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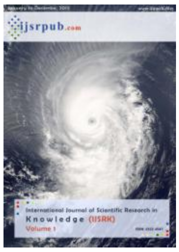
Mohajan, Haradhan

Premier University, Chittagong, Bangladesh

26 March 2014

International Journal of Scientific Research in Knowledge, 2(6), pp. 265-276, 2014
Available online at http://www.ijsrpub.com/ijsrk
ISSN: 2322-4541; ©2014 IJSRPUB
http://dx.doi.org/10.12983/ijsrk-2014-p0265-0276



Mini Review

Chinese Sulphur Dioxide Emissions and Local Environment Pollution

Haradhan Kumar Mohajan

Premier University, Chittagong, Bangladesh;
Email: haradhan_km@yahoo.com

Received 26 March 2014; Accepted 08 May 2014

Abstract. During the last 30 years Chinese economy has increased rapidly. The pollution of air in many Chinese cities exceeds both national and international standards due to rapid urbanization, industrialization and increased energy consumption. At present China becomes the highest sulphur dioxide emitter in the world due to its reliance on coal for energy generation. The Government of China has taken different steps to reduce sulphur dioxide and succeeded from the 11th Five-Year Plan. Breathing in sulphur dioxide can irritate the nose, throat and the lungs, causing phlegm, coughing, shortness of breath, development of bronchitis and other respiratory diseases, as well as aggravation of existing cardiovascular disease. Long-term contact to sulphur dioxide at lower concentrations can cause temporary loss of smell, headache, nausea and dizziness. In this paper an attempt has been taken to discuss sulphur dioxide emissions of China and stresses on desulphurization processes.

Keywords: SO_2 control policy, Human health, Acid rain, Desulphurization.

1. INTRODUCTION

People's Republic of China is situated in the Eastern Asia on the western shores of the Pacific Ocean. Beijing is its capital city and Shanghai is its largest city. Its area is 9,640,821 km^2 and it is considered as the 3rd largest country (after Russia and Canada) in the world. In 2010, its population becomes about 1,339,724,852, which is in the 1st position in the world (20% of the world's total) and density of population is 138.96/km^2, which is the 53rd in the world. The landforms of China's vast territories are extremely varied and include mountains, hills, plateaus, plains, basins, and deserts. Coasts of China are on the East China Sea, Korea Bay, Yellow Sea, and South China Sea. It has a continental coastline extending over 18,000 km and an adjacent sea area of 4.73 million km^2. China has administrative control over 22 provinces (excluding Taiwan Province) (Mohajan, 2014).

The country holds the largest and highest plateaus, most of the highest mountains, and the world's two longest rivers, the Yellow and Yangtze Rivers. Due to its various landforms and large land area, spanning tropical, sub-tropical, temperate and boreal zones, China contains a remarkable range of different ecosystems (Liu and Diamond, 2005). Mountainous regions in China occupy about 66% of the total area. Only 16% of the territory has an altitude lower than 500 meters; the areas with an altitude higher than 1,000 meters occupy 65% of China's total land area (Jiang et al., 2007).

The economy of China has grown with an average 10% per annum during the last two decades. Its per capita gross domestic product (GDP) in Purchasing Power Parity (PPP) has increased more than 20 times from $379 in 1980 to $7,632 in 2010 (Cai and Lu, 2013). As a result people migrate to urban areas and energy demand has increased. China is now the world's largest energy consumer (British Petroleum, BP, 2011a) and energy demand is expected to continue growing rapidly through 2030 (BP, 2011b). The quality of air in many Chinese cities exceeds both national and international standards due to rapid urbanization, industrialization and increased energy consumption (Huang et al., 2009). Coal-dominated energy consumption structure in China faces some of environmental problems such as acid rain, air pollutions and a large amount of greenhouse gas (GHG) emissions (National Bureau of Statistics (NBS), 2010).

Sulphur dioxide is a chemical compound with the formula SO_2 and chemical structure is O=S=O. It belongs to a family of sulphur oxide gases (SO_x). It is a poisonous gas that released by volcanoes and in various industrial processes (by roasting metal sulphide ores). It has a variety of industrial applications, from refining raw materials for preserving food. The poisonous gas SO_2 is considered as a local pollution problem worldwide. It is emitted in the atmosphere from both anthropogenic and natural sources. It is estimated that anthropogenic sources account for more than 70% of SO_2 global emissions, half of which are from fossil-fuel combustion (Whelpdale et al., 1996). SO_2 is the main product from the combustion of sulphur compounds and is of significant environmental concern.

At room temperature under normal conditions, SO_2 is a colorless gas. SO_2 is often described as the 'smell of burning sulphur' but is not responsible for the smell of rotten eggs. SO_2 forms sulphate aerosols that are thought to have a significant effect on global and regional climate. Sulphate aerosols reflect sunlight into space and also act as condensation nuclei, which tend to make clouds more reflective and change their lifetimes.

At present China becomes the highest SO_2 emitter in the world due to its reliance on coal for energy generation. When SO_2 combines with moisture in the atmosphere, it can form sulphuric acid (H_2SO_4), which is the main component of acid rain. Acid rain destroys various living organisms (harmful for humans, animals and vegetation) and structures (paints, buildings, infrastructure and cultural resources). Atmospheric SO_2 emissions are a major contributor to particular matter (particles or droplets (aerosols) suspended in the air) $PM_{2.5}$, (whose particles are less than 2.5 μm in diameter, 1 μm = 10^{-6} m) in China (Mohajan, 2014).

Zheng et al. (2011) examined the issue of ancillary benefits by linking SO_2 emissions to CO_2 emissions using a panel of 29 Chinese provinces over the period 1995–2007. They inspected both the long-run and short-run elasticities of SO_2 with respect to CO_2.

Some countries, for example, Australia, Greece, India and China experienced a rise of SO_2 emissions during 1990–2007 (United Nations (UN), 2010) and at the same period the UK, Germany, the USA, Italy, and Spain experienced a decline of SO_2 emissions (European Environment Agency (EEA), 2010).

The Government of China has established national goals to reduce SO_2 emissions by 10% in the 10^{th} and 11^{th} Five-Year Plan periods, 2001–2005 and 2006–2010, respectively. Five-Year Plans of China are a series of social and economic development initiatives. During the 10^{th} Five-Year Plan period, economy-wide SO_2 emissions increased at an average rate of 5.5% annually. After the adaption of a number of policies and introducing new instruments during the 11^{th} Five-Year Plan, SO_2 emissions were declined by 14% (Schreifels et al., 2012). The World Health Organization (WHO) (WHO, 2004) estimated that acid rain seriously affects 30% of China's total land area. Tianbao et al. (2012) indicate that China is one of the countries in the world which suffers from severe acid rain contamination. Acid rain causes many hazards to the environment, affects the standard of living, and is even harmful to human health. Due to China's SO_2 emissions, both Japan and Korea are experiencing increases in acid rain (Mohajan, 2014).

2. IDENTIFICATION OF SO_2

SO_2 is a colorless gas or liquid with a strong odor, which affects the human respiratory system and aggravates cardiovascular disease. Its molecular weight is 64.06, vapor pressure is 2,538 mm-Hg at 21.1º C, vapor density is 1.43 g/ml (water is 1 g/ml at 4^0 C), boiling point is –10º C at 760 mm-Hg, freezing point is –72.7º C, it is soluble in water (11.3 g/100 ml at 20º C) and non-flammable.

Since it is a colorless gas that can be detected by taste and smell in the range of 1,000 to 3,000 micrograms (1 μg = 10^{-6} g) per cubic meter (μg/m^3). At concentrations of 10,000 μg/m^3, it has a pungent, unpleasant odor. Thermal power plants burning high-sulphur coal or heating oil are generally the main sources of anthropogenic SO_2 emissions worldwide (for the cleaner fuel the sulphur compounds are removed before burning the fuel), followed by industrial boilers and non-ferrous metal smelters. Emissions from domestic coal burning and from vehicles can also contribute to high local ambient concentrations of SO_2 (World Bank Group, 1998).

2.1. Structure and Bonding of SO_2

SO_2 is a bent molecule with C_{2v} symmetry point group. In terms of electron-counting formalism, the sulphur atom has an oxidation state of +4 and a formal charge of +1. It is surrounded by 5 electron pairs and can be described as a hypervalent molecule. The Lewis structure of SO_2 consists of an O=S=O double bond. From the perspective of molecular orbit theory, most of these valence electrons are engaged in S–O bonding (dative bond) without utilizing d-orbitals, resulting in a bond order of 1.5 (Cunningham et al., 1997).

2.2. Preparation of SO_2

Atomic structure of SO_2 that is produced by the burning of sulphur directly or of burning materials that contain sulphur is as;

$S_8 + 8O_2 = 8SO_2$.

SO_2 is typically produced in large amounts by the burning of common sulphur-rich materials including wool, hair, rubber, and foam rubber such as are found in mattresses, couch cushions, seat cushions, carpet pads and vehicle tires.

SO_2 is produced by the combustion of hydrogen sulphide (H_2S) and organosulphur compounds as;

$2H_2S$ (g) + $3O_2$ (g) = $2H_2O$ (g) + $2SO_2$ (g).

SO_2 is produced by the roasting of sulphide ores such as, pyrite (ferrous sulphide, FeS_2), sphalerite (zinc blend, zinc sulphide, ZnS) and cinnabar (mercury sulphide, HgS) as (Atkins, 2010);

$4FeS_2$ (s) + $11O_2$ (g) = $2Fe_2O_3$ (s) + $8SO_2$ (g)

2ZnS (s) + $3O_2$ (g) = 2ZnO (s) + $2SO_2$ (g)

HgS (s) + O_2 (g) = Hg (*l*) + SO_2 (g).

SO_2 is found as a by-product in the manufacture factory when calcium silicate cement ($CaSO_4$) is heated with coke (C) and sand (SiO_2) as;

$2CaSO_4$ (s) + $2SiO_2$ (s) + C (s) = $2CaSiO_3$ (s) + $2SO_2$ (g) + CO_2 (g).

Action of hot sulphuric acid on copper turnings produces SO_2;

Cu(s) + $2H_2SO_4$ (aq) = $CuSO_4$ (aq) + SO_2 (g) + $2H_2O$ (*l*).

Since coal and petroleum often contain sulphur compounds, their combustion generates SO_2 unless the sulphur compounds are removed before burning the fuel. SO_2 is the predominant form found in the lower atmosphere. Further oxidation of SO_2, usually in the presence of a catalyst such as NO_2, forms H_2SO_4, which creates acid rain.

Table 1: According to World Bank list of most polluted cities in 2004 (Slanina, 2008).

Rank	City	Country	Part. Matter ($\mu g/m^3$)
1	Cairo	Egypt	169
2	Delhi	India	150
3	Kolkata	India	128
4	Tianjin	China	125
5	Chongqing	China	123
6	Not Found (N/F)	N/F	N/F
7	Kanpur	India	109
8	Lucknow	India	109
9	Jakarta	Indonesia	104
10	Shenyang	China	101
11	Zhengzhou	China	97
12	Jinan	China	94
13	Lanzhou	China	91
14	Taiyuan	China	89
15	N/F	N/F	N/F
16	Beijing	China	88
17	Chengdu	China	86
18	N/F	China	83
19	Anshan	China	82
20	Wuhan	China	79

2.3. Use of SO_2

SO_2 has several agricultural and industrial uses. It can serve as a warning marker and fire retardant for liquid grain fumigants. Every year more than 300,000 tons of SO_2 are used globally for the manufacture of sulphur containing chemicals, particularly hydrosulphites. The bleaching of wood pulp and paper is another common use along with processing, disinfecting, and bleaching food products. There are also uses in metal, ore and oil refining as well as in waste and water treatment. It is used in small amounts as a food and wine preservative (Agency for Toxic Substances and Disease Registry (ATSDR), 2004).

Table 2: Blacksmith List of most polluted cities and areas (The Blacksmith Institute, 2007).

Rank	City	Country
1	Sumgayit	Azerbaijan
2	Linfen	China
3	Tianying	China
4	Sukinda	India
5	Vapi	India
6	La Oroya	Peru
7	Dzerzhinsk	Russia
8	Norilsk	Russia
9	Chernobyl	Ukraine
10	Kabwe	Zambia

Table 3: Estimated SO_2 emissions scenario accordance with GDP growth rate in China (Su et al., 2013).

GDP growth Scenarios	Electricity generation (TWh)	Gross SO_2 emissions (MT)	Household SO_2 emissions	SO_2 emission control target
5%	5,306	60.6	2.1	69.9%
7%	5,893	65	2.2	72.1%
9%	6,434	69	2.2	73.8%
11%	8,193	80.7	2.3	77.8%

Table 4: Installation, operation and SO_2 removal rates for plants with SO_2 control in 11th Five-Year Plan in China.

	2006	2007	2008	2009	2010
Operating and absorption rate (%)	57	57	57	57.6	57.7
Installation rate (%)	30	43	60	80	80
Removal rate of all plants (%)	17	24.6	34.4	46	46

Table 5: SO_2 reduction targets and results in the previous Five-Year Plans in China (Su et al., 2013).

	10th (2001–05)	11th (2006–10)
SO_2 reduction targets	10% below 2000 levels	10% below 2005 levels
SO_2 reduction results	27.8% above 2000 levels	14.3% below 2005 levels
Industrial emissions meeting discharge standards	79.4%	97.9%
Industrial desulphurization rate	33.5%	66.0%

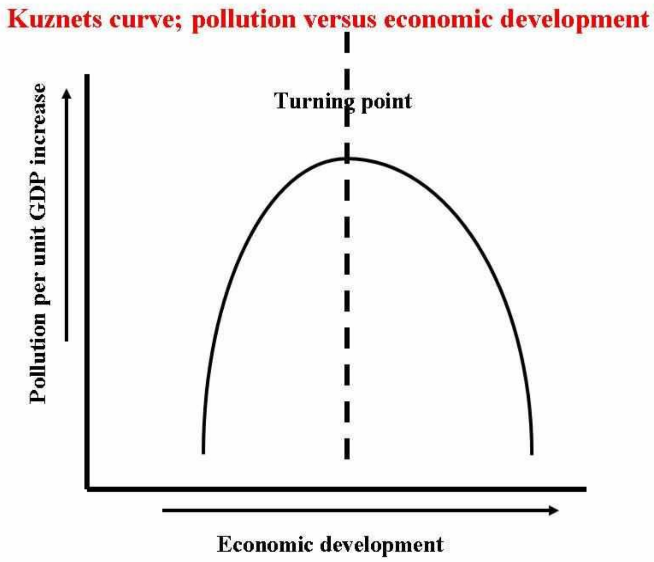


Fig. 1: Kuznets curve: pollution versus economic development (Slanina, 2013).

3. EFFECTS OF SO_2 ON HUMAN HEALTH

SO_2 is considered as severe health effect ingredient, both in short-term and long-term. It is a major pollutant that has a relatively short lifetime in the atmosphere and has negative effects that are local in nature. The negative effects of SO_2 on health have been well documented in toxicological, human clinical and epidemiological studies (Electric Power Research Institute (EPRI, 2009). The human lungs are particularly susceptible to both the chronic and acute effects of SO_2. After entering upper portion of lungs it immediately passes through the mucous membranes into the blood (Petruzzi et al., 1994). In blood it becomes associated with the alpha-globulin fraction of plasma (Toxicology Update, 1995). In the moist pulmonary environment, SO_2 produces sulphurous acid (H_2SO_3), which is a severe irritant. In addition it produces H+, bisulphate (HSO_3–), sulphite (SO_3=), which in turn affects the smooth muscles and nerves involved in bronchoconstriction (Gunnison and Jacobsen, 1987; ATSDR, 2004; Miller et al., 2004). SO_2 increases lipid peroxidation of cell membranes and interferes with antioxidative processes by decreasing the levels of superoxide dismutase, catalase and glutathione peroxidase.

The health effects caused by a short-term (a few minutes) exposures to SO2 are as follows (Bureau of Community and Environmental Health (BCEH), 2001):

(a) difficulty in breathing; (b) coughing; (c) irritation of the nose, throat, lungs; (d) fluid in lungs; (e) shortness of breath, and; (f) forms sulphuric acid in lungs.

The health effects caused by long-term exposure to SO_2 are as follows (BCEH, 2001):

(a) temporary loss of smell; (b) headache; (c) nausea; (d) dizziness; (e) irritation of lungs; (f) phlegm; (g) coughing; (h) shortness of breath; (i) bronchitis, and; (j) reduced fertility.

The people who may be more sensitive to SO_2 than others are as follows (BCEH, 2001):

(a) children; (b) elderly; (c) people with asthma; (d) people with chronic lung disease, and; (e) people with cardiovascular diseases.

A healthy people exposed to 1.5 parts per million (ppm) (1 ppm = 2.616 mg/m^3) of SO_2 for a few minutes may have temporary difficulty in normal breathing. Breathing in SO_2 can irritate the nose, throat and the lungs, causing phlegm, coughing, shortness of breath, development of bronchitis and other respiratory diseases, as well as aggravation of existing cardiovascular disease. Asthmatics can be particularly susceptible to the pulmonary effects of SO_2. Long-term contact to SO_2 at lower concentrations can cause temporary loss of smell, headache, nausea and dizziness. More than 400 ppm concentrations of SO_2 can cause severe shortness of breath and a build-up of fluid in the lungs. The great problem is that SO_2 can go deep into the lungs where it combines with moisture to form H_2SO_4, possibly causing permanent lung damage. Long-term exposure to SO_2 may decrease fertility both in males and females (BCEH, 2001).

In its untransformed, acidic, and particulate state, SO_2 has adverse effects on human health and the environment. Inhaling SO_2 is associated with increased respiratory symptoms and disease, difficulty in breathing and premature death. High levels of SO_2 emissions can cause problems of breathing difficulty, respiratory illness, emphysema, asthma, acute broncho spasm, chronic bronchitis and heart diseases.

Fine particles $PM_{2.5}$ penetrates deeply into sensitive parts of the lungs, where it can worsen respiratory disease, such as emphysema and bronchitis, and can worsen existing heart disease, can increase pulmonary disorders, and can increase morbidity and mortality rate. As a result increased of hospital admissions and sometimes caused premature death. At the cellular level, SO_2 decreases levels of antioxidant enzymes, increases membrane permeability, causes chromosome breakage and is mutagenic or co-mutagenic.

A 2011 systematic review concluded that exposure to sulphur dioxide is associated with preterm birth (Shah and Balkhair, 2011). Children take more air in breathing for their body weight than adults. So, they can be more sensitive to the effects of SO_2 than those of adults. Long-term exposure to SO_2 increased respiratory illness and wheezing fits.

In the winter months when weather inversions occur, air pollution due to SO_2 is trapped close to the ground and cannot escape to the upper atmosphere and the pollution reaches in unhealthy levels.

4. EFFECT OF SO_2 WITH DOSE WISE

Effects of SO_2 in human body are dose dependent. Typical levels of human susceptibility act as follows (Toxicology Update, 1995):

(1) At 5 ppm, dryness of the nose and throat can be felt and resistance to bronchial airflow significantly increases.

(2) At 6–8 ppm, tidal respiratory capacity may evidently decrease.

(3) At 10 ppm, sneezing, coughing and wheezing may be seen, possibly accompanied by eye, nose and throat irritations. In this situation nose bleeding may also be seen. At this level, asthmatics are likely to experience asthmatic paroxysm, lasting possibly for several days.

(4) At 20 ppm, bronchospasms be inclined to begin and eye irritation is a common matter.

(5) At 50 ppm, discomfort becomes extreme, but permanent injury is unlikely if exposure is less than 30 minutes duration.

(6) Above 50 ppm, reflex closure of the glottis can happen and last for a period of minutes.

(7) Disclosure to SO_2 at a concentration of 400 ppm will likely constitute an immediate danger to life.

(8) Concentrations above 1,000 ppm, are usually fatal within 10 minutes; the proximate cause of death is assumed to be respiratory depression.

(9) For asthmatics, experiences as low as 0.1 ppm for as short duration as 10 minutes during tiring physical activity, can result in significant respiratory changes and asthmatic attacks.

5. SO_2 STANDARDS

The existing primary SO_2 standards were established in 1971, which include a 24-hour standard at a level of 140 parts per billion (ppb) (SO_2 conversion factor for ppb to μg/m^3 is 2.616) and an annual average standard of 30 ppb.

WHO (2005) expressed that *"Controlled studies involving exercising asthmatics indicate that a* *proportion experience changes in pulmonary function and respiratory symptoms after periods of exposure to SO_2 as short as 10 minutes."*

The European Union Air Quality Standards (EUAQS) and The United States Environmental Protection Agency (USEPA) established a new 1-hr standard for SO_2 at 350 µg/m^3 and 196 µg/m^3 (75 pbb), respectively. The USEPA estimates that the health benefits associated with this rule range between \$13 billion and \$33 billion annually, which include preventing 2,300 to 5,900 premature deaths and 54,000 asthma attacks in a year. The estimated cost in 2020 to fully implement this standard is around \$1.5 billion (Sulphur Dioxide Standards in Asia, 2010).

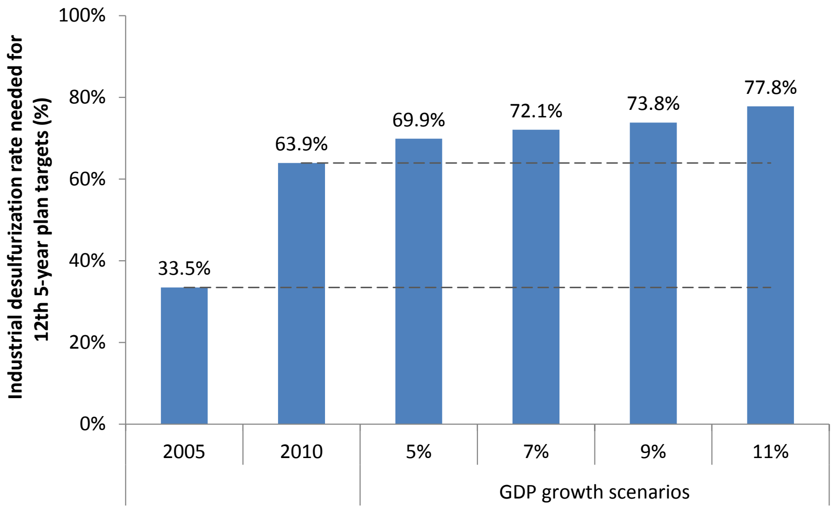


Fig. 2: Industrial desulfurization rate for 11th Five-Year Plan (Su et al., 2013)

6. GLOBAL SO_2 EMISSIONS

Scientist calculated that human beings release about one-third of all sulphur compounds into the atmosphere. SO_2 is released when fossil fuels such as, coal, oil, gasoline, and diesel fuel are burned (commonly containing 1–2% sulphur by weight), from deforestation and agricultural activities and from traditional biomass combustion. Main source of SO_2 emissions are from fertilizer manufacturers, power plants, refineries, wood and paper mills, metal smelters, and other industrial processes.

Fossil fuel combustion at power plants (73%) and other industrial facilities (20%) are the main sources of SO_2 emissions. Other sources of SO_2 emissions are extracting metal from ore, and the burning of high sulphur fuels by locomotives, large ships, and non-road equipment.

Global SO_2 emissions peaked in the early 1970s and decreased until 2000 and then increased from 2000 to 2005 due to increased emissions in China, international shipping, and developing countries in general. At present China represents one-third of global SO_2 emissions from man-made sources. Between 2000 and 2010, SO_2 emissions in North America and Europe continued to decrease. But SO_2 emissions in India, the second largest source in Asia (China is the highest SO_2 emitter in Asia, as well as in the world), are rising, largely due to an increase in coal consumption and the absence of laws requiring flue-gas desulphurization. In 2010, Indian SO_2 emissions exceeded those of the USA and were about one-third of China's total.

In 2006, China became the world's largest SO_2 polluter, with 2005 emissions estimated to be 25.49 million tons (MT). This amount represents a 27% increase since 2000, and is roughly comparable with the US emissions in 1980 (United Press International, 2006).

7. AIR POLLUTION IN CHINA

Ambient concentrations of SO_2 in some regions of China are several times higher than air quality standards. Rapid economic growth of China has been increased emissions of SO_2 (a major air pollutant), NO_x and CO_2, due to increase of burning of fossil fuels. These three gases pollute air and environment, which increase human morbidity and mortality rates. Approximately 40% of China's land area is affected by acid rain. The proportion of SO_2 emissions from the industrial sector grew from 76% to 85% between 1998 and 2006. Since 1990, SO_2 generated in China has been responsible for about one-fourth of the global emissions and more than 90% of the East Asian emissions. In 2006, Coal-fired power plants emitted about 11.12 MT of SO_2, which is about half of the total SO_2 emissions in China.

Between 1980 and 2006, total coal consumption in China increased from 0.6 billion tons (BT) to 2.58 BT, and SO_2 emissions reached 25.89 MT in 2006

(Ministry of Environmental Protection of the People's Republic of China (MEPPRC), 2007).

In the early stages of Chinese economic development, the heavy use of coal and inefficient boilers were responsible for high concentrations of particulate matter and SO_2 in the air (Slanina, 2008).

In the last 30 years, China has achieved rapid economic growth, industrialization, and urbanization, with annual increases in GDP of 8 to 9% (Cost of Pollution in China 2007). At present China is the world's second-biggest economy (behind the USA) and it consumes 21.9% of the total primary energy in the world in 2012 and also it is now the world's largest energy consumer (BP, 2013).

According to Chinese Government statistics, SO_2 emissions in China were 19.95 MT in 2000; of which, 85% were from direct coal combustion (Yang et al., 2002).

In January 2013, a long-lasting episode of severe haze occurred in central and eastern China. The two harshest conditions occurred during 9–15 January and 25–31 January. During these two haze pollution incidents, the maximum hourly $PM_{2.5}$ mass concentrations in Beijing were 680 and 530 μg/m^3, respectively (Wang et al., 2014).

Energy consumption of China increased 120% from 2000 to 2010. Coal accounted for most of the primary energy consumption (up to 70%), which is much higher than the coal consumption in developed countries (20% to 30%).The vast majority of coal consumption was concentrated in the haze pollution regions of northern China, central China and eastern China (Wang et al., 2014).

The energy consumption per unit of GDP in China is high, about 8 to 10 times greater than that of Japan or Germany. Kuznets curve explains the pollution versus economic development in China (Figure 1). When economic development is in an early stage, the air pollution is low. Later stage the pollution growth lags behind economic development. China is reaching this turning point rather fast, compared with US and EU developments (Slanina, 2013).

According to the World Bank (World Bank, 1997), the air pollution in China ranks among the highest in the world (Table 1). In 1995 about 178,000 premature deaths, 346,000 registered hospital admissions, more than 75 million asthma incidences happened in China due to the air pollution. Due to the expansion in manufacturing industries and fueled by coal in China, the source of more than 70% of the energy consumed nationwide (National Bureau of Statistics (NBS), 2008). The Blacksmith Institute in London (The Blacksmith Institute, 2007) has assembled another list, based on a large array of different types of air, water and soil pollution (Table 2).

The SO_2 related pollution has momentous adverse impacts on human health, ecosystems, and cultural resources, and has caused direct economic loss of China in each year (Zheng et al., 2010). Zhang et al. (2008) have estimated that the total particular matters (PM) concentrations in 111 key Chinese cities contributed to more than 280,000 premature deaths and 680,000 cases of chronic bronchitis at a cost to the economy of more than 187.7 billion RMB ($29.2 billion) annually.

In China's thermal power industry emits more than 50% Chinese SO_2. From 2000 to 2006, total SO_2 emission in China increased by 53%, from 21.7 trillion gram (Tg) to 33.2 Tg, which is an annual growth rate of 7.3%. Emissions from power plants are the main sources of SO_2 in China. These plants have increased from 10.6 Tg to 18.6 Tg in the same period.

Particulate matter, especially the smaller particles, has harmful effects on human health. Estimates of deaths due to respiratory and heart diseases caused by air pollution in China vary between 200,000 and 600,000 per year (HEI International Scientific Oversight Committee, 2004).

From 2000 to 2006 SO_2 emissions from north China increased by 85%, but in the south increased by only 28%. The anthropogenic SO_2 emission in China is of increasing global concern, as it contributed to about one-fourth of the global SO_2 emissions and more than 90% of Eastern Asia emissions since the 1990s (Streets et al., 2009; Ohara et al., 2007). Air pollution due SO_2 emissions of China are effecting larger regions from the Asian continent to the Northwestern Pacific, North America, and the rest of the northern hemisphere. Because of the harmful effects of SO_2, plants cannot grow robustly and some also die in severely polluted industrial areas.

SO_2 emissions vary accordance with the regions of China, depending with different sectors and characteristic of fuels. The relative emissions of SO_2 are defined as emissions energy thermal consumption multiplied by emission factors, considering corresponding removal efficiency. SO_2 emissions in specific region are calculated as follows (Su et al., 2013):

$$E = \sum_{s}\sum_{e} 2Q_{se}S_{e}\alpha_{e}\left(1-\delta_{e}\right) \qquad (1)$$

where the multiplication factor 2 in the right hand side of (1) indicates that the atomic weight of SO_2 is twice as S, the suffices *s* and *e* indicate sector and energy source, respectively. Q_{se} is the energy thermal consumptions in specific region, sector and energy source, S_e is the sulphur content in specific region and energy source, α_e is the SO_2 emission factor in specific region and energy source, δ_e is the desulphurization rate in specific region and energy source.

SO_2 creates acid rain. The Chinese Central government's environment agency has estimated that the economic costs of acid rain at more than 83 billion RMB ($13 billion) per year (Hao et al., 2007).

8. SO_2 EMISSIONS CONTROLLING POLICY IN CHINA

To control SO_2 emissions, in 1998 the Chinese Government implemented Two Control Zone (TCZ) policy (the Acid Rain and Sulphur Dioxide Emission Control Zones Policy). The policy package contains the following two conditions (Li and Gao, 2002):

(a) Any new coal mine with sulphur content greater than 3% will be shut down and will be limited.

(b) The construction of new thermal power plants will not be approved in large and medium-size cities or their suburbs; for newly built or rebuilt thermal power plants, if the sulphur content in burning coal exceeds 1%, desulphurization facilities must be installed.

Since 2006, China has taken steps to reduce energy intensity, emissions, and pollutants in multiple guidelines and in the Five-Year Plans. Government of China takes various steps to control SO_2 emission. In the 4th plenary session of the 10th National People's Congress, the central Government explicitly mandated a 10% reduction in national SO_2 emissions to be accomplished by 2010. Unfortunately during this period SO_2 emissions have increased by about 28% in the 10th Five-Year Plan (2001–2005) (National Bureau of Statistics (NBS), 2010). Desulphurization devices are required to be installed in most power plants, which had 52% of total coal consumption in China (NBS, 2009) and has effectively reduced SO_2 emission in China (Cao et al., 2009). SO_2 emissions began to decrease in China after 2006 mainly due to the wide application of flue-gas desulfurization (FGD) devices in power plants (Lu et al., 2010). The Ministry of Environmental Protection (MEP) of China resolved in its 11th Five-Year Plan (2006–2010) to cut the national SO_2 emissions by 10% and total SO_2 emissions declined by more than 14.3% by the end of 2010 (NBS, 2010).

Chinese Government has planned to reduce SO_2 emissions by 8% in the new 12th Five-Year Plan (2011–2015). China has targeted to popularize of wet-type SO_2 scrubbers and to improve the environmental emission standards, which plays an important role in the achievement of SO_2 control target by 2015 (State Council of China (SCC), 2011).

The maximization discounted consumption of each decision variables in equation (1) can be calculated as (Su et al., 2013);

$$D = 5\sum_{r=1}^{R}\sum_{t=1}^{T}\prod_{j=0}^{t-1}\left(1-d_{j,r}\right)^{5}\ln C_{t,r}. \qquad (2)$$

5 in equation (2) indicates 5 years per period, C is annual consumption and d is utility discount rate. During the 12th Five-Year Plan five possible desulfurization rates in China are 50%, 60% 70%, 80% and 90%, covering the desulfurization rate in 2010 of 66%. In the planned 7% GDP growth scenario, China generates 5,893 TWh electricity and the gross SO_2 emissions reaches to 65 MT in 2015. The corresponding figures for 5%, 9% and 11% GDP growth scenarios are given in Table 3.

The provinces of China that emit SO_2 seriously like Shandong, Jiangsu and Guangdong are assigned high emission reduction targets, as 14.9%, 14.8% and 14.8%, respectively, comparing to 2010 levels. On the other hand, the most important industrial and commercial municipalities in China, Shanghai and Beijing are also allocated relatively severe SO_2 emission control targets, reducing 13.7% and 13.4% below 2010 levels, respectively. But some provinces of China are even allowed to increase the SO_2 emissions due to previous lower emissions, such as Hainan, Qinghai and Gansu, which are able to raise the SO_2 emissions by 34.9%, 16.7% and 2% above 2010 levels, respectively (Su et al., 2013).

The ancillary benefits of damage of per ton of SO_2 are different in different countries.

9. DESULPHURIZATION IN CHINA

The desulphurization rate is calculated based on the historic trend of the emission intensity, given the installation rate of the technology, an actual operating rate of the technology and the derived absorption rate. The installation rate was 2% in 2000, and increases to 6% in 2005. After the initiation of the 11th Five-Year Plan, it surged to 60% in 2008, and 80% in 2009 (China Electricity Council (CEC), 2009). The absorption rate remained at only 79% in 2009 in difference to the technical maximum removal rate of 95–98% of the technologies (Yang, 2009). Based on an overall 46% removal rate derived from the SO_2 emission intensity (Table 4), the ratio of the operating facility is estimated to be around 70% in 2009 (Zhou et al., 2011).

According to the 11th Five-Year Plan to reduce energy intensity by 20% by 2010, the State Council also approved a plan to close 50 Giga-watt (GW) of small coal-fired power plant capacity (small plants are considered those with less than 100 MW of capacity). By the end of 2009, a total of 60.38 GW of capacity of small coal-fired power plants has already been shut down since 2006 (Ministry of Industry and Information Technology (MIIT), 2010). It is forecasted that removal rate in China will be 81% by 2015 and 98% in 2020 (Zhou et al., 2011).

Desulphurization rate in China in the 10^{th} Five-Year Plans was not satisfactory but in the 11^{th} Five-Year Plans it was in progress (Table 5). Industrial desulphurization rate was 33.5% in 2005 and 63.9% in 2010 in the 11^{th} Five-Year Plan (Figure 2). The thresholds of desulfurization for different growth scenarios, namely 5%, 7%, 9% and 11% scenarios, to achieve the SO_2 emission control target be 69.9%, 72.1%, 73.8% and 77.8, respectively (Su et al., 2013).

10. RECOMMENDATIONS

Desulfurization rates of China should be raised above 70% in 12^{th} Five-Year Plan due to the uncertainty of GDP growth in urban areas. Desulphurization equipment should be installed in the petrochemical sector for catalytic cracking units with sulfur recovery rate in excess of 99%.

The popularization of wet-type SO_2 scrubbers and improvement of the environmental emission standards play an important role in the achievement of SO_2 control target by 2015. The improvement in energy consumption structure contributes to SO_2 and other energy related emission controls effectively, as well as the sustainable development of energy.

Strengthen flue gas treatment in mid- to large-sized coal-fired boilers, so that the boilers with capacity above 20 tons per hour should have sulphur removed, and the desulphurization rate will be greater than 70%. Desulphurization equipment should be installed in all coal-fired power units of the country, and substandard desulphurization equipment should be upgraded and reconstructed. The overall desulphurization efficiency in thermal power should be greater than 90%.

11. CONCLUSION

Global rapid urbanization and industrial development increased wealth and welfare. On the other hand pollution also increased due to emissions GHGs and SO_2. In this study we have not included GHG emissions and discus only SO_2 emissions and reduction policies of China. We have stressed on SO_2 emissions of China, as it is the world's largest SO_2 emitting country. In this article we have discussed some properties of SO_2 and then discussed Chinese SO_2 situations.

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Haradhan Kumar Mohajan is an assistant professor at Premier University, Chittagong, Bangladesh. He received his Master Degree in Mathematics from the University of Chittagong and M. Phil in Theoretical Physics from the same University. He has submitted his PhD Dissertation in Mathematical Economics and Social Science in January 2012 in the same University. He has 60 published papers in the reputed journals. He has also 16 published books and 2 books to appear. He is a member of American Association of International Researchers (AAIR) and advisor of Hasnabad Graduate Forum.