STACK EMISSION MODELING IN THE PROCESS INDUSTRY

Kaushalya Illangasinghe[1], Manisha Gunasekera[2], Ajith de Alwis[2]
[1]Open University of Sri Lanka, [2]University of Moratuwa, Sri Lanka.

ABSTRACT

Air being an important part of the environment is always required to be in a satisfactory condition for proper functioning of the entire eco system. Air quality is affected due to several reasons such as increasing number of industries and vehicles. Therefore current practice is to carrying out an Environmental Impact Assessment (EIA) before a new industry is started. The purpose of the EIA is to predict and identify potentially significant environmental impacts of development proposals and to suggest mitigation measures to minimize the negative impacts and maximize the positive impacts. Further, monitoring emissions from industrial activities during plant operation helps identification and prevention of adverse environmental impacts.

In the process of determining environmental impacts due to new development projects, estimating the distribution of emitted substances into the environment is necessary. For this purpose identifying mathematical models to use in EIA studies in Sri Lanka as well as in monitoring emissions from existing plants is needed.

This work presents the results of application of one such model called Australian Plume Dispersion Model (AUSPLUME) to predict the downwind concentrations of a substance in the stack emission of a cement plant in Sri Lanka. It uses the meteorological data for the area of the cement plant location. The "areas of worst impact", the buffer zone and the maximum height of the buildings that can be built in this area are identified considering emissions from different stack heights and for different wind velocities also referred to as plume velocity in the atmosphere.

INTRODUCTION AND OBJECTIVES

Many industrial stacks observed in Sri Lanka today are not constructed according to proper stack design requirements. In most cases the stack is constructed without considering appropriate height required, impacts on the stack efficiency due to the geographical location and the meteorological conditions. The quality of exit gas is analyzed seldom, to check whether the regulatory requirements are satisfied or to see whether the operations done in the industry are efficient. So far very little attention has been given to monitor the contribution from a specific industrial stack on the ambient air quality, which is of utmost importance.

Measurement of air pollutants at ground level or at an elevated location needs very costly equipment. Analyzing few samples from a specific location may also not give good representative results because the meteorological conditions vary frequently. Therefore it is more practical if estimations can be done using mathematical models and then real values can be compared with them from time to time. As a result identifying and validating of appropriate models for the Sri Lankan scenario which can be used for estimating the stack emission dispersion, is needed. These models can be used for analyzing the effects of existing stacks and also for predicting the effects of emissions from stacks which are going to be constructed in the future.

The Australian Plume Dispersion Model (AUSPLUME) was studied in this work. This model has been used in several countries and it is one of the models recommended for the regulatory purposes by several authorities. Ausplume is a Gaussian plume dispersion model whose mathematical basis is derived from the Victorian Environment Protection Authority's "Plume Calculation Procedure" (EPAV, 1985), which is an extension of the ISC model of Bowers *et al.* (1979). It is designed to predict ground-level concentrations or dry deposition of pollutants emitted from one or more sources, which may be stacks, area sources, volume sources, or any combination of these. Line source are not explicitly handled, but it is possible to improvise by modelling with multiple volume sources. This model is capable of predicting the worst possible conditions by considering a full year weather data. It is still in the developing stage for use in locations in Sri Lanka and it is not a substitute for monitoring of actual pollutants. The basis of the Gaussian model is shown in the following format and the concentration, C is calculated by equation (1) (EPAV, 1985).

$$C = \sum\{(\text{source factor})^* (\text{lateral dispersion factor})^* (\text{vertical dispersion factor})^* (\text{decay factor})\} + \text{Background concentration} \quad \text{———} \quad (1)$$

For a single source, (1)

$$\chi(x, y, z; H) = [Q/(2\pi\sigma_y\sigma_z u)]\{\exp[(-1/2)(y/\sigma_y)^2]\} \times \{\exp[(-1/2)(z - H/\sigma_z)^2 + \exp[(-1/2)(z + H/\sigma_z)^2]\} \quad \text{———} \quad (2)$$

where,

χ (x,y,z; H)	the downwind concentration at a point x,y,z , µg/m^3
Q	emission rate of the pollutants, g/s
σ_y, σ_z	plume standard deviations, m
u	the mean vertical wind speed across the plume height, m/s
y	the lateral distance, m
z	the vertical distance, m
H	the effective stack height, m

There are several assumption made in developing this model. They are,

- The concentration distribution of the constituent of interest averaged over 3 minutes is Gaussian in both lateral and vertical directions
- Q and u are constant over the period in which the constituent travels from the discharge point to the most distant receptor considered in the calculation
- Advection of the constituent can be described by a uniform wind speed and direction
- Atmospheric turbulence is homogeneous but not isotrophic
- Longitudinal diffusion is assumed negligible compared to the advection process

The following advantages can be expected in employing a model like AUSPLUME in the process of EIA (http://www.epa.vic.gov.au).

i) Estimation of the contribution to the air pollution by the stack considered

ii) Estimation of the downwind concentration at elevated locations will help in deciding what effects will be there on future constructions (Which are not going to be higher than 0.4 times the height of the stack)

iii) Facilitation in identifying the area of most damage which will help in deciding the buffer zones

iv) Facilitate in determining the downwind concentration distribution pattern which will be helpful in locating the buildings, other constructions, which may get affected due to the emissions

v) To identify whether ecologically or socially sensitive areas are going to be damaged or get affected by the emissions

METHODOLOGY

A stack in a cement plant was selected for estimating the pollutant dispersion. The stack selected could be considered as a clear point source since there were no other industries located in the vicinity. The geographical location was considered as a flat terrain because there were no interferences. According to ambient air quality standards in Sri Lanka the maximum permissible level in this area for suspended particulate matter (SPM) is 0.35 mg/m^3 for an eight hour averaging time. The maximum permissible levels for carbon monoxide and for sulphur dioxide are $10mg/m^3$ and 0.12 mg/m^3 respectively for the same averaging time.

The model requires hourly meteorological data for one year including wind speed, wind direction, ambient temperature, stability class and mixing height. The first three were taken from the meteorological department and the latter two were taken by referring to a standard table (Lees, 2003). The model requires hourly meteorological data for 365 days. The meteorological data for year 2003 were collected for this purpose. Wind speed values available were 3 hourly values and it was assumed that the variations were linear and the missing values were linearly interpolated. The wind directions available were also 3 hourly values and it was assumed that the same direction remained for 3 hours. The temperatures available were maximum and minimum daily temperatures and it was assumed that the average temperature remains constant throughout the day.

The mixing height and stability class were taken from the available data tables. These values are approximations since they are not validated to a specific country's conditions. This is another shortcoming that had to be addressed locally when developing and utilizing models for impact analysis.

Most of the other parameters used in the software are made to be calculated automatically once the above meteorological data are provided.

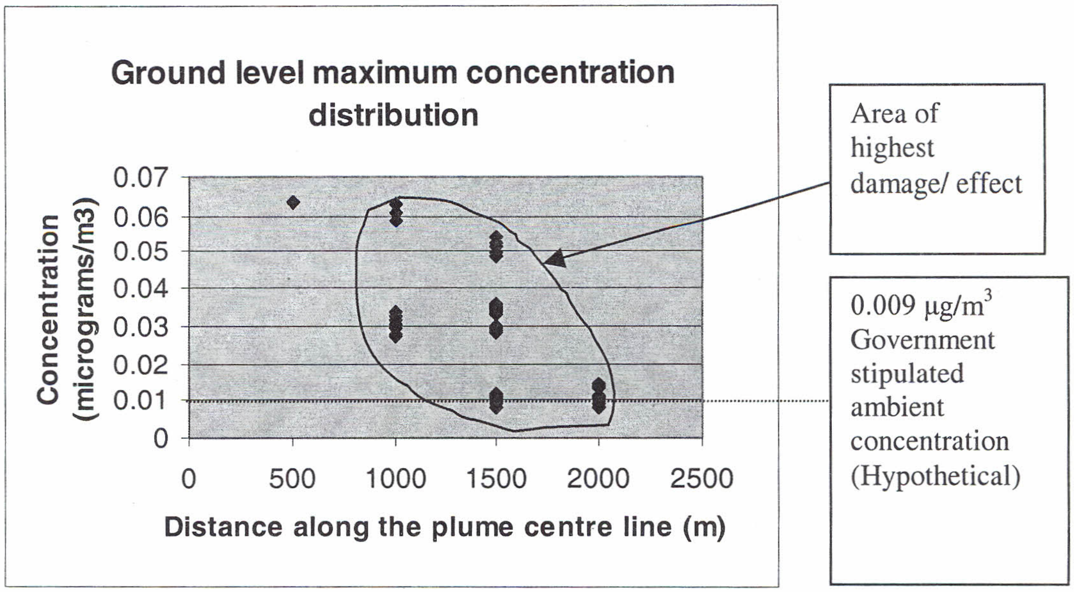
RESULTS

A hypothetical constituent in the cement plant stack emission was considered in this work. The hypothetical data related to this constituent and the stack dimensions are shown in Table 1. The considered constituent can be any non reactive one which would not be gravitationally settled. The AUSPLUME model can estimate the worst hundred cases of pollution by the constituent concerned in selected locations under the given meteorological data conditions. These hundred maximum concentration points of the constituent distributed along the plume centerline were calculated for varying parameters shown in Table 1. The results of these estimates are discussed in this section.

Parameter	Value
Height of the stack (m)	80
Diameter (m)	1.4
Exit temperature (^{0}C)	120
Exit velocity of the plume (m/s)	20
Emission rate of the constituent (kg/hr)	0.0125

Table 1. Emission Data For The Hypothetical Constituent In The Stack Emission

Figure 1 gives the ground level maximum concentrations of the constituent along the plume centerline estimated using AUSPLUME model for an emission rate of 0.0125 kg/h of the constituent. The other parameters required for this estimation are shown in Table 1.



Area of highest damage/ effect

0.009 $\mu g/m^3$ Government stipulated ambient concentration (Hypothetical)

Figure 1. Ground Level Maximum Concentration For An Emission From A Stack Height 80m And Plume Exit Velocity 20m/s

The area where most of the highest concentration values are distributed is considered as the "area of highest damage or effect".

Figure 1 clearly shows that the area between 1000 m - 2000 m is the area where most damage can be expected throughout the year. These results can be used to decide on the extent of the buffer zone. A buffer zone is an area of appropriate size around the plant that is essentially kept to avoid any possible adverse effect, especially to the community. If the concentration of the constituent considered is above the government stipulated level there would be a necessity of extending the buffer zone up to the distance of acceptable level. However, if this distance is going to be very long, necessary steps should be taken to reduce the emission load. As for an example if the constituent considered in Figure 1, the concentration of 0.009 $\mu g/m^3$ is considered to be the government stipulated ambient concentration it is better if a buffer zone of about 2 km can be kept where the industry can grow plants and maintain an attractive environment. However, this may not be possible due to the scarcity of land. Therefore, other possible alternatives such as changing the stack dimension to have low ground level downwind concentrations or improve the process to reduce the emission load can be considered. Further, if the government stipulated ambient concentration is assumed to be 0.06 $\mu g/m^3$, the buffer zone can be limited to 1 km.

Figure 2 given below shows the downwind concentration parameters at an elevation of 30 m from the ground level with all the other conditions same as at Table 1.

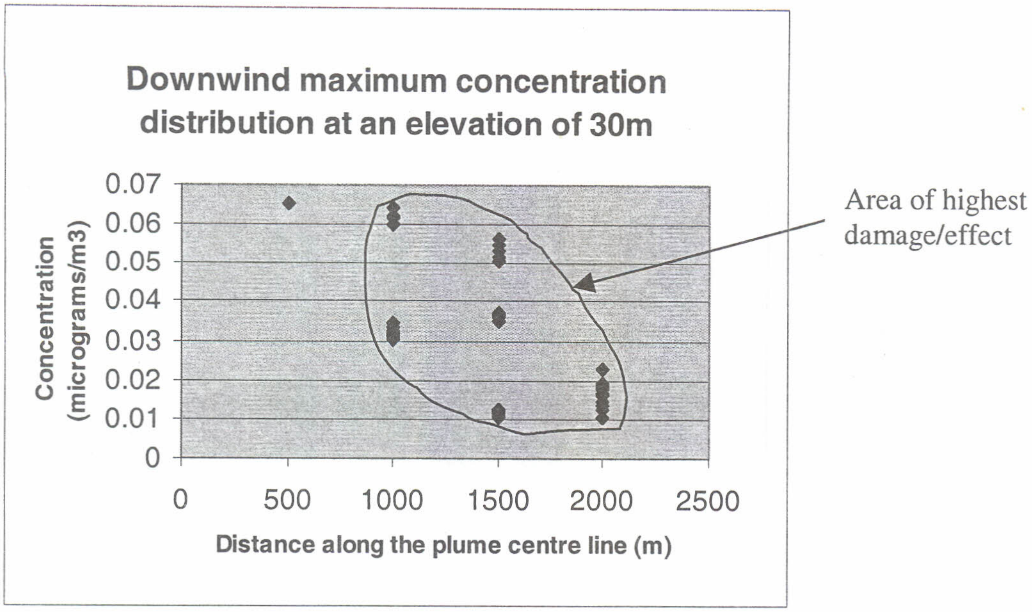


Figure 2. Maximum Concentration At A 30m Elevation For An Emission from a Stack Height 80m And Plume Exit Velocity 20m/s

The concentration distributions in both Figure 1 and Figure 2 are almost the same other than the differences in the values. The area of the highest damage is also similar in both cases. The concentrations at the same distance but at a higher elevation are greater than those at the ground level. Therefore, it is obvious that effects to a high-rise building are more. The maximum height of the tallest building can be built in this area can be taken as 30m, because the height of the nearby tallest building should not exceed 0.4 times height of the stack (http://www.epa.vic.gov.au). If the construction is more than 32m in height there will be building wake effects. Building wake effects can be described as a low-pressure region, which can occur when wind passes a high rise building. If a stack is close by, the plume may spread in this low-pressure region making the pollutant concentration higher.

Figure 3 shows the downwind concentration parameters at ground level for a plume exit velocity of 25 m/s with all the other conditions as in Table 1.

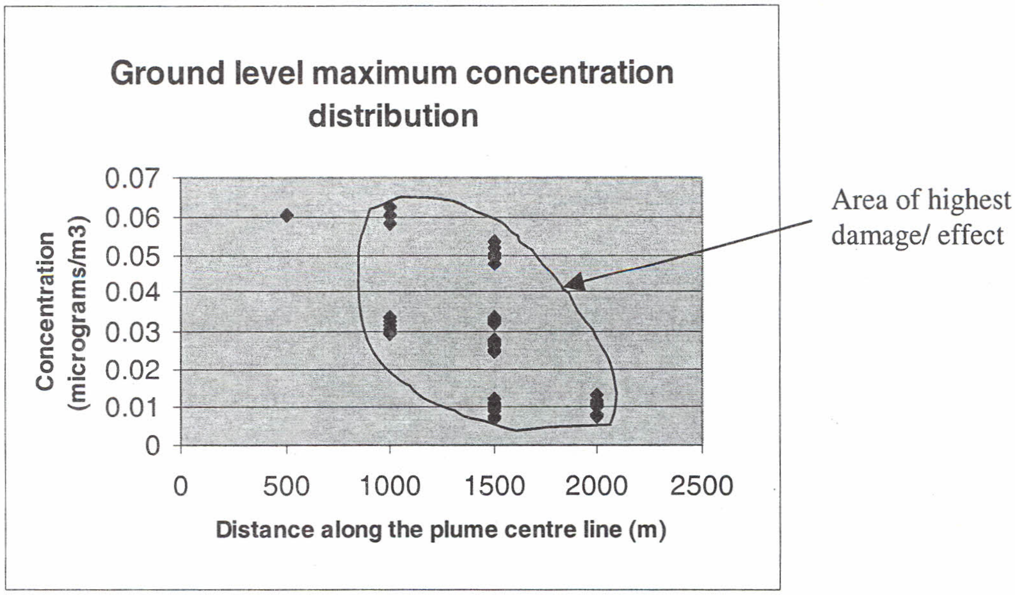


Figure 3. Concentration At Ground Level For An Emission From A Stack Height 80m And Plume Exit Velocity 25m/s

According to the above graphs it is clear that the highest concentration distribution is confined to the same area. This could be due to the meteorological conditions considered in all above cases being the same. Further, the concentration changes that can occur when the pollutant load is changed by any manner such as changes in exit velocity, emission concentration or stack dimensions can also be studied using the AUSPLUME model.

Figure 4 gives the maximum concentration points distribution in the downwind direction at the ground level with all the other parameters remaining the same as in Table 1 except the stack height. A stack height of 50m was considered in this case. It is clear from the graph that the area of highest impact falls in the range 1000m - 1500m. However, these concentration values are much higher than those estimated for a stack height of 80m. Therefore it can be seen that the stack height is one of the critical factors in stack designing to prevent adverse environmental impacts due to pollutant dispersion.

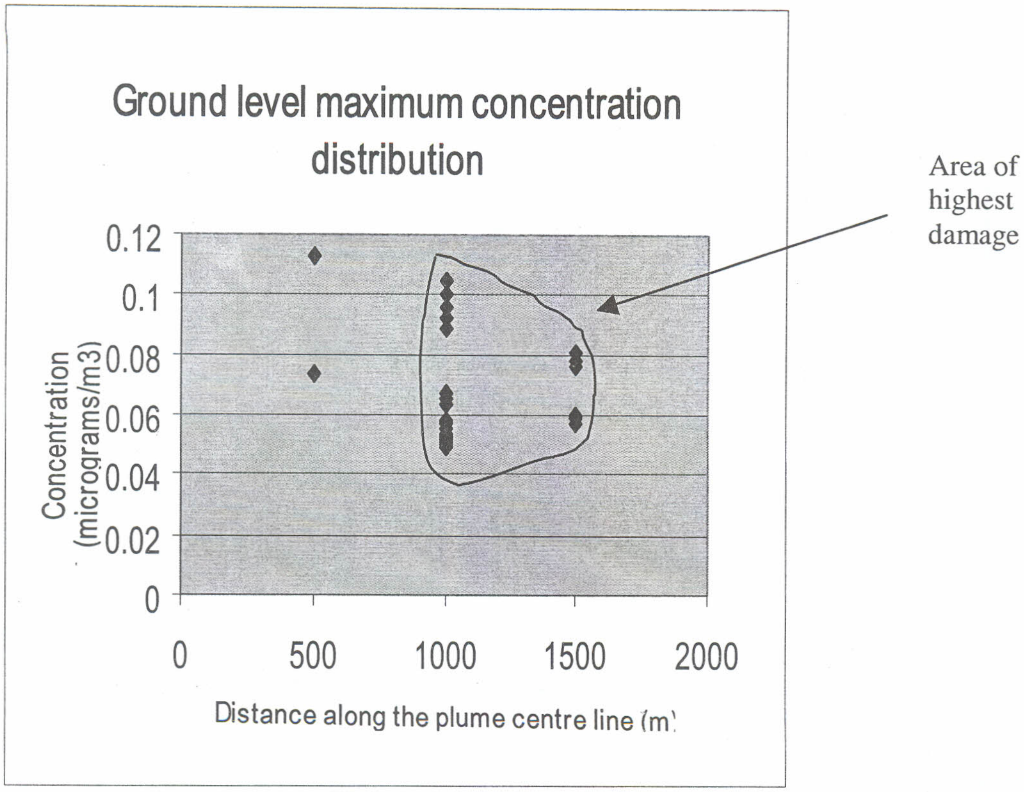


Figure 4. Maximum Concentration Points At Ground Level For An Emission from a Stack Height 50m and Plume Exit Velocity 20m/s

Parameter	Value
Height of the stack (m)	50
Diameter (m)	1.4
Exit temperature (^{0}C)	120
Exit velocity of the plume (m/s)	25
Emission rate of the constituent (kg/hr)	0.0125

Table 2. Emission Data for the Hypothetical Constituent In The Stack Emission

Table 2 shows the stack emission data for the same hypothetical constituent considered in earlier cases in this study, with different stack height and exit plume velocity also referred to as the wind velocity to that in Table 1. The results determined by applying data in Table 2 in the AUSPLUME model are discussed below.

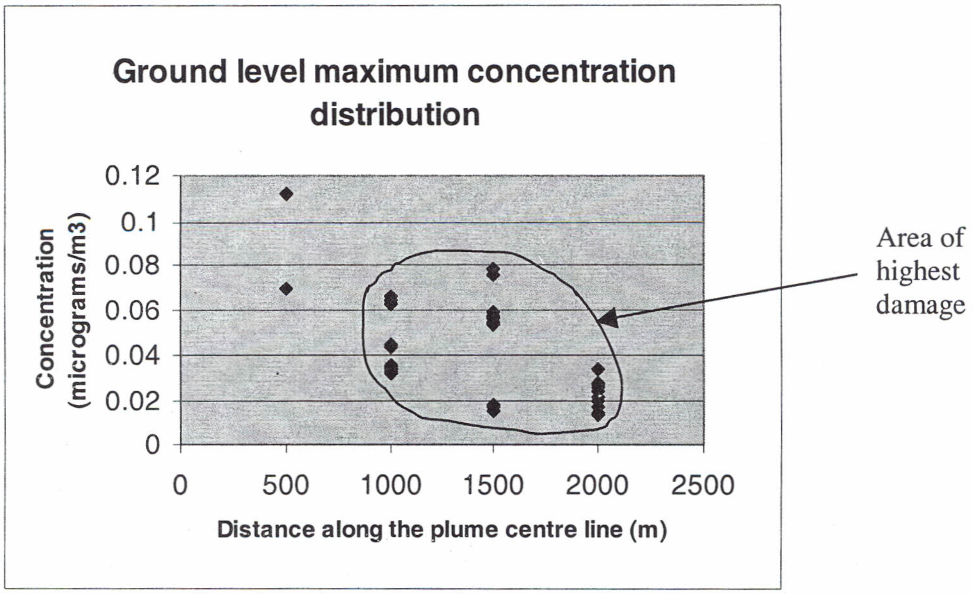


Figure 5. Ground Level Maximum Concentration For An Emission From A Stack Height 50m And Plume Exit Velocity 25m/s

Figure 5 shows the maximum concentration distribution related to the parameters given in Table 2. The maximum concentration points have reached a distance up to 2000m which is 500m further from the case shown in Figure 4. This could be because the exit velocity of the plume being higher than the case given in Figure 4. The concentrations also show higher values and this could be due to the shorter stack height considered in Table 2.

It can be also checked whether there are any type of sensitive areas such as archeologically valuable sites, high bio diversity or populated areas are located in the area of highest effect.

If these types of areas are situated within the sensitive area, necessary remedial measures have to be proposed to mitigate them through the EIA.

DISCUSSION AND CONCLUSION

The results obtained in the previously given analysis can be summarized in Table 3 as follows.

Figure No.	Height of the stack (m)	Diameter (m)	Exit temperature (^{0}C)	Exit velocity of the plume (m/s)	Emission rate of the constituent (kg/hr)	Concentration Value estimated elevation (m)	Range of maximum 100 concentration distribution (m)	Maximum Concentration (μg/m^3)	Minimum concentration (μg/m^3)
1	80	1.4	120	20	0.0125	0	1000-2000	0.0634	0.00775
2	80	1.4	120	20	0.0125	30	1000-2000	0.0651	0.0102
3	80	1.4	120	25	0.0125	0	1000-2000	0.0628	0.0068
4	50	1.4	120	20	0.0125	0	1000-1500	0.113	0.0497
5	50	1.4	120	25	0.0125	0	1000-2000	0.112	0.0131

Table 3. Pollutant Dispersion Results using AUSPLUME

According to the above results it is clear that for a shorter stack height the downwind ground level concentrations are also very high. Even though the maximum 100 concentrations are used in this analysis, it can be further predicted that even the concentrations below the 100th one can be relatively higher. This indicates that all the concentration values above the government stipulated concentration of the constituent must be considered in deciding the extent of the buffer zone.

In the process of EIA, depending on the predicted impacts the mitigatory measures needed to be done can be prioritized. Therefore, the estimations done using the model must be fairly accurate because the measures to mitigate will cost money. However, these predictions carry a certain amount of inaccuracy. The coefficients or constants used in the AUSPLUME model which have been validated for some other country may carry a certain percentage of inaccuracy when applying it in Sri Lanka. The estimation of coefficients suitable for this country should be looked at in a further study.

More future work will involve in studying the dispersion under different conditions. As for an example effects due to different stack heights, diameters, locations and exit flow rate can be compared by using the earlier described results. Effects of the high rise buildings can be analyzed by considering different stack positions. Cumulative effects of the possible future construction, effects due to increase in road traffic can also be analyzed.

Sri Lanka as a developing country has not paid much attention towards the environmental sustainability. The people are not fully aware of the importance of protecting the environment. However, the government of Sri Lanka has paid a certain amount of attention on these issues especially the industrialists are being made responsible for the actions they take which can cause adverse environmental impacts. Sri Lanka has not faced air pollution of serious magnitude and it is not among five key environmental issues of the country (Ministry of environment and natural resources, 2000). This may be because of the location of the country. It is an island in the Indian Ocean and it has continuous sea breeze, monsoon and inter monsoon winds which keep the air always in motion. When we look at the other countries in the region we can clearly see that the situation will not be the same for a long time. Therefore, we will have to be prepared to face air pollution problems in the near future.

Hence it is very much important to construct the industries with preventive measures for the mitigation of air pollution problems. The industrial stack is very critical under this aspect and therefore it is recommended to use a model like AUSPLUME, which has proven results worldwide in the process of EIA to identify the impacts due to the stack and then develop mitigation measures.

REFERENCES

BOWERS, J. F., BJORKLAND, J. R. AND CHENEY, C. S., 1979, Industrial source complex model users guide, Report EPA-450/4-79-030.

EPAV, 1985, Plume calculation procedure, Publication 210 EPA, Melbourne

Formulations in AUSPLUME, VicEPA Pubn. 210 http://www.epa.vic.gov.au, 2000, AUSPLUME Gaussian plume dispersion model, technical user manual, EPA Publications.

LEES, F. P., 2003, Loss Prevention in the Process Industries, Hazard Identification, Assessment and Control, Butterworth Heinemann, Delhi, India.

MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES, 2000, Status of the Environment Report, Sri Lanka.