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SIMULATION OF DISPERSION OF AIR POLLUTANTS AND ACIDIC PRECIPITATION

CHOONG WEI YEE

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SIMULATION OF DISPERSION OF PLUME AND ITS RELATION TO ACIDIC PRECIPITATION

By

CHOONG WEI YEE

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Abstract of thesis presented to the senate of Universiti Putra Malaysia in partial fulfilment of the requirements for the degree of Master of Science

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By

CHOONG WEI YEE

May 1999

Chairman: Associate Professor Tan Ka Kheng, Ph.D., P. Eng.

Faculty: Engineering

Acidic precipitation poses a threat to ecosystems. Many countries in Europe and northeastern parts of the United States of America have experienced forest decline in their mountainous region due to acidic deposition. Malaysia, being a rapidly industrialised nation, succumbed to acidic precipitation too. This study sought to determine the trend of acidic precipitation in Malaysia, particularly in hilly terrain, and to investigate the significance of building an incinerator near a hill.

Wet fallout data for 1996 for three hilly sites were collected. These data were analysed statistically and compared to the data of low-lying areas nearest to the hill sites, and also to a polluted area. Numerical simulations on the dispersion of plume from an incinerator were carried out using a commercial software FLUENT to determine the flow pattern of the plume and its effect on the hill. Simulations were carried out for two scenarios that were for an incinerator located in an open area, and the other located near to a hill.

Results of this study indicated that the studied hill sites received acidic precipitation at an average of 40% for 1996, with an average annual pH of 5.0. This reflected that the tropical forest in these hilly sites has a high potential risk of exposure to acidic precipitation which could be detrimental to them. Results from the simulation showed that the plume emitted by the incinerator has the most significant impact on the leeward side of the hill, whereby the calculated pH of rainwater here was typically around 2. In the case of an open area, the pH of the rainwater was typically around 3 - 4. The calculated pH of the fog/cloud water was found to be two to three order more acidic compared to rainwater. This indicated that the forest in a highland area, which is usually surrounded by high moisture content in the atmosphere, may receive high acidic deposition due to its contact with the fog/cloud. However, the sulphate deposition flux calculated in this study was well below the allowed load of 20 kg/ha.yr.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

SIMULASI PENYERAKAN BAHAN PENCEMAR UDARA DAN HUJAN ASID

Oleh

CHOONG WEI YEE

Mei 1999

Pengerusi: **Profesor Madya Tan Ka Kheng, Ph.D., P.Eng.**

Fakulti: Kejuruteraan

Fenomena hujan asid sememangnya mengancam ekosistem. Banyak negara di Eropah dan juga di kawasan timur-laut Amerika Syarikat telah dilaporkan mengalami masalah kemerosotan hutan akibat kejadian hujan asid. Kajian ini dijalankan bertujuan untuk menentukan corak aliran fenomena hujan asid di Malaysia, terutamanya di kawasan bukit-bukau and juga untuk megkaji kesan pelepasan asap dari sebuah insinerator yang terletak berhampiran dengan sebuah bukit.

Data air hujan bagi tahun 1996 bagi tiga kawasan bukit telah dikumpulkan. Data ini kemudiannya telah dianalisakan mengikut kaedah statistik dan dibandingkan dengan data daripada kawasan tanah rendah yang terdekat dengan

juga dengan sebuah kawasan yang mengalami pencemaran udara yang serius. Kerja simulasi yang menggunakan perisian FLUENT juga telah dijalankan untuk menentukan corak aliran asap pelepasan dan juga kesannya terhadap sebuah bukit. Simulasi telah dijalankan bagi dua senario yang mana senario pertama melibatkan simulasi dengan kawasan lapang dan senario kedua melibatkan kawasan berbukit.

Keputusan daripada kajian ini menunujukkan bahawa kawasan bukit yang dikaji mengalami kejadian hujan asid dengan purata 40% bagi tahun 1996, dengan purata pH bernilai 5. Oleh itu, kawasan hutan tropika di kawasan bukit yang dikaji mempunyai risiko yang tinggi dari segi pendedahannya kepada kelembapan yang berasid. Pendedahan kepada kelembapan berasid boleh mudaratkan pertumbuhan pokok di kawasan tersebut. Keputusan dari kerja simulasi juga menunjukkan bahawa asap pelepasan dari insinerator membawa kesan yang paling ketara kepada bahagian belakang angin bukit, yang mana nilai pH yang dikira bagi air hujannya adalah sekitar 2. Bagi senario kawasan lapang, nilai pH bagi air hujannya adalah sekitar 3 - 4. Nilai pH yang dikira bagi kelembapan dalam kabus/awan didapati adalah dua hingga tiga kali lebih berasid daripada air hujan. Ini menunjukkan bahawa kawasan hutan tropika di kawasan tanah tinggi, yang sering dikelilingi oleh kadar kelembapan yang tinggi sepanjang tahun, kemungkinan menerima lebih banyak kelembapan yang berasid akibat pendedahan secara langsung terhadap kelembapan yang berasid ini. Namun demikian, kadar deposasi sulfat dalam kajian ini masih dalm lingkungan kadar optimum sebanyak 20 kg/ha setahun.

CHAPTER I

INTRODUCTION

The natural acidity of rainwater is often taken to be pH of 5.6 which is that of pure water in equilibrium with the global atmospheric concentration of carbon dioxide CO_2 (330 ppm) and this pH values of 5.6 has been used as the demarcation line for acidic precipitation (Bubenick, 1984). Hence, the term acid rain has come to mean rainfall with a pH of less than 5.65. Any rainfall with a pH of 5.00 and below is deemed to have anthropogenic sources of acidity.

The acid content of rain in many parts of the world has steadily risen over the years as countries became more industrialised and increased their use of fossil fuels. These fuel, oil and coal release to the environment high concentrations of sulfur and nitrogen oxides, precursors of strong acids when burned. The oxides are transformed by chemical and physical processes occurring in the atmosphere, in the soil and in lakes and streams to compounds that may degrade the environment. The transformation processes involving the pollutant oxides are complex and may involve both homogeneous and heterogeneous paths to the resulting strong acids.

Acidity is undesirable because:

- Acidity gives water a greater capacity to attack geological materials, it accelerates rock weathering and so it is usually accompanied by high total dissolved solids (TDS) including hardness;
- Acidity increases the solubility of hazardous substance such as aluminium (Al), and is corrosive and toxic to fish and other aquatic forms;
- Acidity limits the use of water without extensive treatment due to high total dissolved solids (TDS), high metal content and low pH. This often requires that acid waters be diluted, as well as neutralised.

Global Context

Increasing attention has been given to the exposure of highland forests to atmospheric pollutants because of the possible link between the sensitivity of highland forests and the effect of air pollutants onto them. There is evidence that acid rainfall, as a by-product of energy-related activities, is introducing a considerable stress on both rural and urban areas of the United States of America and Western Europe. Studies carried out by several researchers such as Overton and Aneja (1979), Lovcett et al. (1990), Saxena and Lin (1990), Chaumerliac et al. (1990), Raynal (1992) and Johnson et al. (1992) have linked the forest decline to acidic deposition. Researchers have postulated acidic precipitation as one of the main factor for forest decline in Germany, Europe and north-eastern of North America. In Germany, the 1994 inventory indicated severe (> 25% defoliation) damage of about 25% of all trees. In Germany at present, oak stands have the highest degree of visible damage with about 30 – 40% of the trees with severe defoliation. The forest inventory of 1993 in 27 European countries and 4800 sites, evaluating more than 100 000 trees, revealed 23% of all trees in damage class 2 – 4 (defoliation > 25%). The highest degree of damage was found in Central Europe, namely in Poland, Czech Republic, Slowakia and Germany regions suffering from a relatively high level of air pollutants.

It is widely acknowledged that acidic atmospheric deposition can cause soil acidification, leading to nutrient deficiency as a result of leaching of important nutrients such as calcium (Ca), magnesium (Mg) and potassium (K). Furthermore, acidity also cause metal toxicity particularly aluminium (Al) and reduction in tree growth.

Malaysian Context

In Malaysia, acidic atmospheric deposition has been recorded in urban towns such as Klang Valley, Butterworth and Johor Bahru with pH reading reaching 4.0 since 1990. It should be noted here that pH < 5.0 reflects the influence of anthropogenic sources. Data obtained from Malaysia Meteorological Services (MMS) indicated that wet acidic deposition has been observed in highland areas such as Cameron Highlands and Bukit Kledang with pH dipping below 5.0 at certain times of the year. These data reflect that Malaysia is experiencing the acid rain phenomena.

Malaysia being a tropical country has relatively high humidity (> 80%) throughout the year. Forced uplift of moist air over hills or mountains would lead to the formation of fogwater and cloud or a phenomena known as orographic precipitation (Lovett and Kinsman, 1990). As air mass rises over a topological barrier, it expands and cools because of decreased air pressure, forming upslope fogs or clouds. This in turn could lead to the rainout process. As the air mass cools, condensation occurs followed by droplets growth during which various pollutants such as sulphur dioxide (SO_2), nitric acid (HNO_3) dissolve in the droplets, undergo chemical changes and fallout as precipitation. Hence, the forest canopy will be likely to receive the wet acidic deposition due to the occurrence of orographic precipitation and the presence of the moist fog and cloud surrounding the highlands.

Significance of Study

To date, very few studies have been carried out to study the effect and extent of acidic deposition on the tropical highland forest in Malaysia. This study will seek to investigate the cause-effect relationship between the pollutant emission from individual stack and the measured acidity of precipitation at receptor areas, in this case the highland area. It is hope that this study would be able to provide some information on the significance of having a stack built near a hill.

Simulations of dispersion of air pollutants in hilly terrain and in an open area have been carried out. It is hope that the simulation work carried out would be able to enhance the understanding of the dynamics (emission, transport, transformation) of air pollution as a system. Models can have an important role to play in the development of environmental policies aimed at containing and controlling long range transboundary air pollutant transport. Dispersion models for atmospheric pollutants are useful decision support systems for air pollution management. Increasingly, these models are being used to generate inputs to specific catchment areas in environmentally sensitive regions for past, present or future patterns of emissions throughout Europe (Metcalf et. al., 1989; Costa et al., 1996). Hence, they are ideal complement to air quality control networks.

Objective

The objectives of this study are:

1. To determine the trend of acidic precipitation in Malaysia;
2. To identify the impact of plume from a stack onto an open area and to a nearby hill through numerical simulation.

CHAPTER II

LITERATURE REVIEW

Introduction

Precipitation removes gases and particles from the atmosphere by two processes:

- **rainout**
  - which is the incorporation of material into cloud drops that grow in size sufficiently to fall to the ground. Water vapour condensed on cloud condensation nuclei and many of these nuclei are believed to be sulphate particles that have been formed as a result of the gas-to-aerosol conversion of natural and man-made sulphur dioxide emissions. Condensation is followed by droplet growth, during which various pollutants dissolve in the droplets, undergo chemical changes and begin their descent to the ground in falling precipitation.
- **washout**
  - which occurs when material below the cloud is swept out by rain or snow as it falls. The washout of SO_2 by rain falling through a uniform

concentration of SO_2 is a function of the size spectrum of droplets, the initial pH of the rain, height of the SO_2 concentration and the absolute magnitude of the SO_2 concentration. Presence of ammonia (NH_3) hastens the absorption of SO_2 and its conversion to sulphates. In his study, Marsh (1978) concluded that the scavenging of SO_2 gas and particulate below cloud base and in-cloud scavenging contribute about equally to the concentration of sulphates in precipitation.

Together, these two processes account for wet deposition of acidic material on the earth's surface.

Precipitation acidity is primarily attributed to the strong minerals acids such as sulphuric acid (H_2SO_4) and nitric acid (HNO_3). The immediate precursors of these acids are the man-made and naturally produced gases sulphur oxides, SO_x (SO_2 and SO_3^-) and nitrogen oxides, NO_x (NO and NO_2). Natural sources of SO_x and NO_x are generally distributed globally whereas anthropogenic emissions tend to be concentrated regionally near population centres

Formation of Cloud and Rain in Hilly Terrain

Air moving over or around hilly or mountainous terrain often influences cloud formation. For example, mountain ranges are typically preferred locations for fog, stratus, stratocumulus, cumulus and cumulonimbus and valleys between mountains often favour fog occurrence. Orographic cloud occurs due to the cooling of an airmass as it rises to cross ground which is higher than that over which it has been travelling. As the airmass rises and cools, the water vapour reaches saturation point and water starts to condense out on suitable aerosol particles or foliage. As the airmass continues to rise, further cooling occurs, condensation continues and scavenging of gaseous species by the water droplets takes place (Hough, 1983).

When such air has completed its ascent, its path will continue to be controlled by the terrain over which it flows. For a plateau, or for transverse motion across a series of closely spaced ridges, the air will move at an approximately constant altitude with constant liquid water content. If however, the land slopes downwards with no further high ground in the near distance, then the air will descend. On descending, the cloud will evaporate due to the warming of the air and a reverse of the processes discussed above will occur.

Orographically induced flow is able to produce or influence precipitating clouds through the following mechanisms:

- **Seeder-Feeder Mechanism over Small Hills**
  - Convective cells aloft can produce large precipitation particles, which upon falling through a lower cloud layer, grow at the expense of the water content of the lower cloud. By itself, the low-level cloud might not precipitate. Precipitation particles from the upper cloud collect cloud particles from the low cloud and the water collected is then deposited on the ground.

- **Upslope Condensation**

  - If the air forced over a mountain is sufficiently moist through a large portion of the lifted layer, condensation may occur in upslope flow or wave clouds.

- **Orographic Convection**

  - When air flowing over rugged terrain is potentially unstable, the lifting induced by the terrain can lead to the release of instability and eventually, precipitation (Houze, 1993).

The adiabatic ascent of moist air could cause condensation at certain elevations and thus produces clouds. Whenever fogs and mists occur with great frequency, as they do on windward mountain slopes in the condensation or 'cloud belt', they may constitute a significant source of additional moisture. Fog-borne moisture, dew and heavy mists may condense upon exposed vegetational surfaces and drip or run down stems to the ground. Such moisture quantity is known to be highly dependent upon both successional stage and foliage characteristics of the dominant vegetation (Stadmuller, 1987). The inherent vegetational characteristics are as follows:

- height of vegetation
- canopy structure (influencing the roughness thus causing micro turbulence)
- size, quantity, location and arrangement of leaves
- quantity, forms and types of epiphytes