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19th International Conference of the System Dynamics Society

MODELLING AND ANALYSIS OF ENVIRONMENTAL POLLUTION IN AN INTEGRATED STEEL PLANT

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Abstract

Gaseous, liquid, and solid pollutants that are released from the production processes in an integrated steel plant are modeled here using system dynamics. This is a macro model. This model is simulated and experimented with various pollution abating policies, mainly in terms of the investment made for pollution control. The results provide a broad idea of the extent of actions that are required to control pollution.

1. Introduction

The integrated iron and steel plant in large and complex. It had several operations that produce huge amounts of gaseous, liquid and solid wastes. Impact of these pollutants, if uncontrolled, commence from the factory or work place it self, and extend to the surrounding areas. The important operations include preparation of raw materials, such as coke making and sorting, iron ore beneficiation, production of sinter, processing of lime stone etc., hot metal and pig iron production using blast furnace, steel making using BF-BOF route and the rolled products like wire rods. Each of these processes produce pollutants, either /or gaseous, liquid and solids. Therefore, steel industry faces a major pollution problem as the pollution is not confined to a single processing stage. As the industry is very large, pollution control also is costly and has to be applied at many points (UNEP, 1986).

The gaseous emissions, namely, suspended particulate matter, sulphur dioxide, nitrogen oxides, carbon monoxide and hydrocarbons, directly enter the atmosphere causing the values of the said variables to increase. The residence times of these variables in atmosphere depend on the atmospheric conditions, namely temperature, wind speed and rail fall (Vizayakumar, 1990). It is observed that, during rainy season, the values of these variables particularly, SPM, are very low as the particles get loaded by the rain. In summer, its value is very high. It was reported that in favourable conditions, the SPM and other gaseous emissions travel as far as 50kms from the source in the direction of the wind.

Therefore, it is necessary to take into consideration the climatic factors of the location of the plant and include them appropriately in the model equations.

2 Model description:

The model is mainly organized in three sections - gaseous, liquid and solid waste. However, the sources of these pollutants are the same except some, where they may be negligible. As is observed, the environmental model is completely related to the production of hot metal, Sinter, steel, etc. However, the production variables are aggregated taking the maximum and minimum of their values to test and analyze the pollutants generation.

2.1: Gaseous emissions

As shown in Figure 6.1, gaseous emissions are taken as level variables as they accumulate over a period of time depending on the generation and attrition of that pollutant.

The suspended particulate matter, i.e., dust in the atmosphere is the main visual pollutant. It is expressed as

SPM=SPM+DT*(SPMGR-SPMAR)

Where SPM=Suspended particulate matter

SPMGR= SPM generation rate

SPMAR=SPM attrition rate

SPMGR is taken as the sum of the dust released at various processes i.e.,

SPMGR=(ASINTR*DSINTN+ACOLCO*(DCLCRN*SDCLCN)+AINPBF*(DINBFN+ SDINBN)+ASTEKO*(DSTELN+SDSTEN)+ABLOMO*DSTBLN)*DMDCA

Where ASINTR, ACOLCO, AINPBF, ASTELO, ABLOMO represent the average production of sinter, coke, hot metal, steel and steel products respectively.

DSINTN is the normal fraction of the dust released due to sinter production.
DCLCRN, SDCLCN, DINBFN, SDINBN, DSTELN, SDSTEN, DSTBLN are the similar fractions.
DMDCA is the Dust multiplier from dust control actions.

The values of these fractions are taken from UNEP (1986). The dust values vary from the source of input materials. For example, the dust quantity of coal depends on its quality and varies from source to source. It may also depend on the blend made at the mine. Therefore, it is difficult even at the factory to monitor and determine exactly the dust quantity. That is why the values provided in the UNEP report are taken as acceptable approximations.

The equation of SPMGR gives the uncontrolled dust production rate. No company can operate with out controlling the emissions not only due to the environmental legislation, but also due to the increased awareness of the employees, who are the first sufferers. However, the rate of control may depend on the investment made in pollution control.

Several reports indicate that an amount of 10% of the total investment in capital equipment is required to control pollution to the desired limit. The investment is taken as required for all gaseous, liquid and solid pollutants. It is assumed here that the company invests in control of all the pollutants in an equitable manner. Therefore, the control of pollutants is related to the ratio of investment made in pollution control to the total capital investment. Therefore, control function is added to dust generation, SPMGR, by multiplying it with DMDCA where DMDCA is Dust multiplier from dust control activities. It is expressed as a fraction related to the ratio of total investment to desired investment(RATINV).

RATINV=TINDRN/DINDRN

Where TINDRN=total investment in pollution control and

DINDRN=Desired investment in pollution control

TINDRN is expressed as level variable

TINDRN=TINDRN+DT*(RINDRN-DRINDR)

Where RINDRN= Rate of investment in pollution control and

DRINDR=depreciation rate of pollution control equipment

RINDRN is expressed as a policy variable, the discrepancy between the investment made and desired investment

RINDRN=(DINDRN-TINDRN)/AT

Where AT= Adjustment time, may be 1 year, 2 years, 3years depending on the policy

Depreciation is assumed as the linear depreciation over 10 year period.

DRINDR=TINDRN*DRINDF

DRINDF=0.1

The desired investment in pollution control is expressed as

DINDRN=GROSBK*DINDRF

Where GROSBK is the Gross Block, taken from finance sector and DINDRF is the fraction investment required in pollution control which value is taken as 5%.

DINDRF=0.1

For the purpose of this sect oral model, the Gross Block is taken as a level variable and is expressed as

GROSBK=GROSBK+DT*NETGRR

Where NETGRR=Net Growth of gross block rate which is taken as a fixed growth value of 5%

NETGRR=GROSBK*NETGRT

NETGRT=Net growth of gross block fraction=0.05

The attrition rate (SPMAR) of a gaseous pollutant depends upon the amount resident in atmosphere as well as on the atmospheric conditions, namely, temperature, relative humidity and wind speed. Therefore, SPMAR is expressed as

SPMAR=(SPM/DAT)*DMWC

Where DAT=dust attrition time. The average attrition time in normal conditions of 27degrees Centigrade temperature, relative humidity of 90 and 11.5 m/sec wind speed is given as 1 month =1/12year

DMWC=Dust multiplier from weather conditions which is taken as the average of all three impacts.

DMWC=(DMT+DMRH+DMWS)/3

Where DMT=dust multiplier from temperature

DMRH=dust multiplier from relative humidity

DMWS=dust multiplier from wind speed

They are the multiplier values depending on the temperature, relative humidity and wind speed respectively. The relationships are expressed in terms of table values:

TEMP	20	23	26	29	31	33	36	40
DMT	1.2	1.14	1.09	1.0	0.95	0.91	0.88	0.85

WS	7	9	11	13	15	17	19	20
DMWS	1.2	1.14	1.09	1.0	0.95	0.91	0.88	0.85

RH	60	70	80	90	100	110	120	130
DMRH	0.5	0.75	0.9	1.0	1.1	1.25	1.35	1.4

Other emissions, i.e., SO2, NOX, CO and HC are also modeled in the similar way but the parameter values change.

SOX=SOX+DT*(SOXGR-SOXAR)

SOXGR=(ASINTR*SOSNTN+ACOLCO*SOCLCN+AINPBF*SOINBN +ASTELO*SOSTEN+ABLOMO*SOTBLN)*SOMPC

SOSNTN, SOCLCN, SOINBN, SOSTEN, SOTBLN are the respective parameters for Sulphur dioxide emission at various stages.

SOMPC = Sulphur dioxide multiplier from pollution control expressed as table function depending on the investment to desired investment ratio.

SOXAR=(SOX/SAT)*SMWC

Where SAT=SOX attrition time=1/15year

SMWC=(SMT+SMRH+SMWS)/3

Where SMT, SMRH,SMWS are expressed in the following table:

TEMP	20.0	23.0	26.0	29.0	31.0	33.0	36.0	40.0
SMT/NMT/CMT/HMT	1.4	1.24	1.19	1.0	0.95	0.9	0.85	0.8

WS	7	9	11	13	15	17	19	20
SMWS/NMWS/CMWS/HMWS	1.0	1.12	1.21	1.26	1.31	1.35	1.38	1.4

RH	60	70	80	90	100	110	120	130
SMRH/NMRH/CMRH/HMRH	0.7	0.76	0.86	0.96	1.06	1.16	1.26	1.3

NOX=NOX+DT*(NOXGR-NOXAR)

Where NOX=Nitrogen oxides

NOXGR=Nitrogen oxides generation rate

NOXAR=Nitrogen oxides attrition rate

NOXAR=(ASINTR*NOSNTN+ACOLCO*NOCLCN+AINPBF*NOINBN+ ASTELO*NOSTEN+ABLOMO*NOTBLN)*NOMPC

Where NOSNTN, NOCLCN, NOINBN, NOSTEN, NOTBLN are the respective parameters for Nitrogen oxide emissions at various processes

NOXAR=(NOX/NAT)*NMWC

Where NAT= Nitrogen attrition time, 0.125 year

NMWC=nitrogen oxides emission multiplier from weather conditions=(NMT+NMRH+NMWS)/3

CO=CO+DT*(COGR-COAR)

Where CO= Carbon monoxide

COGR= Carbon monoxide generation rate

COAR=Carbon monoxide attrition rate

COGR=(ASINTR*ACOLCO*COCLCN+AINPBF*COINBN+ASTELO*COSTEN +ABLOMO*COTBLN)*COMPC

COAR=(CO/CAT)*CMWC

CAT= 0.08

CMWC=(DMT+CMRH+CMWB)/3.

HC=HC+DT*(HCGR-HCAR)

Where HC=hydrocarbons emitted

HCGR=Hydrocarbons emission rate

HCAR=Hydrocarbons attrition rate

HCGR=(ASINTR*HCSNTN+ACOLCO*HCCLCN+AINPBF*HCINBN +ASTELO*HCSTEN+ABLOMO*HCTBLN)*HCMPC

The parameter values are:

HCSNTN=0.001, HCCLCN=0.0002, HCINBN=0.00005, HCSTEN=0.0005, HCTBLN=0.002

HCAR=(HC/HAT)*HMWC

HAT= 0.25 year

HMWC=(HMT+HMRH+HMWS)/3

SOMPC, NOMPC, COMPC and HOMPC are similar to DMDCA, and dependent on the ratio of investment in pollution control to desired investment.

2.2: ***Water Effluents*:**

Integrated steel plant operations release the following pollutants into water effluents. Water is used in an integrated plant in most of the operations for coal washeries, cooling or granulation at iron, steel and ingot making as well as hot and cold rolling. The pollutants released are: suspended solids, phenols, cyanides, chlorides and sulphates. Therefore, the treatment of water is essential before releasing to the outside streams, lakes, water bodies etc. However, in this plant, the water, after treatment, is reused in the plant operations. The water has to be treated after every use. It is found that phenols, cyanides, etc. are only trace elements constituting 2% of the total pollutants released through effluents. Therefore, they are not considered in the model. As all these pollutants accumulate over time, they are modeled as level variables.

SS=SS+DT*(SSGR-SSRR)

Where SS=Suspended solids

SSGR=SS generation rate

SSRR=SS removal rate

SSGR=(ASINTR*SSSNTN+ACOLCO*SSCLCN+AINPBF*SSINBN

+ASTELO*SSSTEN+ABLOMO*SSTBLN)

where SSSNTN=0.00028, SSCLCN=0.0003, SSINBN=0.00024, SSSTEN=0.00007, SSTBLN=0.0002

SSRR=SS*WTFSS

CHLORD=CHLORD+DT*(CHLGR-CHLRR)

CHLORD=Amount of chlorides in effluent

CHLGR=Chlorides generation rate

CHLRR=Chlorides removal rate

CHLGR=AINPBF*CHINPBF+ASTELO*CHSTEN+ABLOMO*CHTBLN

No Chlorides are released during sintering and coking processes. The values of the parameters are:

CHINBN=0.00005, CHSTEN=0.00005, CHTBLN=0.0002

CHLRR=CHLORD*CHMCA

The amount of sulphate is expressed as:

SULPHT=SULPHT+DT*(SULGR-SULRR)

SULPHT=Amount of sulphates in the effluent

SULGR=Sulphates generation rate

SULRR=Sulphates removal rate

SULGR=ASINTR*SUSNTR+AINPBF*SUINBN+ABLOMO*SUTBLN

No sulphates are released during coking and steel making process. The parameter values are:

SUSNTN=0.000004, SUINBN=0.000003, SUTBLN=0.0004

SULRR=SULPHT*SUMCA

Control of these pollutants depends upon the effluent water treatment both quantity and quality of treatment. It is directly related to investment made and operational expenditure. It is presumed here that once acquired the company puts the plant in operating condition. Therefore, investment is only considered here to determine the amount of pollution control. The relationship between the investment and the extent of pollution control in each case are given in the following table values:

RATINV	0.0	0.2	0.4	0.6	0.8	1.0
SSMCA	0.0	0.05	0.2	0.5	0.75	0.9
CHMCA/SUMCA	0.0	0.05	0.2	0.35	0.65	0.75

6.2.3 Solid Pollutants:

Solid pollutants or solid wastes generally include dust also. However, here, dust emissions are considered in the gaseous emissions. Slag and sludge are only considered here under solids. Though sludge is semi liquid slurry, it is taken as a solid waste as it is not discharged through water. Mill scales and oily wastes are released in the rolling units but are negligible in quantity compared to other solid wastes. Therefore, they are ignored in this model.

Slag and sludge also accumulate over a period of time and therefore, considered as level variables.

SLAG=SLAG+DT*(SLAGGR-SLAGUR)

Where SLAG= Amount of slag accumulate
SLAGGR=Slag generation rate
SLAGUR=Slag utilization rate

SLAGGR=AINPBF*SGINBN+ASTELO*SGSTEN

Slag is produced only during iron making process and steel making process and the parameter values are:

SGINBN=0.3 and SGSTLN=0.1
SLAGUR=SLAG*(SLAGUF+SLAGDF)
SLAUGF=Slag utilization factor
SLAGDF=Slag dispatch factor

Similarly, sludge is expressed in the following equations:

SLUDGE=SLUDGE+DT*(SLDGGR-SLDGUR)
SLUDGE=Amount of sludge accumulated
SLDGGR=Amount generation rate

SLDUGR=Sludge utilization rate

SLDGGR=ACOLCO*SLCLCN+AINPBF*SLINBN+ASTELO*SLSTEN +ABLOMO*SLTBLN

Unlike slag, the sludge is also produced during coal processing and in rolling mills. The parameter values are:

SLCLCN=0.002, SLINBN=0.012, SLSTEN=0.015 and SLTBLN=0.01

SLDGUR=SLUDGE*SLDGUF

SLDGUF=Sludge utilization factor

Generally, the solid wastes, slag and sludge, are reused and/or recycled either by the Steel plant or by other industries such as cement plants. The solid waste that can not be reused or recycled has to be dumped. It requires a large area of land for disposal. These dumping sites create water pollution by leaching. They release effluents containing hydrocarbon residues, soluble salts, sulphur compounds and toxic heavy metals.

6.3 Base Model Simulation and Results

The base model assumes no investment in pollution control. It means that the pollutants are released unabatedly to atmosphere. It is assumed that the sorrounding environment will get affected. In the case of air pollution, the impacts can be observed even as far as 50 kms. away in the favourable wind direction. However, the impact decreases with distance. Here, an area of 125 sq. km. around the Steel Plant is considered as vulnerable to a height of 100 m. It gives the impacted volume of 12.5×10^9 cu. m. Though the impact decreases from the emission source point to the distant point in the area, the impact is considered as uniform because the source points are too many making it almost a non-point source situation. The level of pollutant in the atmosphere is determined by the cumulative value of the pollutant in the atmosphere divided by the impacted volume. The quality related to a pollutant is measured as a ratio of its permissible value to the actual value.

The Steel Plant has an artificial water source made for the purpose, and the water is reused. However, it is observed that some of the water is left to the municipal drain that will ultimately lead to the sorrounding water bodies. For the purpose of modelling, water used per 1 tonne of steel produced (i.e., 250,000 cu. m.) by the Steel Plant is taken as water required. However, using more water reduces the level of pollutants in the water source/effluent.

The solid waste (slag and sludge) is considered as unused and unrecycled in the basic model. The model is simulated using DYMOSIM (Bora and Mohapatra, 1984). The results are presented in Figs. 6.2 to 6.4. Fig. 6.2 depicts the behaviour of gaseous pollutants in the atmosphere. Seasonal variations can be observed in the model. This is due to the effect of the climatic factors, namely, temperature, wind speed, and relative humidity. The behavior of the pollutants in liquid effluent is shown in Fig. 6.3. Here, we observe that the quality of water due to suspended solids, sulphates, and chlorides is decreasing though there is an initial increase observed in the case of sulphates and chlorides. The quality of environment index (QEI) is having a decreasing trend though it is varying seasonally as shown in Fig. 6. 3. As expected, the solid wastes, slag and sludge, are increasing over the years as depicted in Fig. 6.4. This is the true picture of the environment sorrounding any Steel Plant. In fact, huge hills of solid waste can be seen near the plant site.

6.4 **Policy Analysis**

The policy analysis, here, is very complex. Because there are several pollutants, several source points and differing alternatives from one type to another type of pollutant. This macro model is therefore used to experiment with broad policies that are expected to affect on all types of emissions. As explained in section 6.2.1, differing investments are taken as different policies that affect the gaseous emissions and the liquid effluents. Where as, the utilization factors are considered as policy alternatives for slag and sludge. The investment alternatives considered to abate the gaseous and liquid pollutants are

40%, 50%, 65%, and 80% of the desired amount. Figs. 6.5 to 6.9 shows the environmental quality due to SPM, SOX, NOX, CO, and HC respectively. It is observed that a minimum of 80% investment is required to achieve good quality of environment. Similarly, Figs. 6.10 to 6.12 show the quality of water due to suspended solids, chlorides, and sulphates respectively. The quality of environment index has reached the maximum value of 1 (one) in Policy 4 only as observed in Fig. 6.13. Figs. 6.14 and 6.15 show the results of varying utilization factors of slag and sludge. Even after 50% utilization, the accumulation is around 100,000 tons. The model can be used to experiment to know the value of the utilization factor to limit the quantity of solid waste to a desired value.

Further analysis is required for micro level policy analysis, i.e., to determine the number of Electro Static Precipitators, Dust Arresters, type and number of effluent treatment plants required, etc., to control pollution. However, such micro level analysis is outside the scope of this study. The results, depicted here, only show what level of actions are required to be taken to contain pollution with in the threshold limits.

References

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Vizayakumar, K., 1990, A Study on some Aspects of Environmental Impact Analysis, Unpublished Ph. D. Thesis, IIT, Kharagpur, India.

FIG 6.2 BASE MODEL - AIR POLLUTION

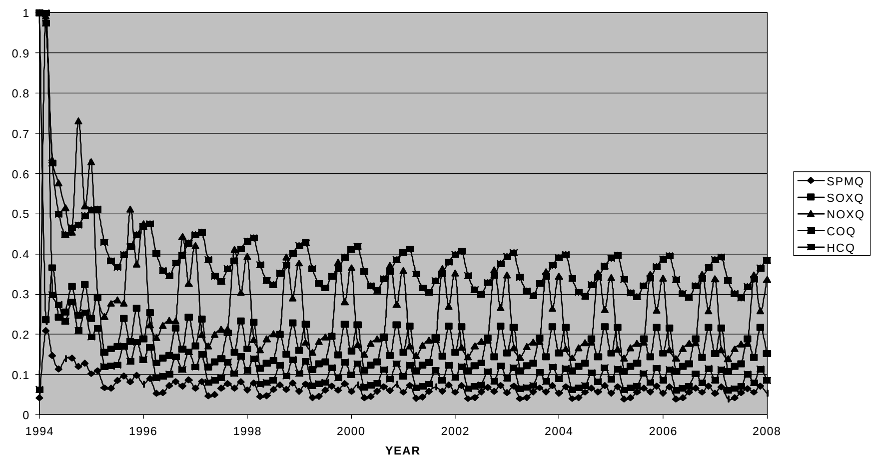

FIG. 6.4 SOLID WASTE

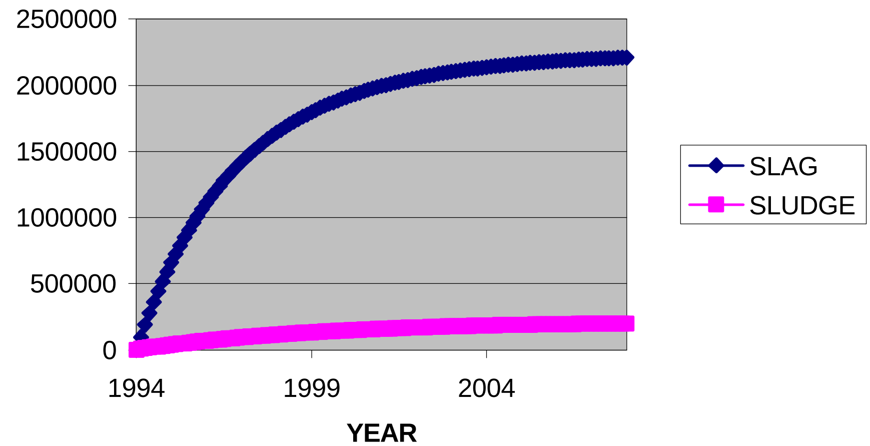

FIG. 6.5 AIR QUALITY DUE TO SPM

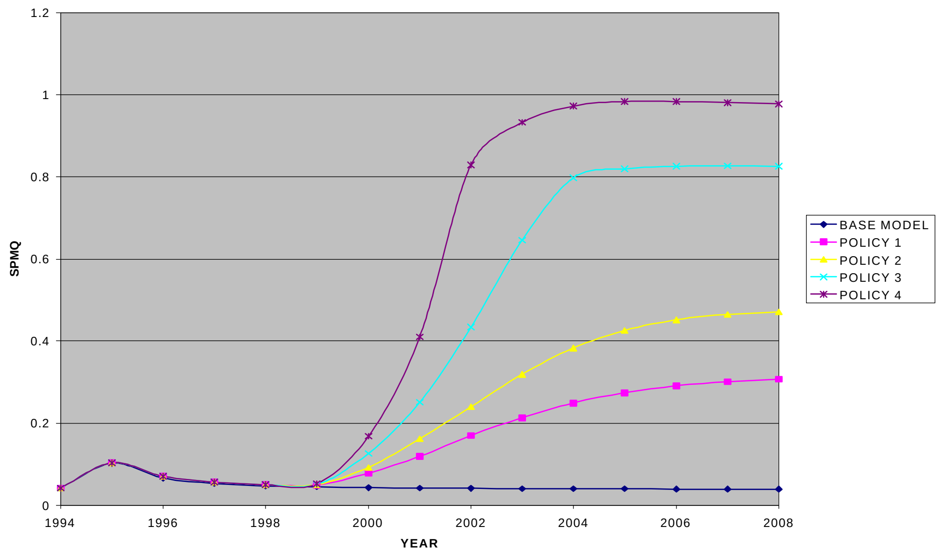

FIG. 6.6 AIR QUALITY DUE TO SOX

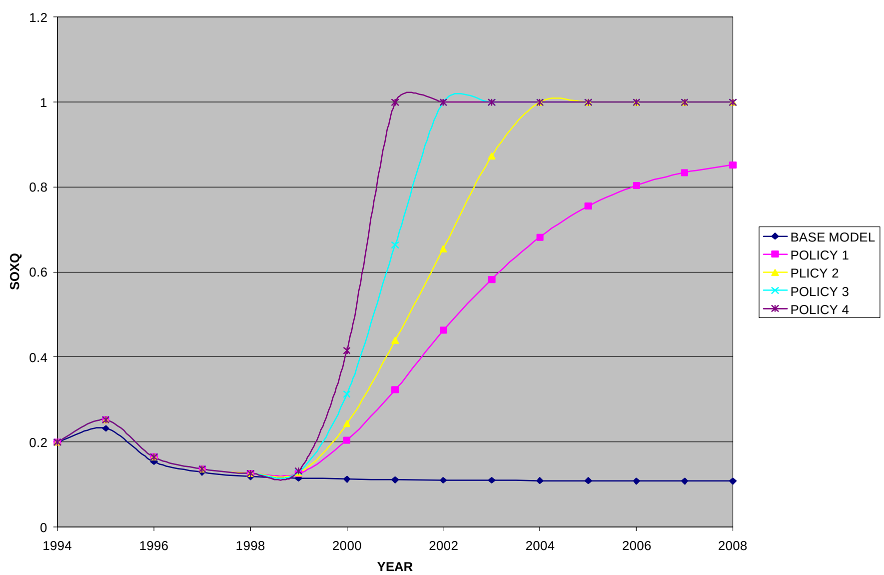

FIG. 6.7 AIR QUALITY DUE TO NOX

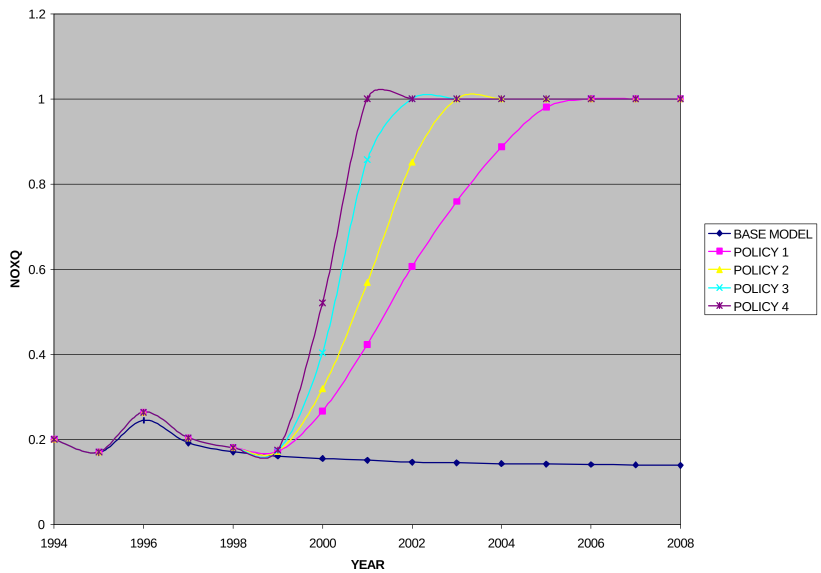

FIG. 6.8 AIR QUALITY DUE TO CO

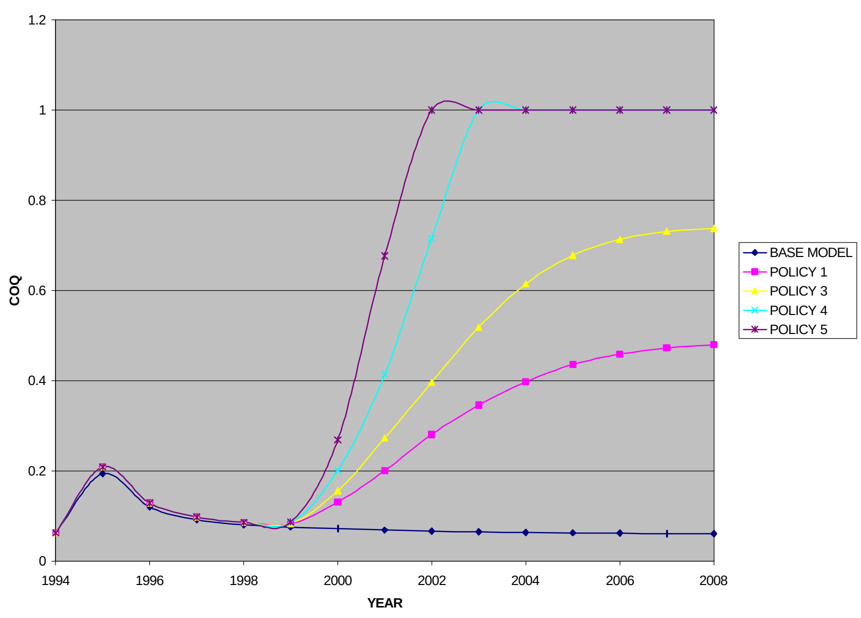

FIG. 6.9 AIR QUALITY DUE TO HC

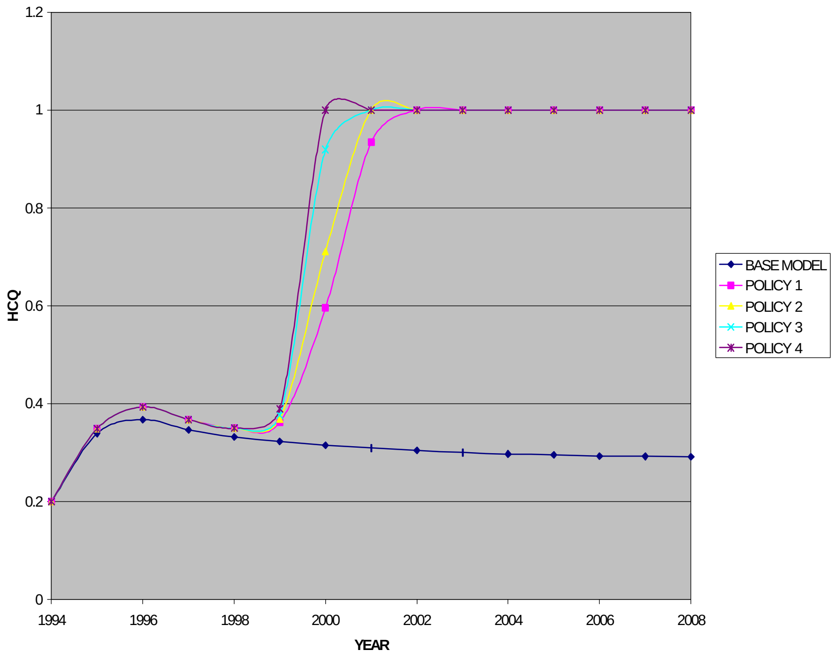

FIG. 6.10 WATER QUALITY DUE TO SS

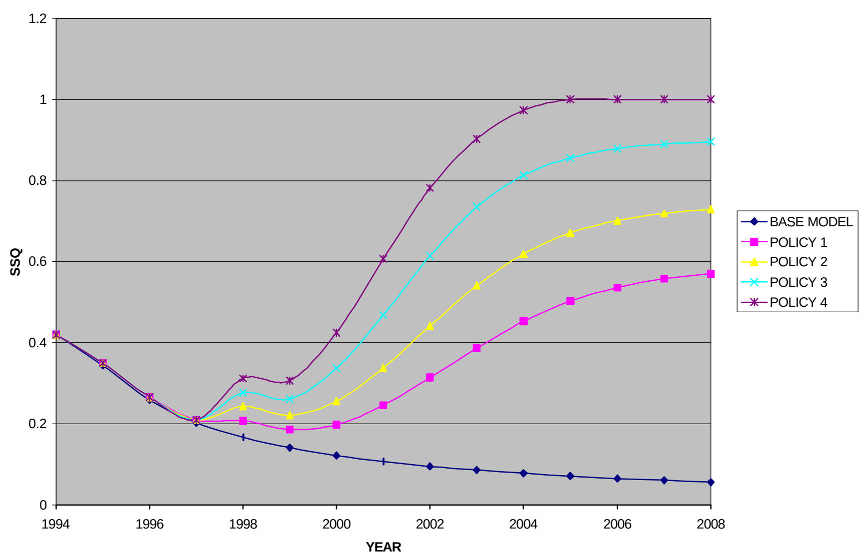

FIG. 6.11 WATER QUALITY DUE TO SULPHATES

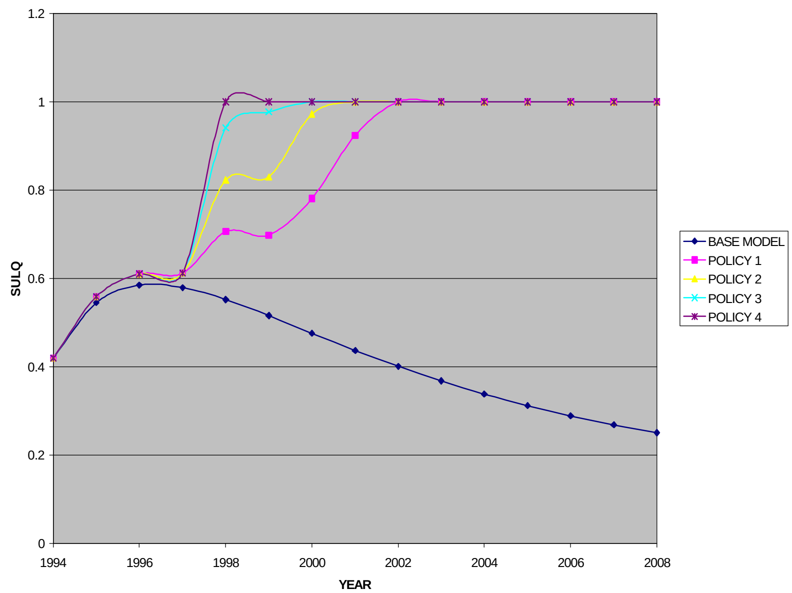

FIG. 6.12 WATER QUALITY DUE TO CHLQ

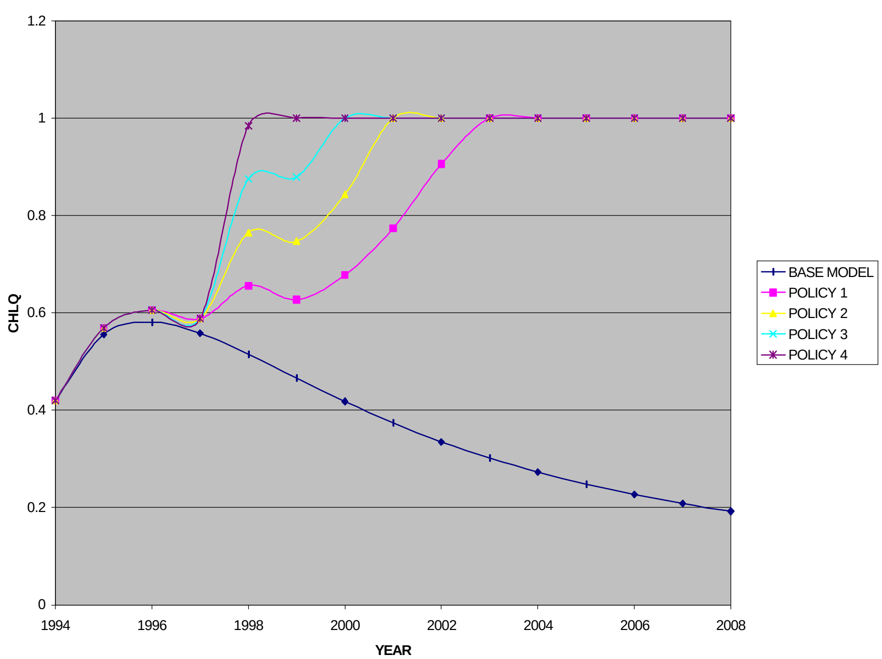

FIG. 6.13 QEI - POLICY RESULTS

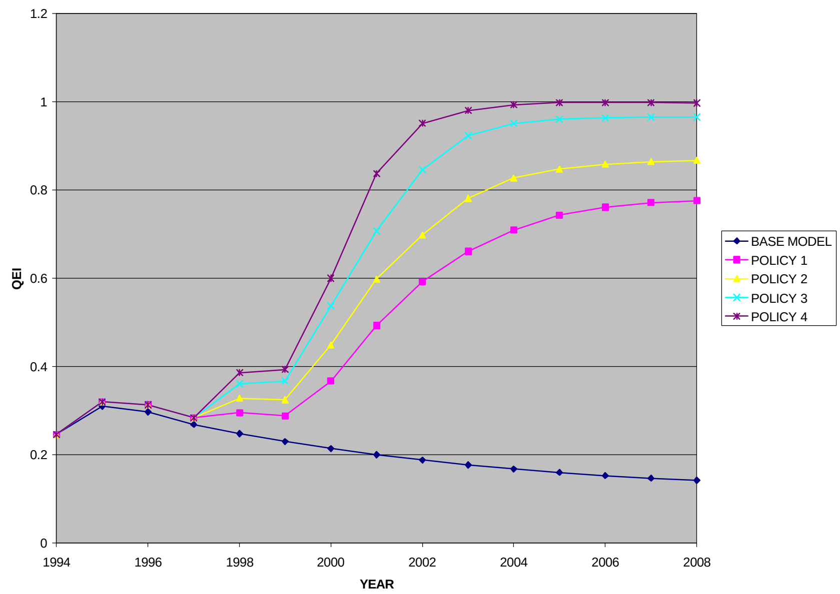

FIG. 6.14 SOLID WASTE POLLUTANT

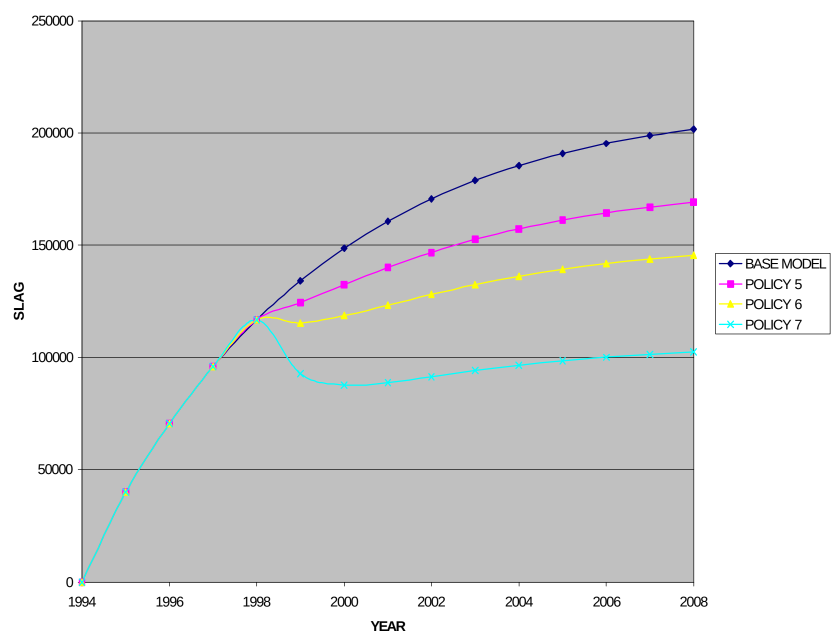

FIG. 6.15 SLUDGE PRODUCTION