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SO_2 pollution of heavy oil-fired steam power plants in Iran

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ABSTRACT

Steam power plants using heavy oil provided about 17.4%, equivalent to 35.49 TWh, of electricity in Iran in 2007. However, having 1.55–3.5 weight percentage of sulfur, heavy oil produces SO_2 pollutant. Utilization of Flue Gas Desulfurization systems (FGD) in Iran's steam power plants is not common and thereby, this pollutant is dispersed in the atmosphere easily. In 2007, the average emission factor of SO_2 pollutant for steam power plants was 15.27 g/kWh, which means regarding the amount of electricity generated by steam power plants using heavy oil, 541,000 Mg of this pollutant was produced. In this study, mass distribution of SO_2 in terms of Mg/yr is considered and dispersion of this pollutant in each of the 16 steam power plants under study is modeled using Atmospheric Dispersion Modeling System (ADMS). Details of this study are demonstrated using Geographical Information System (GIS) software, ArcGIS. Finally, the average emission factor of SO_2 and the emission of it in Iran's steam power plants as well as SO_2 emission reduction programs of this country are compared with their alternatives in Turkey and China.

1. Introduction

Energy is the social and economical growth engine of each country and its generation is considered as a serious challenge especially in developing countries. Electricity generation using fossil fuels has destructive effects on environment. Emission of pollutants such as SO_2 produced by burning fuel oil and coal in power plants has damaged public health, water and forest ecosystem, due to the acidification of soil and lakes (Islas and Grande, 2008).

Sulfur dioxide is a member of a group of highly reactive gasses known as "oxides of sulfur." The largest sources of SO_2 emissions are fossil fuel combustion at power plants (73%) and other industrial facilities (20%). Smaller sources of SO_2 emissions include industrial processes such as extracting metal from ore, and the burning of high sulfur containing fuels by locomotives, large ships and non-road equipments. Emissions that lead to high concentrations of SO_2 generally also lead to the formation of other SO_x. The control measures that reduce SO_2 can generally be expected to reduce people's exposures to all gaseous SO_x. This may have the important co-benefit of reducing the formation of fine sulfate particles, which pose significant public health threats. SO_x can react with other compounds in the atmosphere to form the small particles. These particles penetrate deeply into sensitive parts of the lungs and can cause or worsen respiratory disease, such as emphysema and bronchitis, and can aggravate existing heart disease, leading to increased hospital admissions and premature death (EPA, 2011).

Sulfur oxides are released when fossil fuels such as coal and heavy fuel oil are burned. They mix with the hydrocarbon radicals in the atmosphere and form sulfuric acid. The hydrocarbon radicals may give off an oxygen atom to SO_2 to form SO_3, which in turn is converted to H_2SO_4 droplets resulting in the formation of haze (Rana, 2005). These gaseous emissions can remain in the atmosphere for several days where they can be transported long distances by wind, or they can be scavenged from the atmosphere by rain, snow or fog and deposited to the earth's surface. This phenomenon is referred to as acid rain or, more accurately as acid deposition. The aquatic effects of acid deposition are both chemical and biological. Surface water chemistry can change and become more acidic when exposed to acidic deposition. The underlying geology plays a big role in how sensitive surface waters are to chemical changes from acidic deposition. Materials exposed to the elements will degrade from natural weathering processes. The presence of air pollution and acidic deposition can accelerate the rate of deterioration of certain materials. Materials susceptible to damage include monuments, historic buildings, outdoor structures (such as bridges) and automotive paints and finishes. For some materials, such as carbonate, steel or nickel, the effects are apparent after about one year of exposure. For other materials, including copper and paints, effects may appear after about four years. Research suggests that materials containing calcium carbonate, such as limestone, marble and galvanized steel are particularly sensitive to the effects of acid deposition.

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Links between SO_2 and sulfate aerosols and visibility are indirect, but quite strong. Small particles, such as sulfate aerosols, tend to scatter light and reduce atmospheric visibility (EPA, 2002).

SO_2 emissions from thermal power plants and abatement costs of them were reported in several studies in the countries such as Malaysia, China, India, Mexico, Polish and Turkey (Streets and Waldhoff, 2000; Kaminski, 2003; Islas and Grande, 2008; Reddy and Venkataraman, 2002; Chakraborty et al., 2008; Say, 2006; Vardar and Yumurtaci, 2010; Mahlia, 2002; Zhao et al., 2008; Su et al., 2011).

The emission of SO_2 from large combustion units is proportional to the sulfur content of the fuel and the fuel consumption as well as utilizing emission reduction systems. Containing sulfur and heavy metals, heavy oil is considered as a pollutant producing material. PM and SO_2 generated by heavy oil are more important than other pollutants since they expose habitants of the area to numerous health problems and negative environmental effects, they lead to death in some cases. Therefore, the precise study of emission estimation and dispersion pattern of SO_2 produced by Iran's steam power plants as well as comparing these results with other studies and experiences on SO_2 emission and reduction programs in Turkey (as a neighboring country) and China (as one of the largest electricity markets in the world) are inevitable and vital (Developing Pollutant Map of Iran's Thermal Power Plants, 2008).

Iran, as a developing country, has experienced a considerable industrial growth and population and citizenship increase in the last decade. In addition, electric energy demand in this country has annually increased by 10% during the last 30 years. This demand is expected to encounter an annual 8% growth over the coming years until 2025 (MOE, 2007). Possessing significant fossil fuel resources, Iran enjoyed 10.4% of stabilized crude oil resources and 18.5% of natural gas resources in the world in 2007. Existence of these resources has resulted in utilization of thermal systems for electricity generation in this country, so that near 90% of the required electric energy is produced by thermal power plants. Natural gas (66 %) is the largest source of fuel for electricity generation followed by heavy oil (17.4 %) and gas oil (6.6%) (Energy Balance Book, 2007). Among thermal units of Iran, steams units, with the capacity of 15.6 GW, occupy one third of total power plant installed capacity. In 2007, steam power plants generated 97 TWh of electricity (equivalent to 45% of total electricity generation) (Statistical Book of Iran's Power Industry, 2007).

In Turkey, the most significant development in production was observed in the thermal power plants. In 2009, its share was about 80.3% (155.8 TWh) of total production (194.1 TWh) of the country. Turkey has mainly focused on more usage of natural gas for electricity generation. In 2009, natural gas share was about 48.6% (94.4 TWh) of the total electricity generation in this country. Electricity generation from lignite and coal in Turkey was 55 TWh and share of them in total generated electricity was 28.3 % in 2009. Consumption of lignite for electricity generation was 87% of total lignite production (IEA, 2009a, b).

Air pollution is getting a great environmental concern in Turkey. Air pollution is a result of energy utilization in turkey due to the combustion of coal, lignite, petroleum, natural gas, wood and agricultural wastes. On the other hand, SO_2 emissions have increased rapidly in recent years in Turkey because of the rapid growth of primary energy consumption and increasing use of domestic lignite. The major source of SO_2 emissions is the power sector, contributing more than 50% of the total emissions (Turkey-National study, 2007).

China is the second-largest electricity market in the world, second only to the United States. The excessive usage of fossil fuel in China, which has also sharply increased releases of acid gases such as SO_2 into the atmosphere (U.S. DOE, 2009).Total electricity generation (predominantly coal-fired power plants) was 3695 TWh in 2009. In this year, shares of coal, hydro electric, oil fuel, nuclear energy and natural gas in total electricity generation in China were 78.8%, 16.6%, 0.4 %, 2% and 1.4%, respectively (IEA, 2009a, b).

China has been the largest emitter of SO_2 in the world since 2005, and aggressive deployment of Flue Gas Desulfurization (FGD) at coal-fired power plants appeared in China when this country faced the formidable impact of environmental pollution. From 1990 to 2007, annual SO_2 emission was fluctuated with two peaks (1996 and 2006), and total emission doubled from 15.4 Tg to 30.8 Tg, at an annual growth rate of 4.4% (6.3% since 2000). The total emissions from combustion in 2007 were 28.3 Tg, half of which was contributed by coal-fired power plants. Due to the extensive application of FGD technologies and the phase-out of small, high emitting units, the SO_2 emission began to decrease after 2006 (Su et al., 2011).

2. An overview of current electricity generation condition in Iran

Electricity consumption in Iran has experienced a considerable growth in recent years due to economical development, industrialization and population increase. Electricity generation in Iran in the last years is shown in Fig. 1. In 1973, electric energy generation per capita was 310 kWh, which increased to 2935 kWh in 2008 (Statistical Report on 42 Years of Activities of Iran Electric Power Industry, 2009). Over the last few decades, Iran has confronted two interconnected phenomena: population growth and citizenship increase. These phenomena and their mutual impact have resulted in a high increase in electricity consumption in Iran. Iran's population was equal to 36 million persons in 1973. This amount rose to 73 million persons in 2008, which means the population has doubled over this period (Iran Statistical Year Book, 1973, 2008). Aside from these factors, keeping electricity price reasonable by means of considerable governmental subsides has also affected electricity consumption growth in this country. Electricity consumption growth in the world increases by 3% annually while this amount reaches 8% in Iran (Statistical Report on 42 Years of Activities of Iran Electric Power Industry, 2009). Table 1 represents the distribution of electricity generation by other energy resources in Iran and the world in 2006. As one can see in Table 1, more than two third of electricity consumed in the world is generated by fossil fuels. In Iran, fossil fuels produce approximately 90% of total electric energy. This amount is much higher than its counterparts in OECD and non-OECD countries (IEA, 2006). Meanwhile, 24% of electricity in Iran is generated by oil products including heavy oil

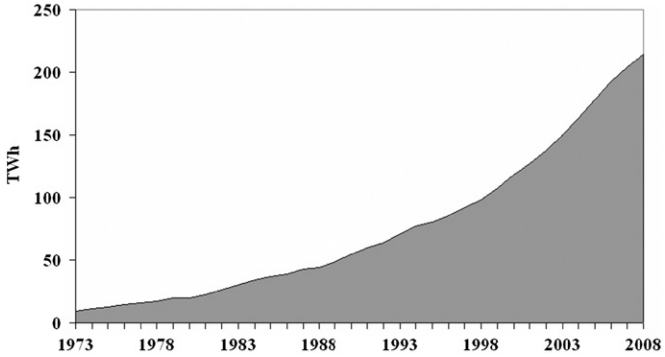

Fig. 1. Electricity generation in Iran from 1973 up to 2008 (adopted from Statistical Report on 42 Years of Activities of Iran Electric Power Industry (2009)).