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ADVANCES IN AIR POLLUTION, ITS MONITORING & REMEDIAL MEASURES - A REVIEW

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Abstract –

Air quality have been long-standing concerns in the India and elsewhere, primarily due to rapid economic growth, industrialization and urbanization with associated increase in energy demand. Lack of implementation of environmental regulation is contributing to the bad air quality of most of the Indian cities. The World Health Organization reports that every year several million people die prematurely due to air pollution. Particulate matter (PM), Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Carbon Monoxide (CO) and Ozone (O_3) are the major element of polluted air. The presented review is an effort to discuss various aspects of advances in air pollution and control technologies emphasizing on the history and present scenario.

Keywords *- Air Quality, Air Quality Index, Urban air pollution, Particulate Matter, Ozone,*

I. INTRODUCTION

Air pollution means the presence in the outdoor atmosphere of one or more contaminants, such as dust, fumes, gas, mist, odour, smoke, or vapors, in quantities, with characteristics, and of duration such as to be injurious to human, plant, or animal life or to property, or which unreasonably interfere with the comfortable enjoyment of life and property. (Engineers Joint Council-USA). Air is one of the five vital basic natural ingredients of life system. The immediate environment of human-being comprises of air on which depends all forms of life. The major anthropogenic sources of air pollutants are industrial emissions, domestic fuel burning, emissions from power plants and transportation activities etc. The advent of technological and scientific innovations in various fields and diverse activities of human race for its sophistication have put extra load on the atmosphere by way of releasing air pollutants like suspended particulate matter (SPM), respirable suspended particulate matter (RSPM), sulphur dioxide (SO_2), oxides of nitrogen (NOx), carbon monoxide (CO), unburned hydrocarbon (HC), hydrogen fluoride (HF) and other organic as well as inorganic pollutants including trace metals responsible for causing health consequences. Air Pollution indeed is now a serious worldwide public health problem. The short term health impacts of air pollution have been studied extensively since the London fog in the mid 20th Century and subsequent series of dreaded incidents in industrialized countries. The compatibility between ecology and economy is one of the most burning issues of the present times. Developmental activities e.g. industrial expansion, mining exploration, transportation and constructional works etc. cause degradation and drastic changes in every component of environment namely; hydrosphere, lithosphere, atmosphere and biosphere through pollution. Air pollution has emerged in the past few decades as the most crucial problem to the mankind and a large number of studies in this regard have been undertaken in all over the World.

Urban air pollution (UAP) is a major concern throughout the world in both, developed and developing countries. Swelling urban population and increased volume of motorized traffic in cities have resulted in severe air pollution affecting the surrounding environment and human health. The World Health Organization (WHO) has estimated that in developing countries, increasing UAP has resulted in more than 3 million deaths per annum along with various cases of respiratory illnesses. One of the major sources of UAP is the road transport sector. Besides, domestic, commercial and industrial activities also contribute to UAP. It is reported that over 70–80% of air pollution in mega cities in developing nations is attributed to vehicular emissions caused by a large number of older vehicles coupled with poor vehicle maintenance, inadequate road infra‒ structure and low fuel quality. Re–suspension of road dust due to movement of traffic and tyre and brake wear are also some of the significant sources of ambient PM concentrations in urban areas. Ambient air pollutant concentrations are distributed non–uniformly in urban areas, creating hot spots mostly in central business district, traffic intersections and signalized roadways. Besides, topographical and meteorological variations in urban areas lead to complex spatial and temporal variations in pollutant concentrations. The spatial scale of Urban Air Quality Management Plan (UAQMP) varies from macro (national level) to medium (city level) and micro level (site specific). The temporal scale is either long–term or short term, based on the national ambient air quality standard (NAAQS).

II. ADVANCES IN AIR POLLUTION

A. Urban air quality management plan (UAQMP) is an effective and efficient tool employed in managing acceptable urban air quality (Sunil Gulia et al. 2015). However, the UAQM practices are specific to a country's needs and requirements. Majority of the developed countries have full–fledged UAQMP with a regulatory management framework. However, developing countries are still working in formulating the effective and efficient UAQMPs to manage their deteriorating urban air environment. The first step in the process of formulation of UAQMP is to identify the air quality control regions based on ambient air quality status and second, initiate a time bound program involving all stakeholders to develop UAQMPs. The successful implementation of UAQMPs depends on the strength of its key components, e.g. goal/objective, monitoring network, emission inventory, air quality modeling, control strategies and public participation.

Motorized road transport is the dominant source of urban air pollution in almost all the countries of the world. However, increasing ambient air pollution at urban hot spots is one of the critical problems with frequent violations of NAAQS and/or WHO guidelines for pollutants like PM2.5, PM10 and NO_X. An effective and efficient UAQMP may include all the key components, which may help in sustaining an acceptable ambient air quality. The UAQMPs can be implemented at national, city and/or local levels. In most of the developed countries, the UAQMPs are already being implemented successfully. The UAQMPs like SIP and LAQMP possess efficient communication system between national and local authorities, which ensures its effective implementation and thus maintain the acceptable ambient air quality. These UAQMPs have strict air quality standards/limits for all criteria and hazardous air pollutants; continuous real time air quality monitoring network along with display systems; efficient emission inventory model; air quality modeling and control practices and public participation. In London, congestion and road user charging schemes have been implemented successfully aiming to reduce vehicular pollution in specific defined zones which have significantly reduced CO_2, NO_X and PM10 concentrations by 16.4%, 13.4% and 6.9%, respectively (EEA, 2008). Further, Tonne et al. (2008, 2010) have reported significant reduction in PM and NOX concentrations after the implementation of "congestion charging" in London which thereafter resulted in an increase in associated health benefits. Hasheminassab et al. (2014) have evaluated the impact of UAQM strategies in the reduction of PM2.5 emissions from vehicular source using SA. Results have indicated that PM2.5 emissions from the year 2002 to 2012 have been decreased by 24% and 21% in Los Angeles and Rubidoux, respectively. Another successful implementation of UAQMP can be observed at Cardiff and Norwich cities, where significant reductions in NO_2 concentrations have been achieved (Moorcroft and Dore, 2013). In USA, efficient and effective SIP in regions of Connecticut, Georgia, Illinois, Indiana, Kentucky, Maryland, Michigan, Missouri, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Tennessee and West Virginia and the District of Columbia has helped in achieving the goal of bringing down the concentrations of PM2.5 within the prescribed standards (Cohan and Chen, 2014). Soret et al. (2011) and Soret et al. (2013) have described how the improvements in urban traffic fleet and vehicle technologies can significantly reduce ambient concentrations of NO_2 and PM10 in the city of Barcelona, Spain. Using WRF ARW/HERMES/CMAQ modeling system at very high spatial and temporal resolutions, it is observed that NO_2 and PM10 reductions are in the range of 15 g/m^3 and 5 g/m^3, respectively. In addition, Henschel et al. (2012) have reviewed control strategies that have been implemented to reduce air pollution levels and their health impacts. They have reported that interventions have successfully reduced air pollution levels and increased associated health benefits, mainly through reduced cardiovascular and/or respiratory mortality and/or morbidity. Further, Pope et al. (2009) have observed that a reduction in the exposure to ambient fine PM concentrations has resulted in significant and measurable improvements in life expectancy in 211 county units in 51 U.S. metropolitan areas. The decrease of 10 g/m^3 in the concentration of PM2.5 has been associated with an increase in mean life expectancy of 0.61 years in urban and densely populated counties. Later, Correia et al. (2013) carried out similar studies in 545 counties in USA and found that reductions in PM2.5 concentrations due to implementation of efficient and effective UAQM strategies resulted in an increase in life expectancy. Similarly, in EEA member countries, a decrease in emission levels of NOX and PM2.5 from transport sector from 1990 to 2005 has resulted in a reduction in health impacts in the range of 2.5% in Bulgaria to 25% in Luxembourg and Switzerland (EEA, 2010). In another study, involving 25 cities of 12 European countries, it has been estimated that decrease of long term exposure to PM2.5 to 10 g/m^3 can prevent more than 19000 premature deaths, annually (APHEKOM, 2011). In addition, Pererz et al. (2009) have estimated that reducing the mean PM10 exposure by 30 mg/m^3 has resulted in 3500 lesser deaths, 1800 lesser hospitalizations for cardio–respiratory diseases, 5100 lesser cases of chronic bronchitis among adults, 31100 lesser cases of acute bronchitis among children and 54000 lesser asthma attacks among children and adults. As a consequence, the mean total monetary benefits have been estimated to be 6400 million Euros per year.

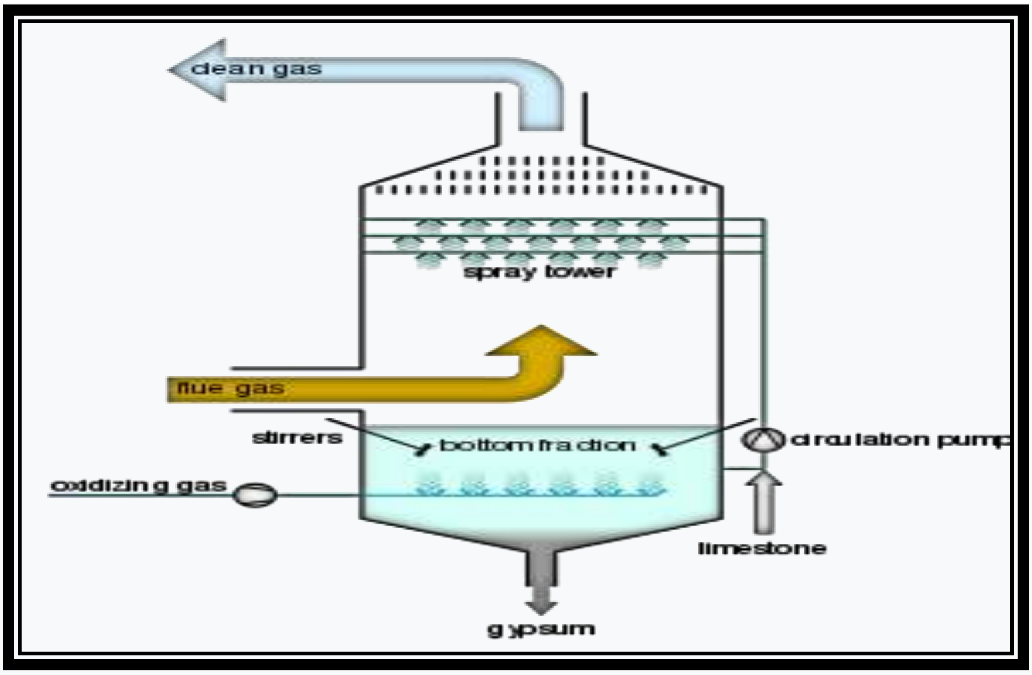
Table 1: UAQM strategies of developed and developing countries

UAQM Strategies	US [a]	UK [b]	EU [c]	Australia [d]	British Columbia [e]	Japan [f]	Hong Kong [g]	Singapore [h]	Mexico [i]	Thailand [j]	South Africa [k]	China [l]	India [m]
Alternative fuel option in vehicles	x	x	x	x	x	x	x	x	x	x	o	x	x
Improvement in fuel quality	x	x	x	x	x	x	x	x	x	o	o	x	x
Fitting of catalytic converter	x	x	x	x	x	x	x	x	x	o	o	o	o
Inspection and maintenance program	x	x	x	x	x	x	x	x	x	o	o	o	o
Use of low and zero emission vehicles	x	x	x	x	x	x	x	o	x	o	o	o	o
Banned on street parking	x	x	x	x	x	x	x	x	x	o	o	o	o
Support for cycling	x	x	x	x	x	x	x	x	o	x	–	x	n
Congestion charging	x	x	x	x	–	–	–	–	x	n	n	n	n
Specific bus corridors	x	x	x	x	x	x	o	o	x	o	o	o	o
Pedestrians corridors	x	x	x	x	x	x	o	o	x	o	o	o	o
Low emission zone	–	x	x	o	–	–	–	n	o	n	n	n	n
Banned on entry of old vehicles in air quality control regions	x	x	x	x	x	x	x	x	x	o	o	o	o
Banned of heavy good vehicles in air quality control regions	x	x	x	x	x	x	x	x	x	o	o	o	o
Banned on idling of vehicles at traffic signal	x	x	x	o	x	–	o	–	–	–	n	–	n
Split Cycle Offset Optimization Technique (SCOOT) system	o	x	x	–	–	–	n	n	–	n	n	n	n
Intelligent transport system	x	x	x	–	–	–	–	–	–	–	n	n	n
Banned on smoky vehicle	x	x	x	x	x	x	x	x	x	x	o	o	o
On–board diagnostic system in vehicle	x	x	x	x	x	x	x	x	x	x	o	o	o
Subsidy on registration tax on environment–friendly vehicles	x	x	x	–	x	x	–	–	x	n	n	n	n
Mass rapid transport	x	x	x	x	x	x	x	x	x	x	o	x	x
Encouraging carpools	x	x	x	x	x	–	–	x	–	o	n	n	n
Maintenances of road infrastructure	x	x	x	o	x	x	o	x	x	o	o	o	o
Stringent emission norms	x	x	x	x	x	x	x	x	x	o	o	x	x
Reduction in diesel vehicles	x	x	x	x	x	x	x	x	x	o	n	n	n

B. Flue-gas desulfurization (FGD) is a set of technologies used to remove sulfur dioxide (SO_2) from exhaust flue gases of fossil-fuel power plants, and from the emissions of other sulfur oxide emitting processes (e.g trash incineration). Fossil fuels such as coal and oil can contain a significant amount of sulfur. When fossil fuels are burned, about 95 percent or more of the sulfur is generally converted to sulfur dioxide (SO_2). Such conversion happens under normal conditions of temperature and of oxygen present in the flue gas. However, there are circumstances under which such reaction may not occur. When flue gas has too much oxygen, the SO_2 further oxidizes into sulfur trioxide (SO_3). Too much oxygen is only one of the ways that SO_3 is formed. Gas temperature is also an important factor. At about 800°C, formation of SO_3 is favored. Another way that SO_3 can be formed is through catalysis by metals in the fuel. Such reaction is particularly true for heavy fuel oil, where a significant amount of vanadium is present. In whatever way SO_3 is formed, it does not behave like SO_2 in that it forms a liquid aerosol known as sulfuric acid (H_2SO_4) mist that is very difficult to remove. Generally, about 1% of the sulfur dioxide will be converted to SO_3. Sulfuric acid mist is often the cause of the blue haze that often appears as the flue gas plume dissipates. Increasingly, this problem is being addressed by the use of wet electrostatic precipitators.

1. *Basic principle*

Most FGD systems employ two stages: one for fly ash removal and the other for SO_2 removal. Attempts have been made to remove both the fly ash and SO_2 in one scrubbing vessel. However, these systems experienced severe maintenance problems and low removal efficiency. In wet scrubbing systems, the flue gas normally passes first through a fly ash removal device, either an electrostatic precipitator or a bag house, and then into the SO_2-absorber. However, in dry injection or spray drying operations, the SO_2 is first reacted with the lime, and then the flue gas passes through a particulate control device. Another important design consideration associated with wet FGD systems is that the flue gas exiting the absorber is saturated with water and still contains some SO_2. These gases are highly corrosive to any downstream equipment such as fans, ducts, and stacks. Two methods that may minimize corrosion are: (1) reheating the gases to above their dew point, or (2) using materials of construction and designs that allow equipment to withstand the corrosive conditions. Both alternatives are expensive. Engineers determine which method to use on a site-by-site basis.



2. Fig 1. Scrubbing with an alkali solid or solution

Schematic design of the absorber of an FGD SO_2 is an acid gas, and, therefore, the typical sorbent slurries or other materials used to remove the SO_2 from the flue gases are alkaline. The reaction taking place in wet scrubbing using a $CaCO_3$ (limestone) slurry produces calcium sulfite ($CaSO_3$) and may be expressed in the simplified dry form as:

$CaCO_{3(s)} + SO_{2(g)} \rightarrow CaSO_{3(s)} + CO2_{(g)}$

When wet scrubbing with a $Ca(OH)_2$ (hydrated lime) slurry, the reaction also produces $CaSO_3$ (calcium sulfite) and may be expressed in the simplified dry form as:

$Ca(OH)_{2(s)} + SO_{2(g)} \rightarrow CaSO_{3(s)} + H_2O_{(l)}$

When wet scrubbing with a $Mg(OH)_2$ (magnesium hydroxide) slurry, the reaction produces $MgSO_3$ (magnesium sulfite) and may be expressed in the simplified dry form as:

$Mg(OH)_{2(s)} + SO_{2(g)} \rightarrow MgSO_{3(s)} + H_2O_{(l)}$

To partially offset the cost of the FGD installation, some designs, particularly dry sorbent injection systems, further oxidize the $CaSO_3$ (calcium sulfite) to produce marketable $CaSO_4$-$2H_2O$ (gypsum) that can be of high enough quality to use in wallboard and other products. The process by which this synthetic gypsum is created is also known as forced oxidation:

$CaSO_{3(aq)} + 2H_2O_{(l)} + ½O_{2(g)} \rightarrow CaSO_4 \cdot 2H_2O_{(s)}$

A natural alkaline usable to absorb SO_2 is seawater.The SO_2 is absorbed in the water, and when oxygen is added reacts to form sulfate ions SO_4- and free H^+. The surplus of H^+ is offset by the carbonates in seawater pushing the carbonate equilibrium to release CO2 gas:

$SO_{2(g)} + H_2O_{(l)} + ½O_{2(g)} \rightarrow SO_4^{2-}{}_{(aq)} + 2H^+$

$HCO_3^- + H^+ \rightarrow H_2O_{(l)} + CO_{2(g)}$

In industry caustic (NaOH) is often used to scrub SO_2, producing sodium sulfite: $2NaOH_{(aq)} + SO_{2(g)} \rightarrow Na_2SO_{3(aq)} + H_2O_{(l)}$.

C. Chakr Shield -Energy, a building blocks for economic growth and development remains a major issue globally, specially developing nation like India with around 15% populations still deprived of electricity and millions more with unreliable access. This people are highly dependent on unsustainable means of power generation to meet their demands. Diesel generator predominant method of generating electricity in absence of regularize connection, is a major source of backup in industries, large residential colonies, commercial places construction sector, Telecom sector etc. This generates hazardous exhaust which not only as upsurges GHG emission but also intensifies carcinogenic and respiratory risk to the people, contribute to more than 4.2 million death globally every year. Addressing this often neglecting source of pollution there is a need of capturing a pollutant release from diesel generator. Such as Particulate matter(PM) from diesel generator thereby reducing the black carbon emission to the atmosphere and improving the quality of air.

Chakr Shield is the technology developed by Chakr Innovation Private Limited is a retrofit solution that captures PM and helps combat air pollution. The device is installed over the exhaust pipe of the DG that captures the exhaust and cools it to cause agglomeration of the soot particles. These soot particles, which primarily consist of PM are then made to pass through contours and meshes and captured with up to 90% efficiency. The collected PM is used as a raw material for making inks. Chakr Shield is available for use in a wide variety of DG capacities ranging from 20 kVA- 3000 kVA. Chakr Shield consists of non-moving parts, and therefore is a low maintenance device which is made of corrosion free material for better performance.

Key Features

- Reduces PM emissions up to 90%- helps reduce air pollutions and GHG emissions.
- Applicable for use in diesel generators using biodiesel as well.
- Successfully completed over 40 installations covering more than 4 MW of generation capacity.
- Applications in telecom towers, large residential societies, construction sites, malls, multiplexes, hospitals and industries.

- Used in diesel generators of wide range of capacities.

Benefits

Capturing PM using Chakr Shield is an effective solution to reduce the emissions to the atmosphere and to improve the quality of air. Chakr Shield ensures prolonged life for old diesel generators by equipping them to meet the latest environmental norms. The estimated GHG reduction by global adoption of this technology is likely to be 10.5 million tonnes by 2027.

D. ***Air Pollution Modelling*** Air pollution modeling is a numerical tool used to describe the causal relationship between emissions, meteorology, atmospheric concentrations, deposition, and other factors. Air pollution measurements give important, quantitative information about ambient concentrations and deposition, but they can only describe air quality at specific locations and times, without giving clear guidance on the identification of the causes of the air quality problem. Air pollution modeling, instead, can give a more complete deterministic description of the air quality problem, including an analysis of factors and causes (emission sources, meteorological processes, and physical and chemical changes), and some guidance on the implementation of mitigation measures. Various models are suggested to predict the urban air quality such as Gaussian plume model, BOX Model, Lagrangian model etc. ***Linear and nonlinear modeling*** was also performed to predict the urban air quality of the city (India). Partial least squares regression (PLSR), multivariate polynomial regression (MPR), and artificial neural network (ANN) approach-based models were constructed to predict the respirable suspended particulate matter (RSPM), SO_2, and NO_2 in the air using the meteorological (air temperature, relative humidity, wind speed) The ANN models may be useful tools in the air quality predictions (Kunwar P. Singh, 2012). In recent years, several research efforts have been made to develop the air quality prediction models. Atmospheric dispersion models used to predict the ground level concentration of the air pollutants around the sources (Cimorelli et al., 2005; EPA, 2005; Kesarkar et al., 2007; Bhaskar et al., 2008) require précised knowledge of several source parameters and the meteorological conditions (Collett and Oduyemi, 1997). The statistical models attempt to determine the underlying relationship between a set of input data and targets. Several linear (multiple linear regression, principal component regression, partial-least squares regression) and nonlinear (multivariate polynomial regression, artificial neural networks, support vector machines) regression models are now available, which have ability to relate the input and output variables. Although, linear regression modeling finds some applications in the air quality prediction (Ziomas et al., 1995; Shi and Harrison, 1997), it generally does not permit for consideration of complex and non-linearity in data (Gardner and Dorling, 1998). Partial least squares (PLS) is a multivariate regression method that projects the input–output data down in to a latent space, extracting a number of principal factors with an orthogonal structure, while capturing most of the variance in the original data. PLS derives its usefulness from its ability to analyze data with strongly collinear, noisy and numerous variables in the predictor matrix X and responses Y (Wold et al., 1984, 2001). The PLS method has successfully been applied to predict the dependent variable(s) through modeling the input–output relationship in the data (Kimura et al., 1996; Singh et al., 2007; Pires et al., 2008).Multivariate polynomial regression (MPR) captures nonlinearities in data to some extent and is considered a low-order nonlinear method (Singh et al., 2010). MPR has been applied to air quality prediction (Szyda et al., 2009). The artificial neural networks (ANNs) are considered as standard nonlinear estimators and their predictive and generalization abilities have been well established through their successful applications in a variety of fields (Yoon et al., 2011). Properly designed and trained with adequate data, a neural network is capable of learning process dynamics and making accurate prediction on process output based on the learned knowledge. This learning mechanism is not limited by the structure of data collection, and is robust because of its non-parametric nature. Different variants of ANN, such as multilayer perceptron network (MLPN), radial basis function network (RBFN), and generalized regression neural network (GRNN), have been used in various prediction modeling (Lu et al., 2002; Karakitsios et al., 2006; Du et al., 2008; Yilmaz and Kaynar, 2011; Shu and Lam, 2011; Vlachogianni et al., 2011; Paschalidou et al., 2011; Kassomenous et al., 2012). However, ANN is based on the empirical risk minimization (ERM),which can cause the solution to be captured in a local minimum and over-fitting of the network. The main objectives of this study were (i) to develop the linear and nonlinear approach based models (PLSR, MPR, ANNs) for predicting the urban air quality using selected air quality parameters (SPM, NO_2, SO_2) and meteorological conditions (air temperature, relative humidity, wind speed) as the estimators, and (ii) to compare the predictive and generalization abilities of these modeling approaches using a limited data set (http://www.cpcbedb.nic.in). Subsequently, linear (PLSR) and nonlinear (MLPN, RBFN, GRNN) models were developed and their predictive and generalization abilities were compared using several statistical performance criteria parameters.

II. CONCLUDING REMARKS

Today, air pollution in developing countries, has imposed a significant negative effects on public health and the environment. An effective and efficient UAQMP may include all the key components, which may help in sustaining an acceptable ambient air quality. The UAQMPs can be implemented at national, city and/or local levels. In most of the developed countries, the UAQMPs are already being implemented successfully. The UAQMPs like SIP and LAQMP possess efficient communication system between national and local authorities, which ensures its effective implementation and thus maintain the acceptable ambient air quality. These UAQMPs have strict air quality standards/limits for all criteria and hazardous air pollutants; continuous real time air quality monitoring network along with display systems; efficient emission inventory model; air quality modeling and control practices and public participation. Flue Gas Desulphurisation (GHC) among the techniques that are used for removal of Sulphur Dioxide from exhaust flue gases of fossil-fuel power plants, and from the emissions of other sulfur oxide emitting processes. It is a control device that absorbs and react using the alkaline reagent to produce a solid compound. The FGD technology is based on a chemical reaction that occurs when the warm exhaust gases from the coal-fired boiler come into contact with limestone. This reaction removes 92% of the sulphur dioxide from the flue gas and converts the limestone into Calcium Sulphite. In Flue Gas Desulfurization lime plays a key role in many air pollution control applications. Air pollution models play an important role in science, because of their capability to assess the relative importance of the relevant processes. Air pollution models are the only method that quantifies the deterministic relationship between emissions and concentrations/depositions, including the consequences of past and future scenarios and the determination of the effectiveness of abatement strategies. This makes air pollution models indispensable in regulatory, research, and forensic applications.

Hence from above discussion we can concluded that pollution from diesel generator or Sulphur Dioxide generating plant where fossil fuel is burn can reduce by desulphurization process and for validation of the work we can apply different modeling after evaluation and assessment of particular area or city.

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