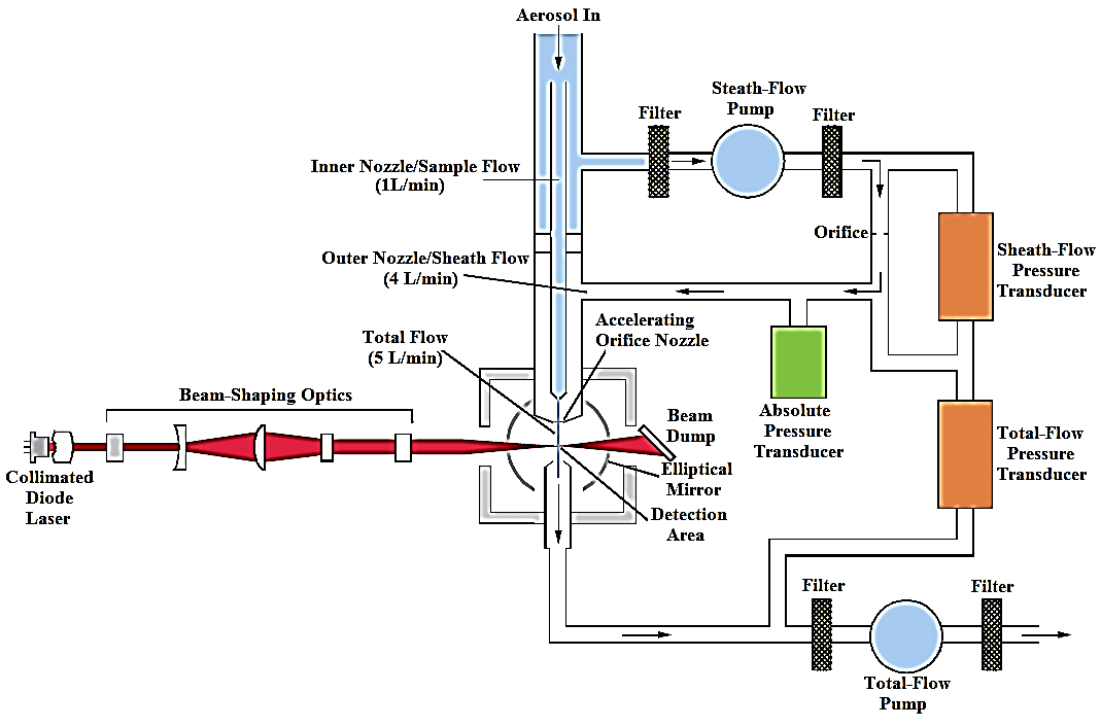


Figure 1.10 Schematic diagram of the aerodynamic particle sizer (TSI Company 2012).

2.5) Light Detection and Ranging (LIDAR). The LIDAR is based on a principle measuring a light scattered in the direction of the light source or "back scattering" along a sight path. Aerosol LIDAR is used for determining aerosol distributions while differential absorption LIDAR (DIAL) can measure concentrations of several gases. A basic aerosol LIDAR system consists of a receiver and a transmitter located next to each other. The transmitter is a pulsed laser that can send a short pulse of collimated light into the atmosphere. A small part of this pulse is scattered back into the receiver by gas molecules and suspended particles. Light scattered at a distance r arrives at the receiver after a round trip time ($t = 2r/c$), while c is the light speed. The LIDAR returns signal S as a function of distance r, depending both on the backscattering coefficient $\beta_{(r)}$, at the distance r and the path integrated extinction $\sigma_{(r)}$, between LIDAR location r_0 and range r. For each measured signal $S_{(r)}$, there are two atmospheric parameters $\beta_{(r,\lambda)}$ and $\sigma_{(r,\lambda)}$, that need to be determined. The absolute system calibration is generally unknown. The LIDAR equation is, therefore, under-determined and cannot be solved without additional assumptions or data. The DIALs are made at two different wavelengths with substantially different absorption coefficients for the gas of interest. The range resolved gas concentration is calculated from the ratio of the LIDAR signals at the two wavelengths. This wavelength with the larger absorption coefficient is referred to as "on-line", while the smaller absorption coefficient is referred to as "off-line", respectively. Generally DIAL is used for measuring a number of relevant tropospheric trace gases, including ozone (O_3), sulfur dioxide (SO_2), nitric oxide (NO), nitrogen dioxide (NO_2), ammonia (NH_3), and aromatic hydrocarbons. The commercially DIALs are expensive and must be individually designed or modified for each specific application.

3) Visible Light Absorption. Visible light absorption is a continuous method that can also be used to measure the PM2.5 component consisting of light absorbing particles. Three instruments show a difference of a particle light absorption measurements.

3.1) Aethalometer. The Aethalometer principle is to measure the attenuation of a beam of light transmitted through a filter, while the filter is continuously collecting an aerosol sample. The Aethalometer converts the attenuation measurement on

filter into black carbon mass concentration by using a conversion factor. It can be applied to monitoring an air quality in urban and more remote locations, transport studies, and source characterization.

3.2) Particle Soot/Absorption Photometer (PSAP). The PSAP uses an aerosol light absorption at on a filter for real-time measurement. The PSAP can continuous measurement by monitoring the absorption change in transmittance across a filter for two areas between a particle deposition area and a reference area on the filter. It uses a light emitting diode (LED) at 550 nm serving as light source.

3.3) Photoacoustic Spectroscopy. The Photoacoustic can detect particle light absorption that related to the black carbon concentration. Sensitive Photoacoustic techniques use a light source from a power-modulated laser. The sample air passes through an acoustic resonator, modulating the laser power at its resonance frequency, then the varying pressure disturbance or acoustic signal is amplified by the buildup of a standing acoustic wave in this resonator. The Photoacoustic has a detection limit of about 0.5 Mm-1or 0.05 $\mu g/m^3$ in black carbon particles.

4) Electrical Mobility. The electrical mobility analyzers (EMA) is used for measuring particles smaller than 1 μm. The particle size is found from a mobility equivalent diameter, which can be converted to volume equivalent diameter or aerodynamic diameter. A general EMA consists of (1) a particle charger (diffusion charger type), (2) a particle classifier, and (3) a particle detector as shown in a following subtopic.

4.1) Electrical Aerosol Analyzer (EAA). The EAA was widely applied since 1966 and used to characterize in aerosol studies. The EAA shown in Figure 1.11 was developed by Lehtimaki (1987). The EAA has 10 measuring channels corresponding with particle size between 0.01 to 1.0 μm in diameter. It uses positive charge with an aerosol in a mobility tube, consisting of two coaxial cylinders. The outer tube is grounded and has a negative voltage at the inner tube. When the aerosol flows down in the mobility tube, its mobile fraction is precipitated on the inner tube by electrical forces. The remaining aerosol is detected by an electrometer part that can amplify the ultra-low electrical current and converts to the remaining aerosol in number concentration unit (John *et al.* 1998).

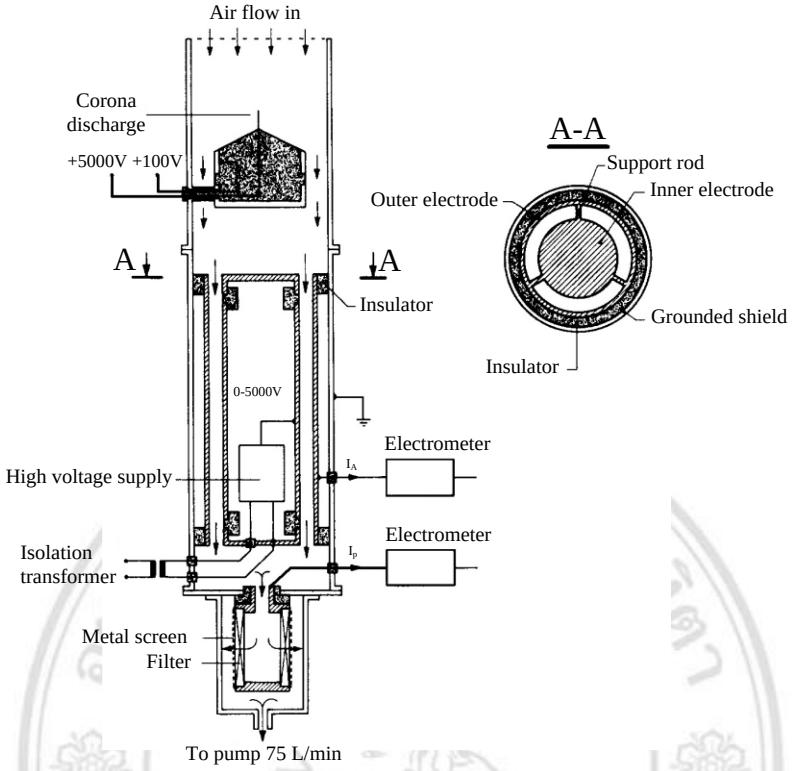


Figure 1.11 Schematic diagram of electrical aerosol analyzer (Lehtimaki *et al.* 1987).

4.2) Differential Mobility Particle Sizer (DMPS). The DMPS shown in Figure 1.12 is developed by Knutson and Whitby (1975), which improves on the EAA by making measurements with much greater size resolution. Generality, measurement times of DMPS by the electrometers can be on the order of one hour, but it can be reduced by using a CNC as detector. Conventional DMPS utilizing a cylindrical geometry is limited for ultrafine particles less than 0.020 μm in diameter due to diffusion losses. The accessible size range can be extended down to 0.001 μm by either modifying the cylindrical DMPS that developed by Reischl (1991) and Winklmayr *et al.* (1991) or by changing to a radial geometry (John *et al.* 1998).

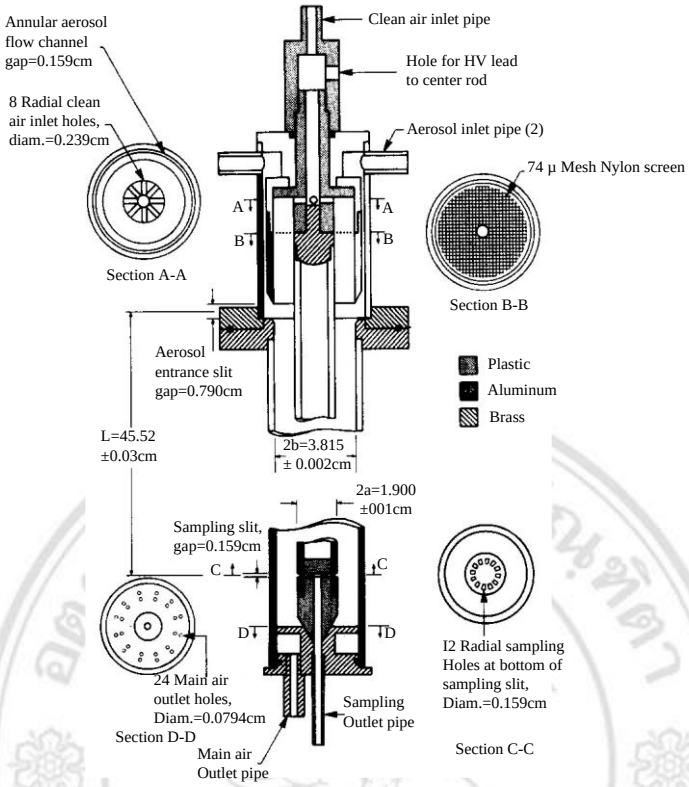


Figure 1.12 Schematic diagram of the differential mobility particle sizer (Knutson and Whitby 1975).

4.3) Electrical Aerosol Spectrometer (EAS). The EAS (Tammet *et al.* 1998, 2002) has DMA for classifying the particle size which can measure particles between 10 nm to 10 μm. The particles are charged by field charger for classifying large particle size in an E-analyzer and diffusion charger for classifying small particle size in a D-analyzer, respectively. It uses an electrometer to detect charge on each particle and send current data to a computer to convert to particle number concentration. The design of the electrical aerosol spectrometer is shown in Figure 1.13.

5) Electrical Technique. Electrical technique is based on measuring the electrostatic charge on a particle which is an important property of aerosols and influences the aerosol behavior. This technique consists of two important parts, including an electrostatic charged mechanism and ultra-low electric sensor. The electrostatic charge on particles was dependent upon the nature of aerosol state. Some particles may be highly charged. There are several techniques for putting electric charge on particles by man-made processes. The ultra-low electrical sensor has a function of the amplifying current

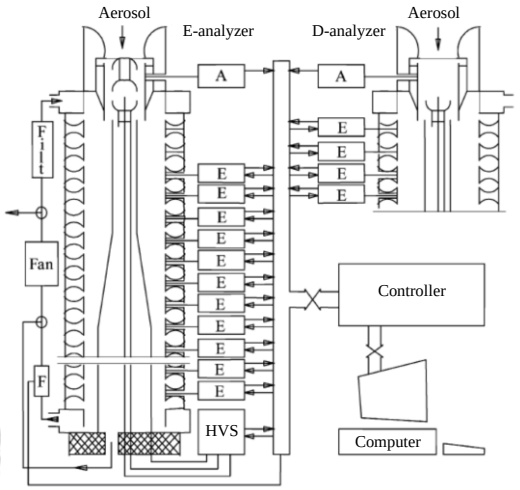


Figure 1.13 Schematic diagram of electrical aerosol spectrometer (Tammet *et al.* 2002).

charge on particles and converting to an electric signal for the processing unit (Willeke and Baron 1993).

5.1) Electrical Low Pressure Impactor (ELPI). The ELPI is a continuous detector that can measure particle size distributions in real time. The schematic diagram is shown in Figure 1.14. ELPI can measure the airborne PM between 0.007 - 10 micrometers. It consists of 12 impactors that set of filter to 13^{th} impactor corresponding to aerosol in the range 0.007 (on the filter), 0.03, 0.06, 0.108, 0.17, 0.26, 0.4, 0.65, 1.0, 1.6, 2.5, 4.4, 6.8 and 10 µm of diameter respectively. ELPI can be set at 10 or 30 L/min of air flow rate. It weighs 35 kg and has the operation temperature between 5 to 40 ^{o}C. The aerosol humidity is between 0 to 90% RH without non-condensing unit. The sensitivity of the measuring system is less than 5 s. The operating system starts by sucking an aerosol into the electric charging part with corona type. After that the particle can pass to the impactor part. The aerosol will pass into the small hole for flow increasing velocity that block by impaction plate in each of impactor steps. This principle makes the large particles accumulated on impaction plate, but small particles can pass into next impactors. The last step impactor is the filter that can collect 0.007 µm. Each impactor is connected to amplifier circuits for measuring current and converting to particle number concentration between $10^{8} – 10^{13}$ particles/m^{3} (Jarvinen *et al.* 2014; Keskinen 1992).

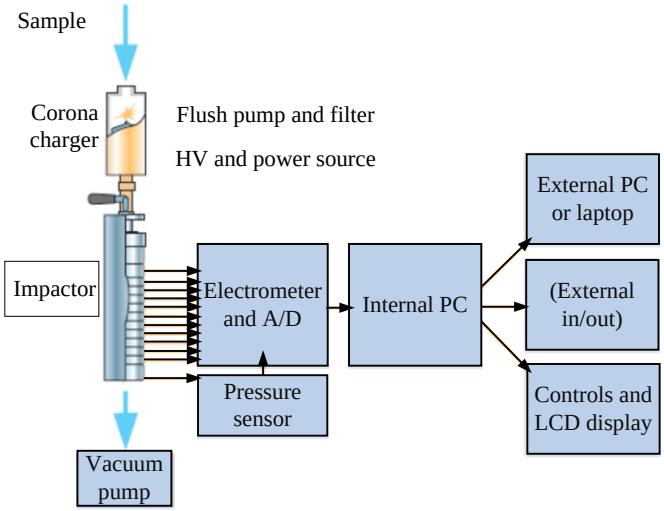


Figure 1.14 Schematic diagram of ELPI^{TM} (Dekati 2015).

5.2) An Analyzer and Sampler for Air and PM2.5. An analyzer and sampler was developed by Intra *et al.* (2010) as shown in Figure 1.15 used to measure air and PM2.5. It can classify PM2.5 by an inertial impactor technique with 5 L/min air flow rate. The coronal charger was applied to generate a high concentration ion about 10^{12} to 10^{17} ions per cubic meter (ions/m^3) into the particles. The electrometer circuit is the particle charge sensor which can measure and amplify the current from particles between 10 fA to 10 pA. Field validation was compared against two miniVolume of AIRmetrics. It was found that particles current between 0.03 to 0.123 μA corresponding with mass concentration between 73 to 140 μg at 5 L/min flow rate, respectively.

5.3) An Electrostatic Sensor or DustDETEC. Schematic diagram of DustDETEC shown in Figure 1.16 is an electrostatic sensor for the continuous monitoring of particulate air pollution. It is used for measuring particle charge that collected on a HEPA filter (Intra and Yawootti 2012; Intra *et al.* 2013; Yawootti and Intra 2013). The particle size selector can classify PM2.5 or PM10 from airborne PM by inertial impaction principle. This device used the charge detection principle at the particle on the HEPA filter. This detector consists of the air-inlet size selector, the particle charger, the high efficiency filter (HEPA filter), the air flow sensor and controller, vacuum pump, high voltage power supply (DC), the ultra-low amplifier, the analog to digital converter, processor and controller. The operation starts at sampling air by vacuum pump. Then the sample is passed to the inlet size selector for classifying particles that larger than the

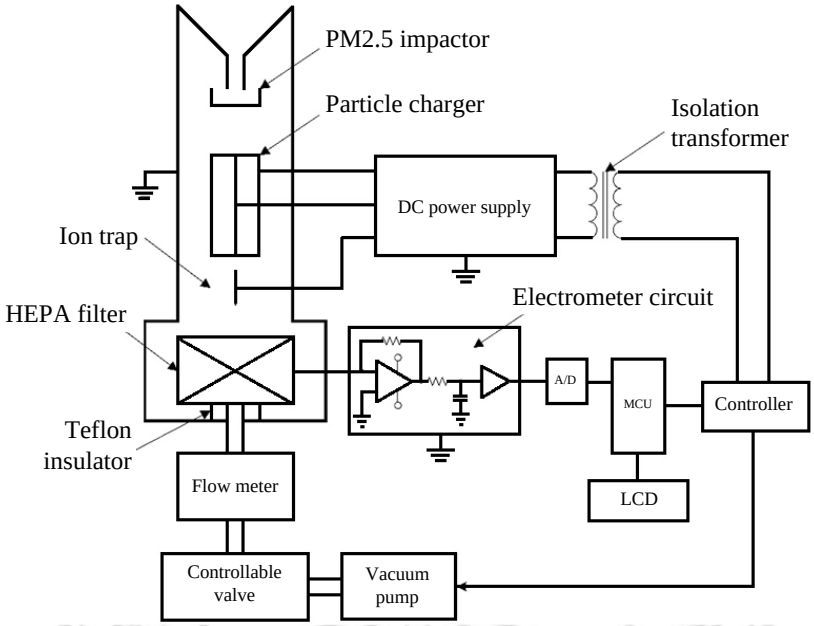


Figure 1.15 Schematic diagram of an analyzer and sampler (Intra *et al.* 2010).

cutoff size out of the sample. The air flow is controlled by the air flow sensor and controller. After that, PM is passed to the corona wire charger. The DC high volt is set at 2.8 kV for generating positive ion at corona discharge zone (combine charging type). The particle charger can generate high concentration ions at about 10^{12} to 10^{14} ions/m^3 in the charging zone. The PM is charged and passed to the ion removal part. The high mobility ion is trapped in this part. Then, the PM is accumulated on the 47 mm filter in the Faraday cage. The measured current is related to the particle number concentration and particle mass concentration. Particles get ions from the corona charger and has ultra- low electrometer for amplifying a signal before sending to the microcontroller unit. An investing opamp circuit is used in this electrometer. Comparison with analytical and numerical analysis revealed that the input current between 0 - 100 fA and 0.1 to 100 pA corresponded to 5.7% and 7.4% error, respectively. A basic test for PM10 continuous measuring with the ParticleScan and the 1400 TEOM for 4 h showed that less than 5% in difference data occurred. It can show particle results on the LCD display and smart phone or personal computer with a wireless connection. This continuous PM monitor can be operated alone about 20 h by battery power supply inside. The air flow was set at 5 L/min by DC suction pump and flow controller and have timer for timing set. The device used power from the battery and can charge by 220 VAC 50 Hz plug.

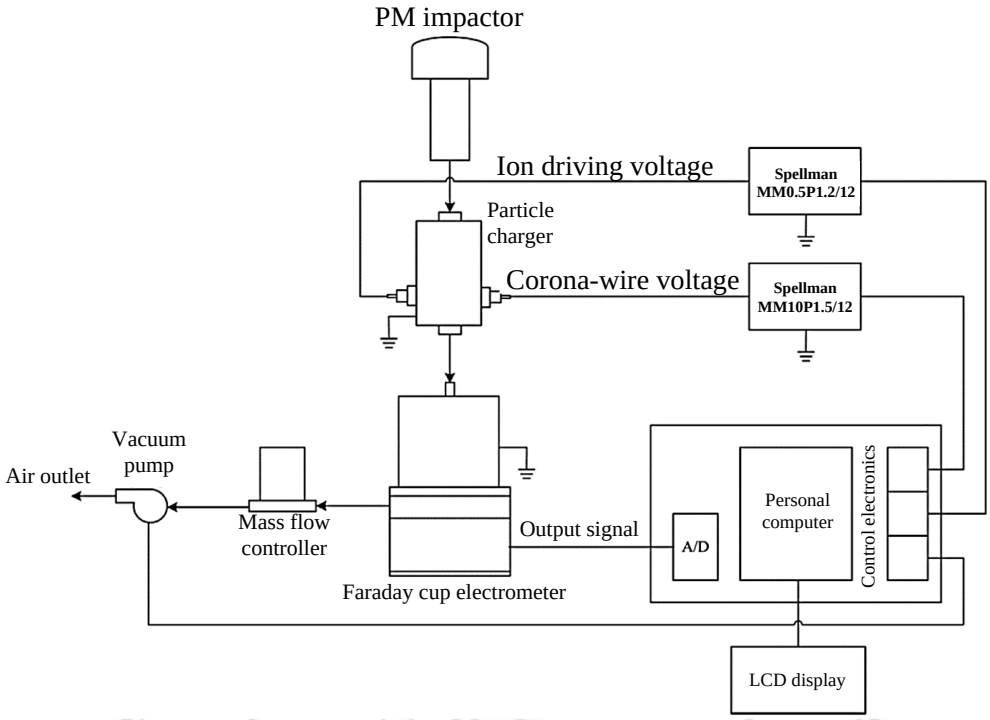


Figure 1.16 Schematic diagram of DustDETEC (Intra *et al.* 2013).

Table 1.1 Comparison of the continuous PM monitor.

Instrument	Specification
Tapered Element Oscillating Microbalance; TEOM (Thermo Scientific 2015; John *et al.* 1998) 	• Methodology; Suck a simple air passes through the impactor and collected into the filter that vibrating in an applied electric field, then, converting this vibration signal to mass of PM. • PM type; PM10 or PM2.5 • Measurement range; 0 to 1,000,000 µg/m^3 • Particle mass has a detection limit about 5 µg/m^3 for a 5 min average. • Operating temperature; -40 to 60ºC • Air conditioning inlet; Nafion® technology • Filter; 13 mm diameter • Flow rate; 16.67 L/min • Accuracy; 0.75% of electrical measurement • Report unit; µg/m^3 • Weight; 18 kg • Electric Power Supply; 100 to 240 VAC, 47/63 Hz • Electric Energy; 440W • Price; 900,000 Bath
Beta Attenuation Monitor; BAM (Thermo Scientific 2015; John *et al.* 1998) 	• Methodology; Suck a simple air passes through the impactor and collected into the cassette tape filter, then emitting the Beta ray on this filter for validated Beta absorption and converting to mass of PM. • PM type; PM10 or PM2.5 • Measurement range; 0 to 1,000 µg/m^3 • Particle mass has a detection limit about 5 µg/m^3 for a 1 h average. • Operating temperature; -30 to 60ºC • Air conditioning inlet; n/a (less than 80%RH) • Filter; 30 mm x 21m. Cassette tape • Flow rate; 16.67 L/min; Accuracy; 2.5 µg or 10% at 24h • Report unit; µg/m^3; Weight; 24.5 kg • Electric Power Supply; 110 to 230 VAC, 50/60 Hz • Electric Energy; 400W, 3.4A • Price; 900,000 Bath

Table 1.1 (con.) Comparison of the continuous PM monitor.

Instrument	Specification
Piezoelectric Microbalance (John *et al.* 1998)	• Methodology; Sample particles are deposited onto the surface of a piezoelectric quartz crystal disk by electrostatic precipitation or inertial impaction. The particle mass that accumulates on this surface make to the natural resonant frequency of the crystal was decreasing. This frequency can be converted to mass of PM. • Particle mass has a detection limit about 10 µg/m^3 for a 1 min averages.
Pressure Drop Tape Sampler; CAMMS (John *et al.* 1998)	• Methodology; The continuous ambient mass monitor system (CAMMS) has principle as measuring the pressure drop across the Fluoropore or a porous membrane filter. Under controlled conditions, this pressure drop is linearly correlated to the particle mass deposited on the filter. • Particle mass has a detection limit about 2 µg/m^3 for a 1 h average.
Nephelometer (Met One Inc. 2011) 	• Methodology; Particulate concentration by forward light scatter laser Nephelometer • Particle size; TSP Inlet Standard, PM10, PM2.5, and PM1 sharp-cut cyclone inlets available. • Measurement range; 0 to 65 mg/m^3 (0 to 65,530 µg/m^3) • Operating temperature; -10 to 50ºC • Ambient Humidity Range; 0 to 90% RH, non-condensing. • Filter; 47mm low flow gravimetric filter sampler • Flow rate; 2.0 L/min ± 0.1, actual volumetric flow. • Accuracy; ± 10% to gravimetric method typical when K-factored to local particulate type. • Report unit; µg/m^3 • Weight; 6.4 kg without tripod, battery, or optional accessories. • Electric Power Supply; Universal 100-240 VAC input, 15 VDC output power supply included. • Electric Energy; 1.1 amps @ 12 VDC (15 Watts) max continuous draw, running with the inlet heater on 0.35 amps (4.2 Watts) running with inlet heater off

Table 1.1 (con.) Comparison of the continuous PM monitor.

Instrument	Specification
Optical Particle Counter; OPC (Grimm Company 2003) 	• Methodology; Light scattered by each of the particles in a light beam is detected at various angles by 90° light-scattering method. The signals are interpreted in terms of particle size by calibrations. • Particle size; PM10, PM2.5, and PM1 or size channels between 0.25 to 32 µm in diameter • Light source; laser diode, wavelength 685 nm • Operating temperature; -20 to +60 °C • Ambient Humidity Range; less than 95% non-corrosive • Accuracy; ±2% over the entire measurement range • Measurement time; From 1 min until continuous • Flow rate; 1.2 L/min ±5% steadily through regulation • Sheath air volume; 0.3 L/min steadily through regulation • Dimensions; 180 : 483 x 177 x 400 mm for model180, 483 x 89 x 120 mm for model181 • Weight; 15 kg for model 180, 2 kg for model181 • Power Supply; 230V / 50Hz,
Condensation Nuclei/ Particle Counter; CNC/CPC (TSI Company 2007) 	• Methodology; Used for detecting a particle by the light scattering method. • Particle size; airborne particles between 0.004 to 1 µm in the size range. • Concentration range; 0 to 50,000 particles/cm^3 • Flow rate; Inlet high-flow at 1.5 L/min, Inlet low-flow at 0.3 L/min • Flow control; Volumetric flow control of aerosol flow by critical orifice, differential pressure across the orifice is monitored • Operating temperatures; Saturator 39°C±0.2°C, Condenser 14°C±0.2°C, Optics 40°C±0.2°C • Data logging and storage; SD/MMC flash memory card • Power requirements; 100 to 240 VAC, 50/60 Hz., 335 W maximum • Dimensions (HWD); 25 cm × 32 cm × 37 cm • Weight; 9.9 kg (22 lb) • Price; 1,900,000 bath

Table 1.1 (con.) Comparison of the continuous PM monitor.

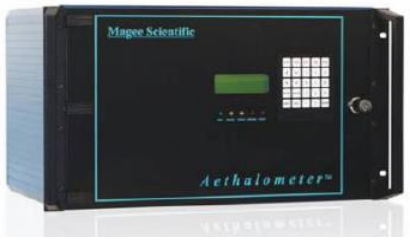
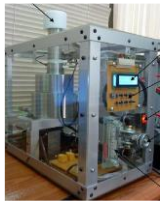
Instrument	Specification
Aerodynamic Particle Sizer; APS (TSI Company 2012) 	• Methodology; Using a sophisticated time-of-flight technique that measures the aerodynamic diameter in real time. • Laser Source; 30-mW, 655-nm laser diode • Particle size; airborne particles between 0.5 to 20 μm in the size range • Particle Type; Airborne solids and nonvolatile liquids • Resolution (Aerodynamic size); 0.02 μm at 1.0 μm, 0.03 μm at 10 μm • Particle concentration; 1,000 particles/cm^3 at 0.5 μm with <5% coincidence; 1,000 particles/cm^3 at 10.0 μm with <10% coincidence; usable data up to 10,000 particles/cm^3 • Flow Rates; Aerosol Sample 1.0 L/min ±0.1, Sheath Air 4.0 L/min ±0.1, Total 5.0 L/min ±0.2 • Operating Temperature; 10 to 40°C (50 to 104°F) • Operating Humidity; 10 to 90% R.H., noncondensing • Power supply; 100 to 240 VAC, 50/60 Hz, 100 W, single phase or 24 VDC • Dimensions; 38 cm × 30 cm × 18 cm • Weight; 10 kg (22 lb.) • Price; 2,000,000 Bath
Aethalometer (Hansen 2005) 	• Methodology; The Aethalometer is a real-time optical measurement of light absorbing carbonaceous aerosols or black carbon that has 7 different wavelengths ranging between 370 nm to 950 nm. The airborne particle is continuously passed through a quartz-fiber filter tape. The particle such as black carbon under a light beam will absorb this light. By assuming that all light-absorbing material is black carbon, and that the absorption coefficient of the black carbon is known and constant, the net attenuation signals can be converted into black carbon mass concentrations. • Sensitivity; 0.1 μg/m^3 • Particle range; 0.1 – 100,000 μg/m^3 • Accuracy; 5% (electrical) • Flow rate; 1 – 6 L/min • Filter change time; 0 – 30 h • Electrical power; 100-240 VAC 50-400Hz power input, auto switching • Weight; 40 Pounds • Price; n/a

Table 1.1 (con.) Comparison of the continuous PM monitor.

Instrument	Specification
Light Detection and Ranging; LIDAR (John *et al.* 1998)	• Methodology; Take a short laser pulse is sent into the atmosphere, then backscattered light from an aerosols is detected as a function of "time of flight" for the light pulse. • Range resolved atmospheric backscatter coefficient (cm^2/steradian) and gas concentrations.
Particle Soot/Absorption Photometer (John *et al.* 1998)	• Methodology; Ambient air is continuously passed through a quartz- fiber filter tape, then a light absorbing particles (black carbon) cause attenuation of a light beam. It was assumed that all light-absorbing material is black carbon, then the constant value from the net attenuation signals can be converted into black carbon mass concentrations. The time resolution of the Aethalometer depends on ambient black carbon concentration. • The light absorption detection limit has about 0.2 Mm^{-1} for a 5 min average. An absorption efficiency of 10 m^2/g, this would correspond to 20 ng/m^3 of black carbon.
Photoacoustic Spectroscopy (John *et al.* 1998)	• Methodology; The PSAP is a continuous measuring device by monitoring the change in transmittance across a filter for two areas of the filter between a particle deposition area and a reference area. It uses a light emitting diode or LED (operating at 550 nm in wave range) is a light source, that followed by an Opal glass serves. The PSAP is calculated with a nonlinear equation correcting from the absorption results in the filter medium. • Light absorption, reported as black carbon. The detection limit has about 50 ng/m^3 for 10 min average.
Electrical Aerosol Analyzer; EAA (John *et al.* 1998)	• Particles are collected according the dependent mobility of particle size in an electric field, then it was detected a particle charge by the electrometer and converting to particle number concentration. • The number of particles in the sub-micrometer size range or about 0.01 to 1.0 μm size range.
Differential Mobility Particle Sizer; DMPS (John *et al.* 1998)	• Particles were classified by a mobility under an electric field, then a condensation nuclei counter (CNC) was counting the population of particles. • The number of nucleating particles in different size ranges or about 0.01 to 1.0 μm size range.

Table 1.1 (con.) Comparison of the continuous PM monitor.

Instrument	Specification
Electrical Low Pressure Impactor or ELPI (Dekati 2015) 	• Methodology; Charge particle with the corona charger and classify the particle by the 12 impactors for particle size between 0.007 to 10 μm in diameter then processing the measuring data by the internal PC. • Particle range; 0.007 – 10 μg/m^3 • Flow rate; 10 or 30 L/min; Weight; 35 kg • Operating temperature; 5 to 40 ºC • Aerosol humidity; 0 to 90% RH without non-condensing unit • Sensitivity; less than 5 s • Particle number concentration; 10^8 – 10^{13} particles/m^3
An Analyzer and Sampler for Air and PM2.5 (Intra *et al.* 2010) 	• Methodology; Classified PM2.5 by an inertial impactor technique with 5 L/min air flow rate then charged the particle by the corona charger and used electrostatic sensor for detect the particle charge before convert to the particle number concentration by the microcontroller. • Particle size; PM2.5 • Flow rate; 5 L/min / Weight; 20 kg • Operating temperature; ambient temperature (about 35 ºC) • Aerosol humidity; ambient RH • Sensitivity; less than 1 s • Price; 100,000B
An Electrostatic Sensor or DustDETEC (Intra and Yawootti 2012; Yawootti and Intra 2013; Intra *et al.* 2013) 	• Methodology; Classified PM2.5 or PM10 by an inertial impactor technique with 5 L/min air flow rate then charged the particle by the corona charger and used electrostatic sensor for detect and convert the particle charge to the voltage signal. The measuring signal was process by the microcontroller and shows the particle number concentration on LCD display. • Particle size/range; PM2.5 or PM10 (solid and liquid) / 0 to 500 μg/m^3 or 10^9 to 10^{14} particles/m^3 • Flow rate; 5 L/min, Weight; 30 kg • Power supply; 220 VAC 50Hz (build in backup battery for 1 h operating) • Operating temperature; ambient temperature (about 35 ºC) / Aerosol humidity; ambient RH • Sensitivity; less than 1 s • Price; 150,000B

1.2.2 Measurement of Airborne PM by the Continuous PM Monitor. Limitation of measuring the airborne PM by filtering method is that it cannot measure data rapidly. There are many processes such as filtering the RH control and weighing to find net mass. The continuous PM monitors are used for airborne PM measurement because they are fast, continuous and automatic. Although US EPA specifies some types of the continuous PM monitors in the group of the federal equivalent method (FRM), but allows research and development of new continuous PM monitors for measuring airborne PM. Several researches compared new continuous PM monitors with reference and equivalence methods that certified by US EPA follows.

Tsai and Cheng (1996) compared three types of measuring devices (1) a Kimoto 180 beta gauge sampler, (2) a Wedding ambient PM10 beta gauge sampler and (3) Andersen SA1200 High Volume Sample for measuring ambient PM10 at Yun-Ho, Chung-Li, and Chia-Yi stations during January to June 1994. It was found that the correlation coefficient (R^2) between SA1200 and Wedding beta gauge sampler were 0.97 and 0.98 for RH more than and less than 80% RH, respectively. The R^2 between SA1200 and Kimoto beta gauge sampler were 0.94 and 0.83 from RH more and less than 80% RH, respectively.

Chung *et al.* (2001) compared seven types of measuring devices (1) a Federal Reference Method (FRM) sampler for PM2.5 concentrations RAAS 2.5-300 (Andersen Instruments), (2) a Size-Selective Inlet high-volume sampler (SSI), (3) a beta attenuation monitor (BAM 1020 from MetOne Instruments), (4) two integrating nephelometers (Optec NGN-2 and Optec NGN-3 from Air Resource Specialists Inc.), (5) a Continuous Aerosol Mass Monitor (CAMM, Andersen Instruments), (6) a Dusttrak sampler (Dusttrak 8520, TSI Inc.), and (7) a Tapered Element Oscillating Microbalance (TEOM 1400, R&P Inc.) for 24-hr average from ambient PM2.5 and PM10 during December 2, 1998 to January 31, 1999 at Bakers fields, CA. It was found that the R^2 between FRM with BAM, nephelometers and CAMM were 0.99, 0.99, and 0.96, respectively. While the R^2 between SSI with TEOM, BAM, and Dusttrak were 0.95, 0.99, and 0.92, respectively.

Cyrys *et al.* (2001) compared two measuring devices (1) a Tapered Element Oscillating Microbalance (TEOM) and (2) a Harvard Impactor (HI) for measuring 24 h

average ambient of PM2.5 in 32 days in Erfurt, Germany. It was found that the ratio mean of TEOM/HI was 0.74 and the regression equation was TEOM = 0.69HI + 0.071, while ratio mean of TEOM/heat HI was 1.06 and the regression equation was TEOM = 1.10HI - 0.668.

Yanosky *et al.* (2001) compared three devices (1) the aerodynamic particle sizer (APS; TSI, Inc. Model 3320), (2) the DustTrak aerosol monitor (DustTrak Model8520 TSI, Inc.) and (3) the federal reference method (PQ200 BGI, Inc.) for measuring ambient PM2.5 in door. It was found that the R^2 was 0.979 from two APS instruments for a 30 min average. While the PM2.5 from the PQ200 between 5.0 - 20.4 μg/m^3 and 11.4 μg/m^3 in mean. 24 h average of R^2 were 0.859 and 0.592 from DustTrak/ PQ200 and APS/PQ200, respectively.

Kim *et al.* (2004) compared two devices include (1) the direct reading instrument (DustTrak aerosol monitor model8520 TSI Inc.) and (2) a gravimetric sampling method for ambient PM2.5 from boilermakers exposed to welding fumes and residual fuel oil ash. It was found that the mean of PM2.5 concentration were 300 μg/m^3 and 310 μg/m^3 from DustTrak and gravimetric method, respectively. The R^2 was 0.68.

Janhong (2005) compared two devices (1) the Partisol-Plus Model 2025 (PM2.5 Sequential Air Sampler) and (2) Beta-ray Absorption (FH62I-N PM2.5 Beta Attenuation Ambient Particulate Monitor) for ambient PM2.5 at and Lampang during April 14 to June 2 and June 8 to July 25, 2002, respectively. It was found that the R^2 was 0.84 and 0.73 at Bangkok and Lampang, respectively.

Huang (2007) compared two devices (1) the Beta Attenuation Monitor (E-BAM, Met One Instruments Inc. Oregon) and (2) Light Scattering Method (Dusttrak Model 8520, TSI, USA) for measuring ambient PM2.5 at the second floor of the Ji-Hsin Building at Yuanpei University (3.7 meters above the ground). It was found that the R^2 was 0.74.

Lopez *et al.* (2012) compared two devices (1) a DustTrak aerosol monitor (model 8520, TSI, Inc., Shoreview, Minn., U.S.) and (2) a gravimetric method (URG Corp., Chapel Hill, N.C., U.S.) for measuring ambient PM10 for 32 livestock houses in the

Netherlands (16 houses for poultry and pigs). It was found that the R^2 were 0.91 and 0.84 of poultry and pigs, respectively.

Mohtar *et al.* (2013) compared two devices (1) the Beta Attenuation Monitor (BAM) and (2) Direct Reading Monitor (DRM) for measuring ambient PM10 in industrial area Perai (Sekolah Kebangsaan Taman Inderawasih) during July 16 to 29, 2011. It was found that the R^2 were 0.917 and 0.8324 of days 18 to 29 and 16 to 29, respectively.

PM less than 10 μm in diameter including PM2.5 and PM1.0 were generated from man-made sources especially exhaust from energy use. It is widely accepted that this PM has linked to the respiratory disease and premature death. Limitation of a mass direct reading is a complex process and not fast, which the continuous PM monitor can be clear on this point. However, the continuous PM monitor has limitation for a high price, import, complex mechanism (such as TEOM and Light Scattering) and dangerous in some part that controlled by government (such as Beta Source). Electrical method was selected to develop the new continuous PM monitor due to high reliability, non-complex, fast response, easy for operation and maintenance. In addition, the multi-channel of PM measurement is needed for studying behavior of particle from different sources. Although PM1.0 is not yet specified in US EPA or PM standard currently, the health research shows dangers of them and accepted that it is likely to increase in the future. This thesis contains five important parts including the air conditioning inlet, the particle charger, the particle size classification, the particle detector and data acquisition and processor system. The air conditioning inlet needs to control and decrease the RH from the sample air. The particle charger needs to generate a high ion concentration to wide range particles including PM1.0, PM2.5, and PM10 and can reject this high ion concentration after charge process. The particle size classification needs to classify required particles including the PM1.0 PM2.5, and PM10, while it must have low electrostatic loss and can continue operating for a long time. The particle detector need to collect the particle and electrical charge and can amplify this electric charge for the data acquisition and processing system. The data acquisition and processing system must have a high resolution ADC, robust, stable and has a data management system by remote control.

1.3 Objectives

1.3.1 To study, design, and develop a multi-channel airborne PM detector using electrical technique

1.3.2 To investigate the motion of particles in a charger, an ion trap, a particle size selector, and a particle collector

1.3.3 To develop a detector for measuring PM10, PM2.5, and PM1.0 according to Thailand regulations and future standard

1.3.4 To evaluate performance of the detector, and compare with standard detectors

1.4 Expecting Benefits

1.4.1 Knowledge about the motion of the particle with charge in the particle impactor, the combined particle charger, the electrostatic detector, and the effect of temperature, humidity, pressure and flow rate is obtained.

1.4.2 The relationship between the electrostatic charges on the particle mass is known.

1.4.3 The prototype of the multi-channel airborne PM detector using electrical technique is obtained.

1.5 Scope of Study

1.5.1 Particle size selection is based on aerodynamic and inertial impactor principles.

1.5.2 Used for measuring airborne PM less than 10, 2.5, and 1.0 μm (PM10, PM2.5, and PM1.0, respectively) in diameter size only.

1.5.3 The measuring data for airborne PM can be reported in units of the particle mass concentration and the particle number concentration.

1.5.4 The system can be monitored and controlled remotely.

1.5.5 Some parts and components are made locally using techniques and main materials available domestically.

1.6 Thesis Outlines

This thesis consists of six Chapters and three Appendices. Chapter 1 shows the statement and significance of the problem that need for solver, the literature review of the continuous particle measurement method and measurement of airborne PM by the continuous PM monitor, the aims, benefits and scope of this study, and outlines of the thesis. Chapter 2 shows definition of PM, source of aerosol particle, standard of the airborne PM, mechanisms of inertia particles, cutoff diameter, aerodynamic diameter and Stoke diameter, diffusion drying for particle in ambient, air flow theory, electric field and corona discharge, particle charging technique, electrostatic precipitation theory, deposition mechanisms theory, measurement of ion and charged particle, analog and digital signal processing, the comparison of the PM measuring devices, statistic for comparing data, and numerical modeling, the health effect, definition and standards of the air PM, including effect from the PM, and difference between standards in Thailand and US EPA. Other theories about PM classification include the density, velocity, pressure, inertia mechanism, flow equation, aerosol impactor, and particle losses, etc. PM charging technique, ultra-low current sensor, flow field and the electric field modeling are also given. The component description and modeling are presented in Chapter 3. The specification of this detector and other components, including the air conditioning inlet section, the particle charging section, size classification for the PM10, PM2.5, and PM1.0, Faraday cup and cage, electrometer circuit, flow and electrical power system, controller and data processor. The experimental setup and field study are presented in Chapter 4. The details are given for the experimental apparatus and process, performance test for ion and particle measurement, field test that comparing with the standard detectors in a long time. Chapter 5 shows the performance results and discussion of the air conditioning inlet section, the particle charging section, the particle size classifies, Faraday cup and cage, electrometer include the relative coefficient and measuring results from a comparing with the standard detectors. Finally, Chapter 6 presents conclusions and recommendation for future works. Appendix shows a technical drawing of the components, operation manual, and a list of publications.