Total Sulfur Deposition over Forest in Tropical Climates, Thailand

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Abstract

Sulfur (S) is the key component of atmospheric acid deposition on ecological system. This study, S components were collected by a four-stage filter pack over a tropical forest from June 2011 to May 2012 at Sakearat Environmental Research Station. The experiment was operated under conditional sampling technique or relaxed eddy accumulation (REA) method. This method was deployed to sample concentration of aerosol particulates and gases over the forest canopy. The REA system consisted of a 3D sonic anemometer, a flow controlling device, software for switching valve controller and a chemical collecting equipment. Concentration and continuous micrometeorological data were measured on a tower height of 36 meter. The S components were analyzed by an ion chromatography. Deposition fluxes of S components were computed by $F = \beta\sigma_w (\overline{C}_{up}-\overline{C}_{dn})$. The empirical coefficient value (β) for the REA equation was evaluated to be 0.50±0.04. The deposition flux of S over the forest canopy was determined to be 1.7 and 57.2 ng m^{-2} s^{-1}, for the dry and the wet season, respectively. The annual mean value for the flux was determined to be 20 ng m^{-2} s^{-1}. The deposition velocities were evaluated to be 0.7 and 1.0 cm s^{-1}, for the dry and the wet season, respectively. The annual mean deposition velocity of S was 0.9 cm s^{-1}.

Keyword: Relaxed eddy accumulation, deposition flux, deposition velocity, β empirical coefficient

1. INTRODUCTION

Acid atmospheric substances have been in focused in many areas of source emissions including industrial estate, city, agriculture, water surface and forest. The atmospheric deposition is the primary removal processes of atmospheric pollutants in gaseous and aerosol phases[1]. They deposit in both wet and dry forms. The wet deposition is characterized by the amount of acid substances dissolved in droplets of rain or dew and then precipitate to the ground. The dry deposition consists of gas and aerosol particles deposited on the earth surface at any time with no rain involved.

Total sulfur (TS) referred to sulfur constituents in both gaseous and aerosol forms. They are the key chemical species of the acid deposition. The main emission source of gaseous sulfur constituent (SO_2) is from fossil fuel combustion in the power plant. Other sources come from sea salt (sulfate), chemical production (H_2SO_4) and secondary photochemical reactions of primary acids (SO_2, NO, etc.) that eventually become new sulfur constituents of SO_4^{-2}. To determine the amount of TS dry deposition requires an appropriate method to collect the air samples as well as to calculate their flux values. Currently, the relaxed eddy accumulation (REA) is a successful method for fluxes measurement of several chemical components, for example, volatile organic compounds (VOC), SO_2, SO_4^{-2})[2, 3]. The REA method does not require a fast-response sensor or device to measure the chemical species.

The purpose of this study is to estimate the dry deposition flux and a global deposition velocity of total sulfur (TS) over the forest using the relaxed eddy accumulation method. The study also investigates some influences of meteorological parameters over the amount of deposition flux and hence, a global deposition velocity.

2. METHODOLOGY

2.1 Relaxed eddy accumulation

The eddy accumulation (EA) method was initiated by Desjardins1977[1] to directly collect the atmospheric samples using two separate reservoirs for positive and negative vertical wind velocities. The relaxed eddy accumulation method (REA) is the work of Businger and Oncley 1990[4-6]. They combine the EA method with the flux-variance similarity. Their method becomes an indirect method. REA was utilized to estimate fluxes of atmospheric trace species both aerosol particles and gases phase. Moreover, the advance of the REA method can be applied to atmospheric monitoring for which fast response equipment is not available. The vertical mass flux is equal to the difference in the mean concentration of the trace gas of interest between the upward and downward moving eddies, multiplied by the standard deviation of the vertical wind velocity and an empirical coefficient. The flux of atmospheric can be determined by the following equation (1).

$$F= \beta\sigma_w (C\square_{up}-C\square_{dn}) \quad (1)$$

Where β is empirical coefficient, σ_w is the standard deviation of vertical wind velocity *w* and $C\square_{up}-C\square_{dn}$ are the average concentrations of chemical species in the updrafts and downdrafts, respectively[4, 7]. The value of β has to be estimated from the parameters that measure at a specific site or experimental area. The necessary parameters for β calculation were measured by a sonic anemometer such as vertical wind speed and standard deviation and fluctuation

temperature[8]. The β coefficient was computed with the REA method following equation equation (2).

$$\beta = F_H / \sigma_w (T\square_{up} - T\square_{dn}) \quad (2)$$

where F_H is the sensible heat flux ($w't'$) and $T\square_{up}$ and $T\square_{dn}$ are the average temperatures of the updraft and downdraft direction, respectively[9]. The β is constant value for flux estimation in equation (1), which is from the parameter measurement at a specific area.
The first suggested of β value is 0.6[4] or namely Businger constant (β). Gallagher et al. used a β value of 0.58±0.13 for their experiment[2]. Other products are still closer to those obtained such as Hamotani et al. (1996), Baker et al. (1992), Pattey et al. (1993) and Woods (1997) have resulted of β value ranging 0.56-0.6[7, 10, 11].

2.2 Site description

The Sakaerat Environmental Research Station (SERS) was located at 14° 30′ 13.68" N, 101°5 7′ 8.67" E in a height land (300 meters above sea level) in the northeast of Thailand (Fig. 1). The area was surrounded by mountain series of 200-272 m height. SERS covers an area of 78 km² by two major forest types: dry evergreen forest (DEF) and dry dipterocarp forest (DDF). Other tree species are bamboo, planted trees, and grasslands. The height of trees was varying between 20-27 m. A highway was situated on the eastern side about 1.5 km from the experimental site. The residential area was surrounded about 20-30 km in the northwest and the southwest direction.

2.3 Experimental system

The REA system consisted of two air samplers, a switching valve controller, a 3D-anemometer, a micrometeorological recorder and a concentration analyzer. The sampling system was designed to take the air through a single inlet at a constant flow of 10 $Lmin^{-1}$ into one of the three filter collectors functioning as updraft (+), mid-draft and downdraft (-) for later analysis of the mean concentration of SO_2. The direction of the air intake in to which filter controlled by a three-ways switching solenoid valve which received signal from the 3D ultrasonic anemometer (HD2003-HD2003.1 model) to indicate the wind direction (Fig. 2). The air collectors are inline filter pack type without particles size cut to avoid aerosol particle deposited on the tube surface. A dynamic velocity deadband was preset at 0.13 ms^{-1}. When the vertical wind velocity was below 0.13 ms^{-1}, the air sample would be directed to flow into the mid-draft filter and discarded.

Figure 1 Location of the SERS research site in the northern Thailand

This study considered a total sulfur deposition which included both gas and aerosol phases. The collection period for daytime was 6:00 – 18:00 hr and for nighttime was 18:00 – 6:00 hr. The air collectors and the ultrasonic anemometer were installed at the same level of 36 m on the tower. The collected samples were extracted and analyzed, following the Guidelines for Acid Deposition Monitoring in East Asia (EANET) and technical Document for Filter Pack Method in East Asia[12], using an ion chromatograph (IC).

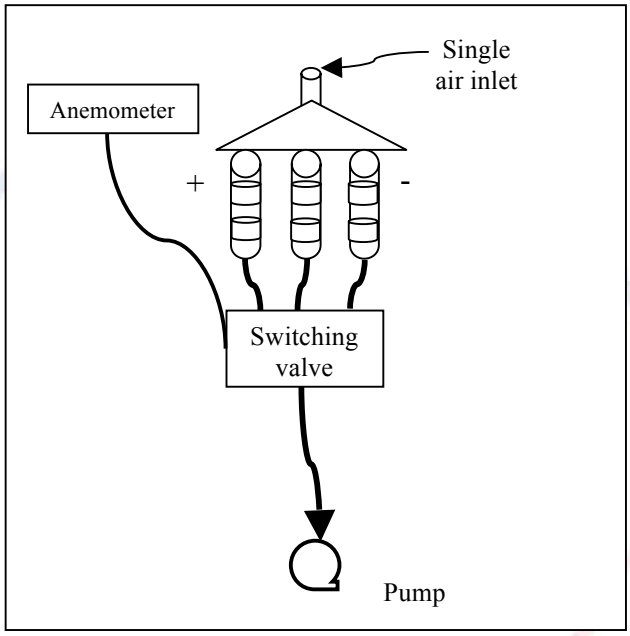

Figure 2 Schematic drawing of the relaxed eddy accumulation air sampling system.

3. RESULT AND DISCUSSION

3.1 Atmospheric conditions

The meteorological parameters in Fig. 3 show the averaged atmospheric condition at the study site during the experimental period (June 2011 – May 2012). The observed values of the wind speed (WS), temperature (T), rainfall (RF) and relative humidity (RH) were found in ranges of 0.19-0.43 m/s, 21.5-27.2 ^{o}C, 0-12 mm and 71.9-84.1%, respectively. The amounts of rainfall in (March-October) were measured to be 4.1-11.4 mm and no precipitation reported in November-February.

a **b**

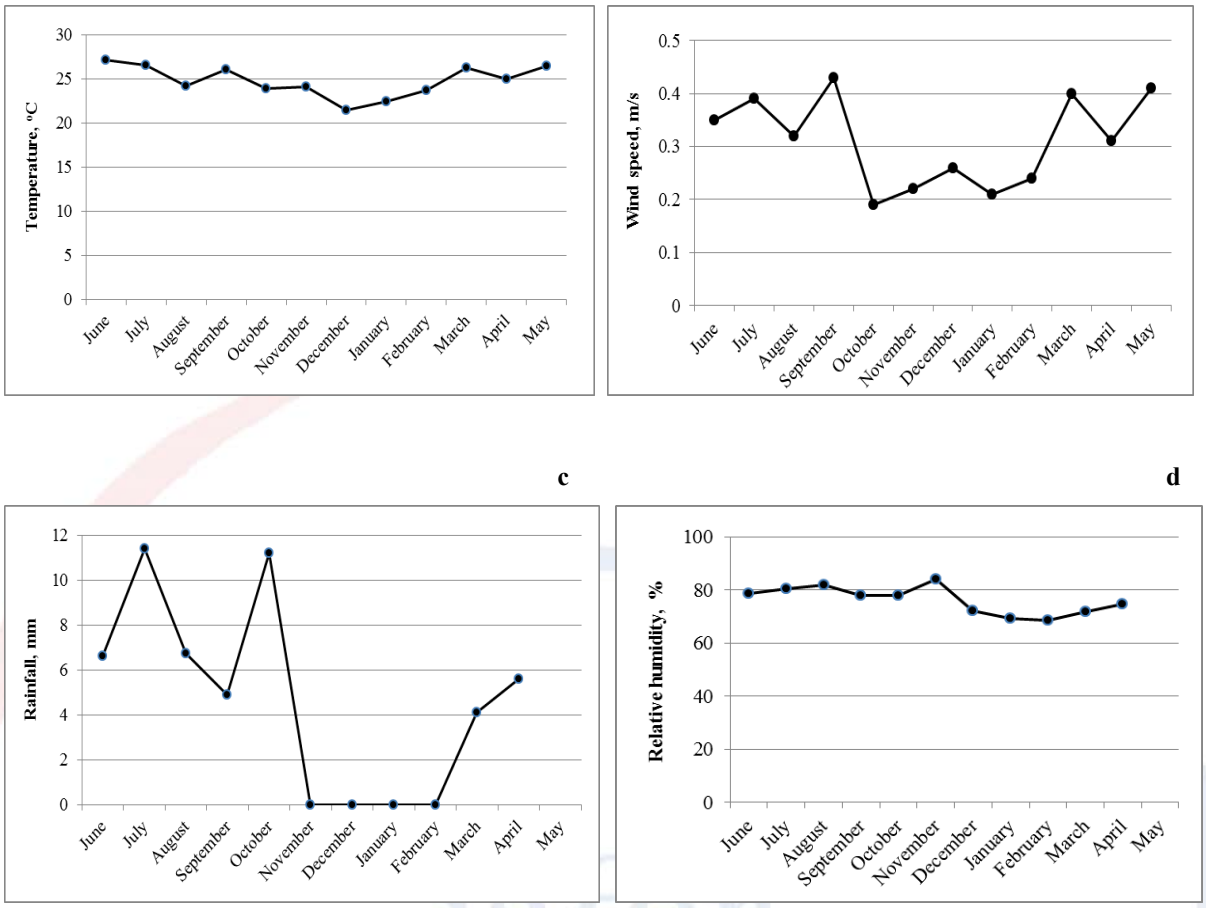

Figure 3 Meteorological parameters measured during June 2011 – May 2012.

3.2 Empirical coefficient (β)

In this experiment, the β value for flux estimation in Eq. 1 was determined by Eq. 2 and the average value for one year was 0.50±0.04. Fig. 4 shows a monthly variation of β coefficient that fell within a range of 0.42 – 0.60.

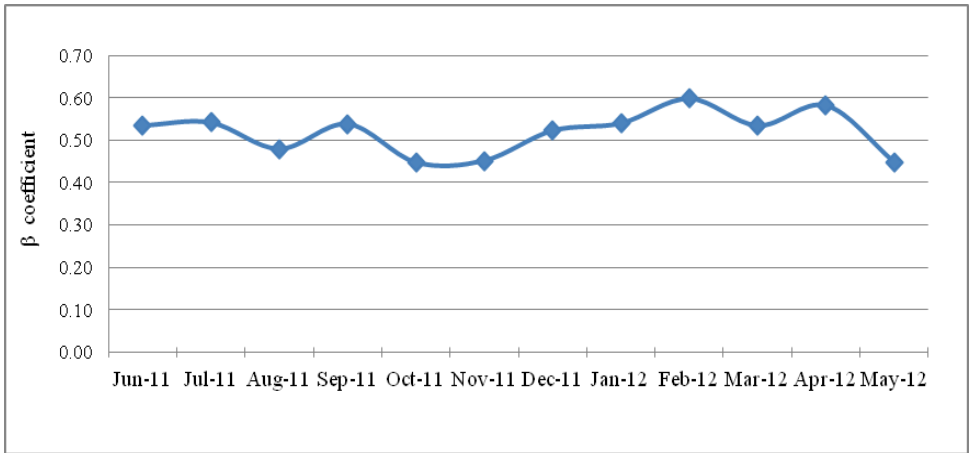

Figure 4 Evaluation of monthly Empirical coefficient (β)

3.3 Total sulfur concentration

Fig. 5 shows monthly average concentrations of SO_2 and SO_4^{-2} in the atmospheric layer over the forest. The concentrations were averaged from the updraft, the mid-draft and the downdraft samples collected by the filter packs. The measured concentrations of SO_4^{-2} and SO_2 were found in ranges of 0.25-1.4 μg m^{-3} and 0.1-0.6 μg m^{-3}, respectively. It was observed that the concentration of SO_4^{-2} and SO_2 were in close ranges during the wet and humid seasons (June-October 2011 and March-May 2012). It is also noticeable that SO_4^{-2} existed in higher concentrations compared with SO_2 during the dry and low humidity conditions (November 2011-February 2012).

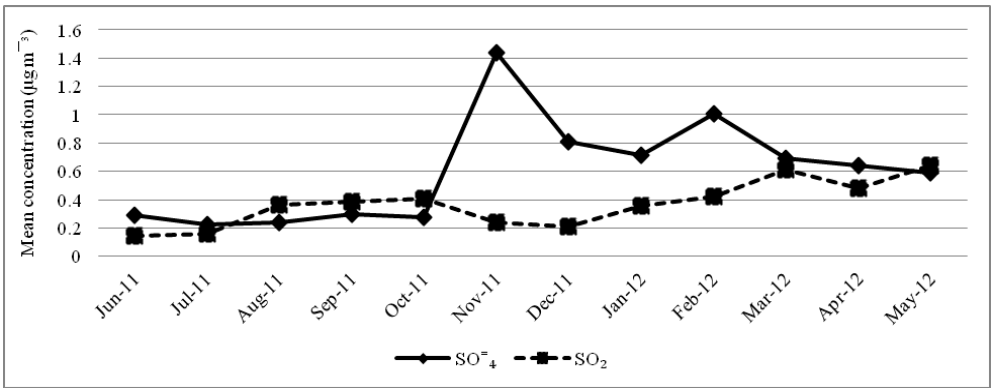

Figure 5 Average measured concentrations of SO_4^{-2} and SO_2 during June 2011 – May 2012.

Fig. 6 shows average concentrations of TS that derived from SO_4^{-2} and SO_2. The concentration of SO_4^{-2} was observed to increase with the ambient humidity. In November 2012, the TS reached the maximum value of 600 ng m^{-3} when the relative humidity was also reached the maximum value of 84.1%. It is believed that SO_2 reacted with water vapor (H_2O) to form a particulate SO_4^{-2} and sulfuric acid mist[13, 14].

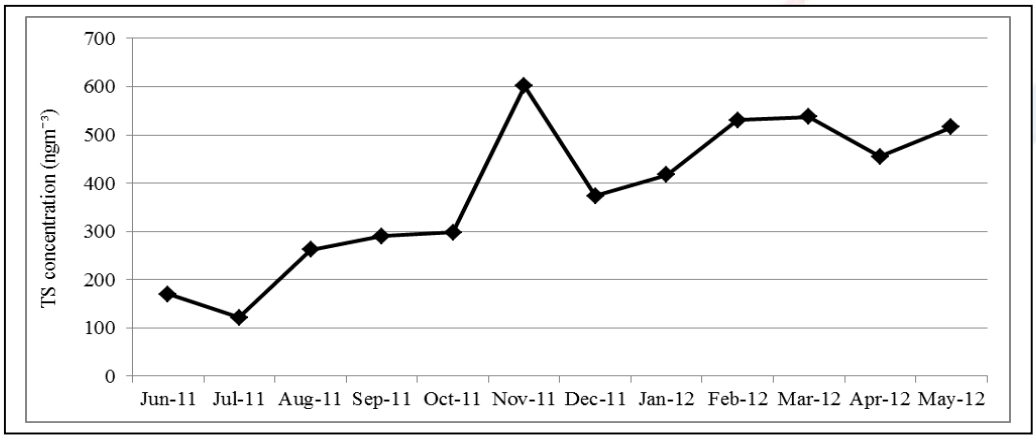

Figure 6 Average concentrations of TS during June 2011 – May 2012.

3.4 Deposition flux and global deposition velocity estimation

Fig. 7 shows the monthly variation of total sulfur (TS) deposition fluxes and global deposition velocities. The term global is referred to the combined deposition velocities of SO_2 and SO_4^{-2} i.e., TS. It was found that the deposition fluxes and the global deposition velocities were low in the dry season (November 2011 to January 2012) where all the important meteorological parameters, i.e. the temperatures, the wind speeds, the relative humidity and the amount of rainfalls were low also during the same period (See Fig. 3a-d). The deposition fluxes during the dry season were observed within a range of 6-20 ng m^{-2} s^{-1} and the global deposition velocities were calculated to be 0.04-0.07 cm s^{-1}. The high values of fluxes as well as the deposition velocities were found during the hot and humid conditions (June-August 2011 and April-May 2012) where the relative humidity reached 80%. The high fluxes were found in a range of 100-120 ng m^{-2} s^{-1} and the high deposition velocities were determined to be 0.18-0.28 cm s^{-1}. It was detected some errors found in measurements for the values obtained in March 2012. Fig. 8 also shows a similar trend between the wind speed and the global deposition velocities.

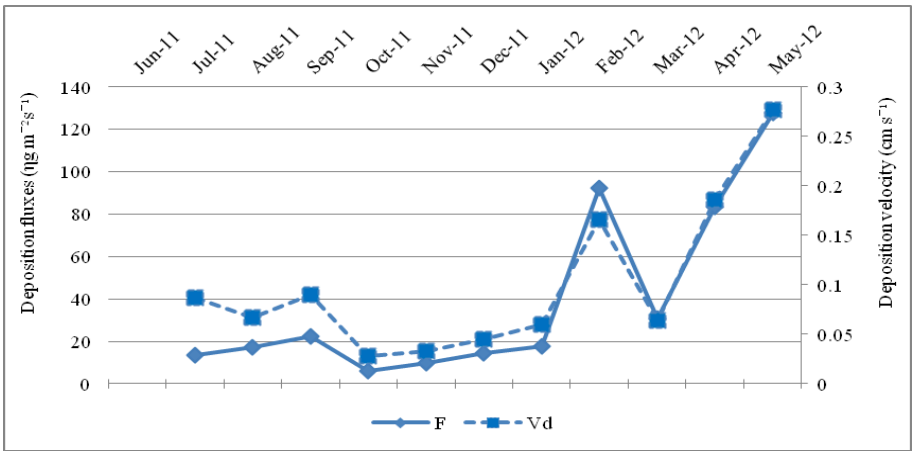

Figure 7 Monthly variation of deposition fluxes and global deposition velocities of TS during June 2011 – May 2012.

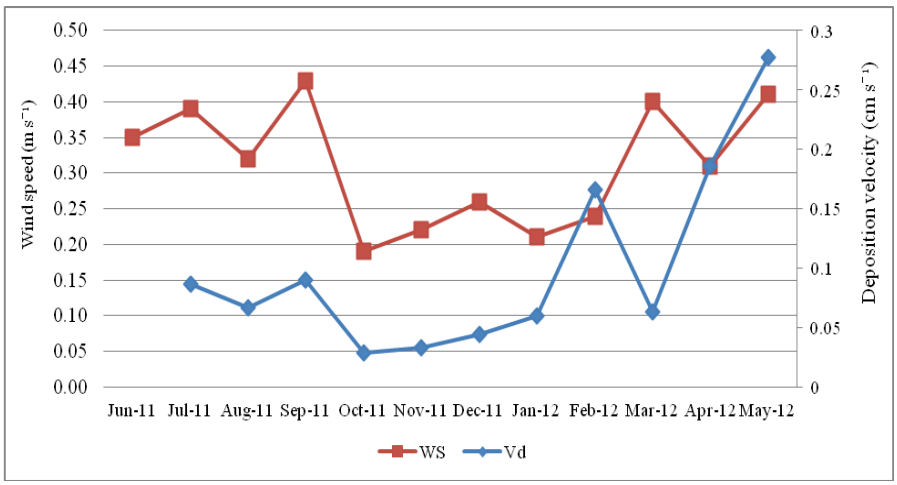

Figure 8 A similar trend of monthly variation of global deposition velocities of TS and wind speed.

4. CONCLUSION

The important meteorological parameters affecting the dry deposition fluxes of TS were observed to be the amount of rainfall, the relative humidity and the wind speed. The monthly average of temperature was not substantially varied in the tropical climate therefore, its effects on the amount of deposition was not clearly shown. The amount of TS deposition flux was observed to be 1.7 ng m^{-2} s^{-1} and 57.2 ng m^{-2} s^{-1} in the dry and wet season, respectively. The annual average of TS was 20 ng m^{-2} s^{-1}. The global deposition velocity of TS was determined to be 0.9 cm/s.

5. ACKNOWLEDGMENTS

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