JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

SIMULATION AND ANALYSIS OF AIR POLLUTION MONITORING SYSTEM

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Abstract: A clean and healthy environment is essential for all the living things. If our surroundings are unclean and polluted, it will directly or indirectly affect all things including human beings. One such pollution is air pollution. Release of gaseous wastes from industries, vehicles, burning of fuels pollutes the environmental air. Many dispersion models have been developed to calculate different pollutant concentration in different cities and emission sources.
This study is to understand the distribution, spread and dynamics of the pollutant from the constant source of emission. Predict the air quality from the primary pollutant stationary source. Matlab Code Program is used in modeling the air pollution monitoring system. The input to the system considered such as meteorological parameters like wind velocity, atmospheric stability and stack parameters like stack height, stack distance from emission pollutant source, number of stacks, aerosol parameters like humidity and its effect on air pollution monitoring system can be studied.
The controllers like Fuzzy Proportional Integrative Derivative and Proportional Integrative Derivative Controller are used in controlling air pollutant concentration by manipulating control variables.

Keywords: Gauss Plume Model, PID controller, Fuzzy PID controller, MATLAB/Simulink.

1 INTRODUCTION

A technique of estimating the relative impact to pollutant concentrations at base level of particular pollution present or prospective source emissions at receptor locations of interest is known as per air quality impact assessment (AQIA) [2]. It is useful as a decision-making tool when some form of emission modification is involved such as the following.

a) An increase or decrease in the rate of mass emissions from single or more existing sources.
b) A variation in the physical properties of sources of emissions (such as discharge height, temperature, volume flow-rate, etc.)
c) The addition or removal of single or more sources.
d) A shift in the relative contributions of different categories of sources to overall dispersion.

Engineering changes are those that modify emissions as a result of adjustments (b), (c), and (d). A number of elements are of central interest in AQIA studies including.

a) Determining the proportional effect of particular source emissions on current air quality over background values with sufficient accuracy
b) Obtaining a sensible estimate of the possible influence of a proposed emission change on future air quality.
c) Estimating current and future 'worst-case' pollutant concentrations, as well as the likelihood of them occurring.
d) Locating present and prospective future areas in which optimum ground level concentrations are predicted especially in terms of population exposure.
e) To weigh the pros and cons of various options, including potential development locations.
f) Comparing air quality estimations which are relevant to standard of air quality or recommendations in order to put the data into context in terms of potential health or other impacts.

The major activities of the AQIA are (a) observation (monitoring) to assess present air quality (b) estimation (modeling) to forecast future air quality. The best methods for a given situation are very reliant on the problem at hand and three types of data are required: emission characteristics, air quality standards or measures, and environmental conditions. Emission features are required to provide statistics on the pollution sources, the mechanism by which the pollutants were emitted and the pollutants' behavior or nature. The time durations and distance scales over which pollutant concentrations ought to be measured ought to be determined.

1.1 PROBLEM STATEMENT

Air pollution is a man created problem for the advancement of technology and causes serious health issue. Every year, over 2 million people die prematurely as a result of air pollution. Emissions from vehicles and industries in urban areas and burning of wood and coal in rural areas contribute to air pollution. The arrival of oxide, hydrocarbon, and other harmful gases has an unanticipated effect on the air. Some of the air pollutants include sulphur dioxide, carbon monoxide, methane which contribute to the major health problems across the world.

1.2 OBJECTIVE OF PROPOSED WORK

The objective of this study is to understand the distribution, spread and dynamics of the pollutant from the constant source of emission. And use the concepts of control theory to demonstrate cost effective strategy.

1.3 ORGANIZATION OF THE REPORT

Implementation of Gaussian plume equation is done to assess the air pollution impact. A PID controller is connected with the mathematical model of air pollution system for understanding the impact parameters on the Atmospheric pollutant's concentration.

2 METHODOLOGY

Considering atmospheric advection-diffusion equation in 3-D:

$$\frac{\partial C}{\partial t}+\frac{\partial uC}{\partial x}+\frac{\partial vC}{\partial y}+\frac{\partial wC}{\partial z}=K_x\frac{\partial^2 C}{\partial x^2}+K_y\frac{\partial^2 C}{\partial y^2}+K_z\frac{\partial^2 C}{\partial z^2} \tag{1}$$

Along with the premise that convection is the domain term able to cancel out the other terms in a logical and efficient manner.[4] With the assumption that wind, denoted by the letter u, is continuous and consistent:

$$u\frac{\partial C}{\partial x}=K_y\frac{\partial^2 C}{\partial y^2}+K_z\frac{\partial^2 C}{\partial z^2} \tag{2}$$

By using sophisticated mathematical techniques, it is possible to solve the equation above for a point source. The problem has been resolved and the solution

$$c(x,y,z)=\frac{Q}{2\text{D}\mu\sigma_y\sigma z}\exp(-\frac{y2}{2\sigma^2{}_y})[\exp(-\frac{(z-H)^2}{2\sigma^2{}_z})+\exp(-\frac{(z+H)^2}{2\sigma^2{}_z})] \tag{3}$$

Where, for the standard case $\sigma^2{}_i = {2k_{ix}}/{u}$

The magnitude of the standard deviation, as well as its significance, is determined by the stability of the atmosphere. It is not essential which of the two conditions is used here; what is relevant is that the unstable condition has a standard deviation that quickly increases the downwind while the stable condition has a standard deviation that always the downwind is modest. Because of this the contaminant may travel a long distance before dissipating under steady condition

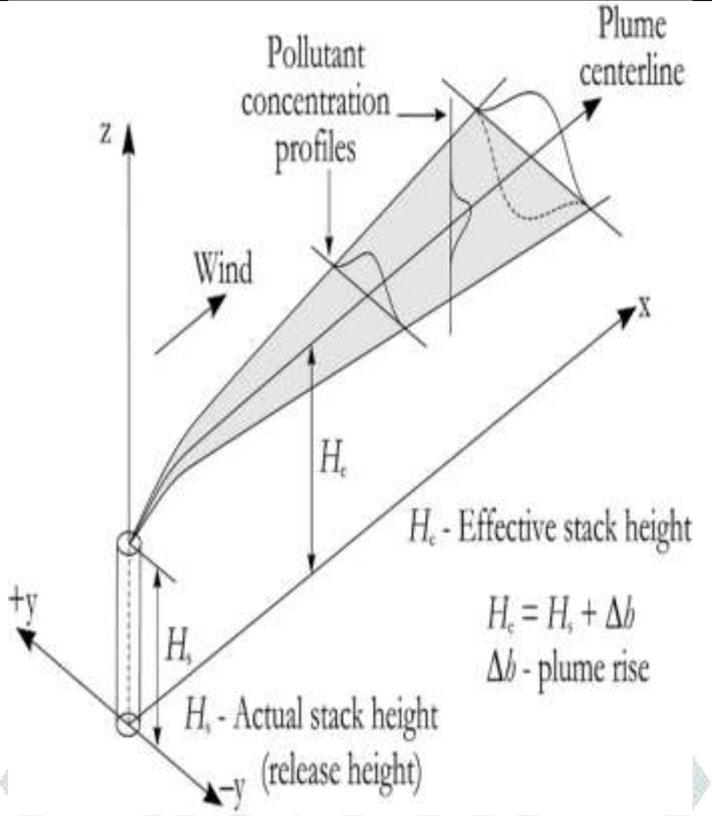

Figure 1*: *Schematic of the scenario being modelled

Variable	Default value	Description
RH	0.90	Relative humidity of the air
Aerosol type	Sodium chloride	Composition of aerosol particles considered
Dry size	$60x10^{-9}$ m	Diameter of aerosol particles assumed
humidify	Dry aerosol	Flag to decide whether to grow the aerosol (Kohler Equations)
X slice	26	If outputting a vertical slice plot along this position
Y slice	1	If outputting a time-series plot at x slice
Stability	constant	Run stability
wind	Prevailing wind	Assumption for input wind field
stack	One stack	Whether to have 1, 2 or 3 stacks
stack x	[0 1000 -200]	x-position of each stack (m)
stack y	[0 250 -500]	y-position of each stack
Q	[40 40 40]	mass in grams s^{-1} emitted from each stack
H	[50 50 50]	height (m) of each stack
days	50	model run-time in days

Table 1: Parameters controlling the behavior of the model.

The computer code for developing the air pollution monitoring system using Gauss Plume Model (Figure 2) is done using MATLAB code. The input parameters defined are as follows [8]

(a) Meteorological parameters

U Wind Speed at stack height in m

H Height slice 3 m

S Surface time in s

Q Mass emitter per unit time

(b)Stack Parameters:

Number of stacks - 1, 2, and 3
Stack x - position of stack at x distance
Stack y -Position of stack at y distance

(c)Aerosol parameters

Humidity - 2 in gm. /l
Dry aerosol-1 in ^{m3}
dx, dy - resolution in both x and y directions
sulphur dioxide – mole/sq. cm

2.1 FLOW CHART OF GAUSS PLUME MODEL

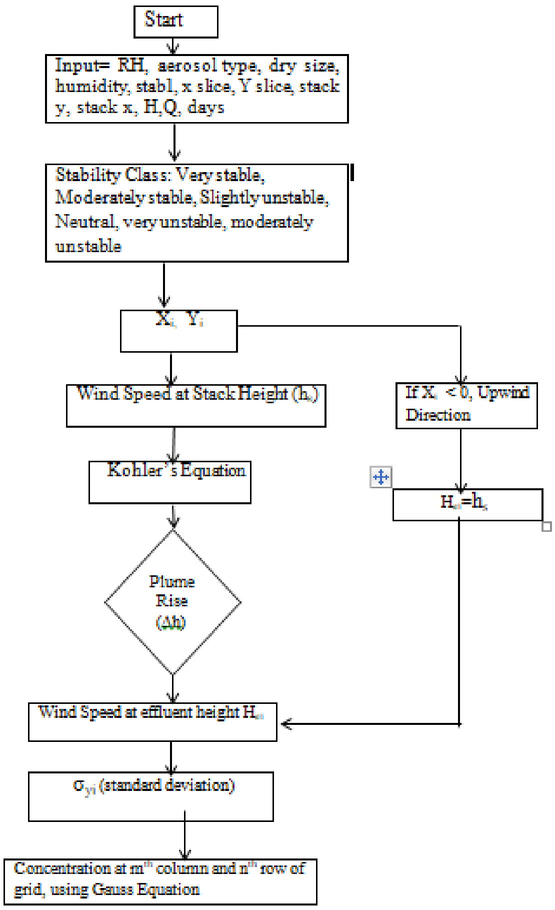

Figure 2: Conceptual frame work

2.2 MATLAB INTRODUCTION

MATLAB stands for Matrix Laboratory. It is a high-performance language that integrates computation, visualization and programming environment. A wide variety of computations can be enabled by using its powerful build-in routines. It has various built-in toolboxes which are application specific and also can be interfaced with programs written in other languages such as C, C++, Java, FORTRAN and Python.

2.3 SIMULINK MODEL

Simulink is a simulation and model-based design environment for dynamic and embedded systems, integrated with MATLAB. Simulink, also developed by Math Works, is a data flow graphical programming language tool for modeling, simulating and analyzing multi-domain dynamic systems. It is basically a graphical block diagramming tool with customizable set of block libraries. It allows incorporating MATLAB algorithms into models as well as exporting the simulation results into MATLAB for further analysis.

2.4 SYSTEM BLOCK DIAGRAM

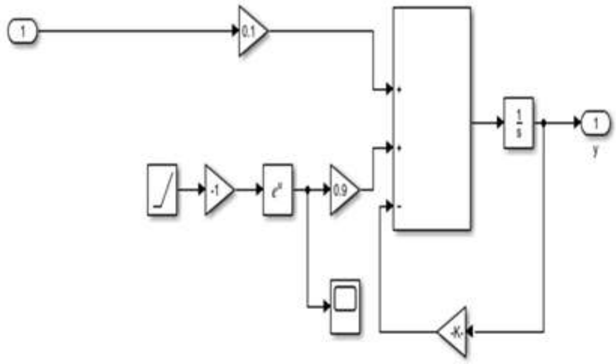

Fig 2: Systems Block Diagram

2.5 DESIGN OF SYSTEM FUNCTION

The regulated pollutants released from various purification devices were accepted by a specified volume of air. Furthermore, since the capacity of the atmosphere to purify itself is mostly influenced by wind and other meteorological variables, an atmospheric section may be defined as a certain volume of air. As a result, a second-order state-space equation may be proposed, which explains the connection between PSO_2 and ASO_2 at an average location in the atmospheric section. The fundamental concept behind modelling is to treat each portion as if it were a perfect stirring reactor. As a result, the whole section's parameters and variables are constant and the PSO_2 and ASO_2 output concentrations are identical to their counterpart concentrations. As a result the following equation from the standpoint of mass balance is considered. [3]

PSO_2 balance equation:

$$\overset{g}{x}_i = -ki_i x_i + \frac{Qi-1}{v_i} x_{i-1} - \frac{Qi+}{v_i} QEx_i \tag{4}$$

ASO_2 balance equation:

$$\overset{g}{y}_i = h_i(y_i^s - y_i) + \frac{Q_i - 1}{v_i} y_i - 1 - \frac{Q_i + Q_E}{v_i} y_i - k_i x_i \tag{5}$$

Where
x_i, x_{i-1} are the PSO_2 of Section i and Section $i-1$ (mg/m3),
Vi is the atmospheric capacity of Section i (m3);
Q_E is PSO_2 gas flow rate of Section i (m3/d),
y_i, y_{i-1} are ASO_2 of Section i and Section $i-1$ (mg/m3),
k_i is daily decay rate of PSO_2 of Section i
h_i is the supply rate of ASO_2 of Section i,
Q_i, Q_{i-1} are atmosphere gas flow rates of Section$i$ and Section $i-1$ (m3/d)
y^s_i is saturating capacity of SO_2 of Section i (mg/m3)

The following values are taken as the coefficients in above equations:

$$k_i = 0.32/day, h_i = 0.2/day, y_i^s = 0.36mg/m3$$
$$Qe/vi = 0.1, \frac{Q_i}{v_i}, \frac{Q_i - 1}{v_i} = 0.9. \tag{6}$$

Thus, the mathematical model of Section i air pollution is

$$\begin{bmatrix} \overset{g}{x}_i \\ \overset{g}{y}_i \end{bmatrix} = \begin{bmatrix} -1.32 & 0 \\ -0.32 & -1.2 \end{bmatrix} \begin{bmatrix} x_i \\ y_i \end{bmatrix} + \begin{bmatrix} 0.1 \\ 0 \end{bmatrix} u + \begin{bmatrix} 0.9x_i - 1 \\ 0.9y_i - 1 + 1.9 \end{bmatrix} \tag{7}$$

2.6 DESIGN OF PID CONTROL SYSTEM

It's simple to comprehend and quite powerful that the PID controller is widely utilised. One of the advantages of the PID controller is that differentiation and integration are theoretically understood by all engineers allowing them to create the control system even if they are unfamiliar. Furthermore despite its simplicity the compensator is highly intricate in that it integrates the system's past and forecasts the system's future behaviour.

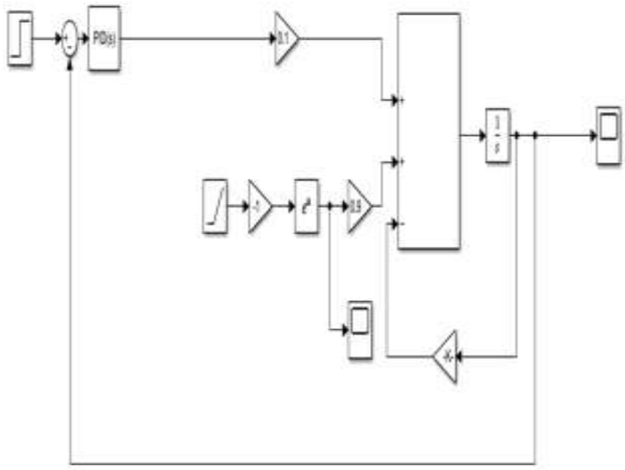

Fig 3: PID control System

2.7 DESIGN OF FUZZY PID CONTROL SYSTEM

The fuzzy PID controller uses the change of the output -(y (k)-y(k-1)), instead of change of error e(k)-e(k-1) as the second input signal to the FIS. Doing so prevents the step change in reference signal from directly triggering the derivative action. The two gain blocks GCE and GCU in the feed forward path, from r to u to ensure that the error signal e is used in proportional action when the fuzzy PID controller is linear. Sugeno Fuzzy Inference System is implemented the Fuzzy PID Control System. The rules are defined in the inference system according to system function.[9]

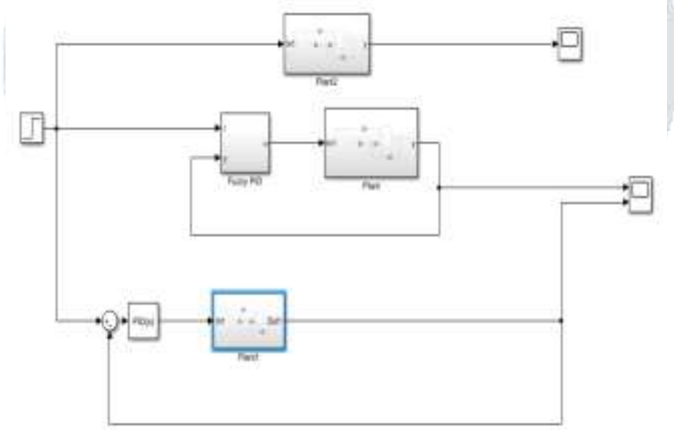

Fig 4: Fuzzy PID control System

3 MATLAB SIMULATION RESULTS

In this project initially uses Matlab Code to execute the Gaussian Plume Model. The below instructions describes about how input variation can be done in MATLAB:

Stab_1value	Vertical stability
1	Very unstable
2	Moderately unstable
3	Slightly unstable
4	Neutral
5	Moderately stable
6	Very stable

Table 2: Stability parameter value, stab_1

1. Section 1 of Gaussian plume can be edited to design the model and save it.
2. Gaussian plume model is typed at the MATLAB command window and run the model.

The required parameters are controlled using a PID controller. Simulations of PID and Fuzzy PID controllers have been completed. Both PID and Fuzzy PID step responses are discussed. Fix the reset time to its maximum value and the level to zero, then increasing the gain until the loop oscillate at constant amplitude. PID tuning is done manually. A larger gain might remain used when the response to an error correction is swift. If the response is slow a slight gain is preferable and the below k_p, k_i, k_d are obtained.

Table 3: PID controller parameters

Parameter	Proportional (k_p)	Integral(k_i)	Derivative(k_d)
Value	103.26	94.23	-2.38

4 RESULTS AND DISCUSSIONS

The proposed setup is designed and tested in simulation mode. The following sections describe the various results obtained while simulating. The tuned waveforms of the controller and the output response of the air pollution are obtained. The step response of controller is shown as follows

4.1 DISTRIBUTION OF GAUSS PLUME

Let's examine the impact that assumptions regarding direction of wind have on pollution scattering. Generally, speed of the wind and direction would be inputted into an air quality model / Gaussian plume model using observational data or a prediction product. A dataset can be created by whichever (1) wind blow from a continual direction; (2) wind blow from entirely random direction and (3) wind blow from one direction with the fluctuation on another side. The neutral vertical stability can also be analyzed using stab1 = 4. According to the parameters of matlab code the values will be assigned and the suitable range of air quality is shown. Fig 5 shows the gauss distribution of very unstable case of table 2. Varying the parameters in section 1 of gauss plume model code and stab1 value

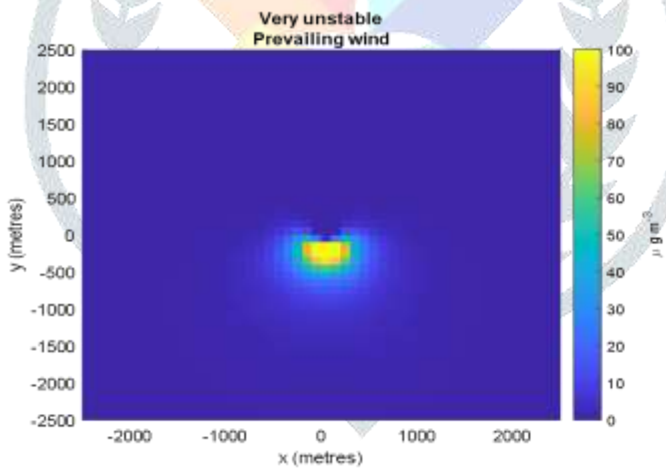

Fig 5: D*istribution of the Gaussian plume: very unstable case*

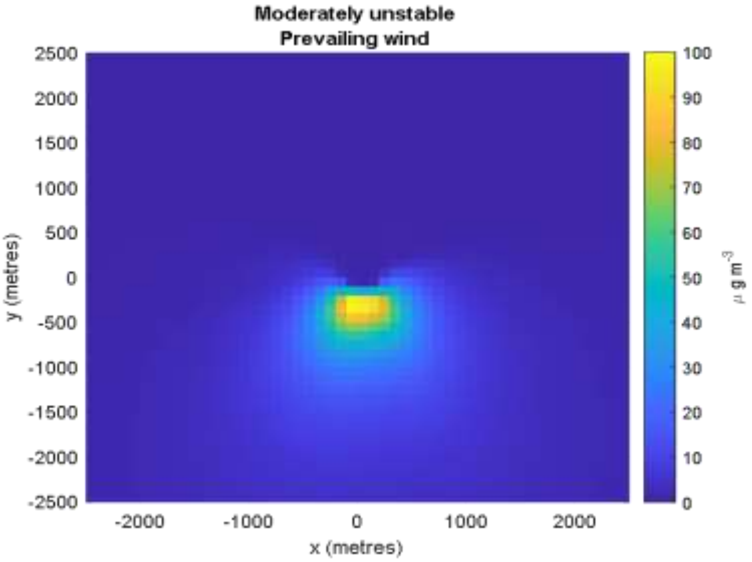

Figure 6: Distribution of the Gaussian plume: moderately unstable case

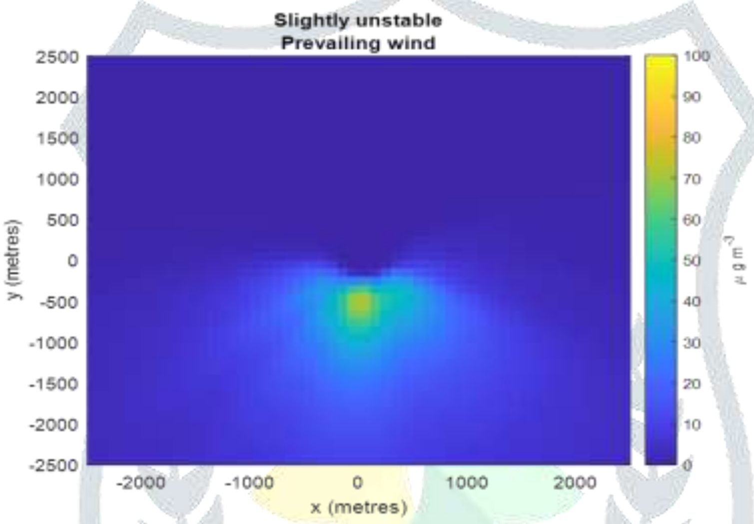

Figure 7: Distribution of the Gaussian plume: Slightly unstable case

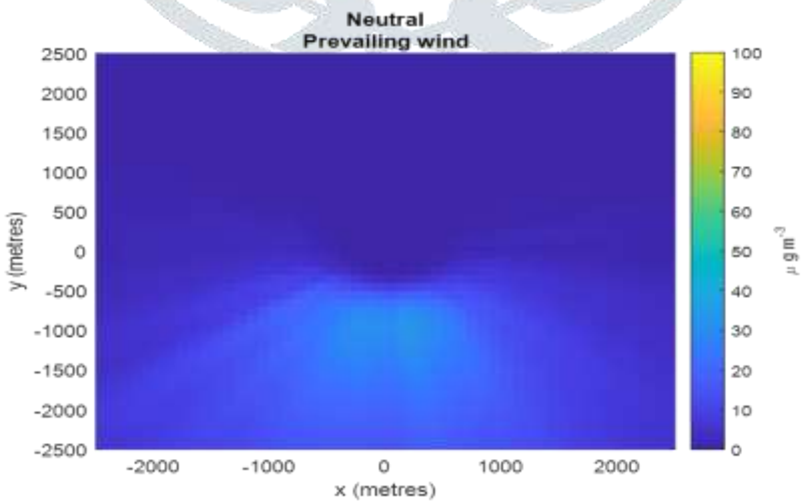

Figure 8: Distribution of the Gaussian plume: Neutral case

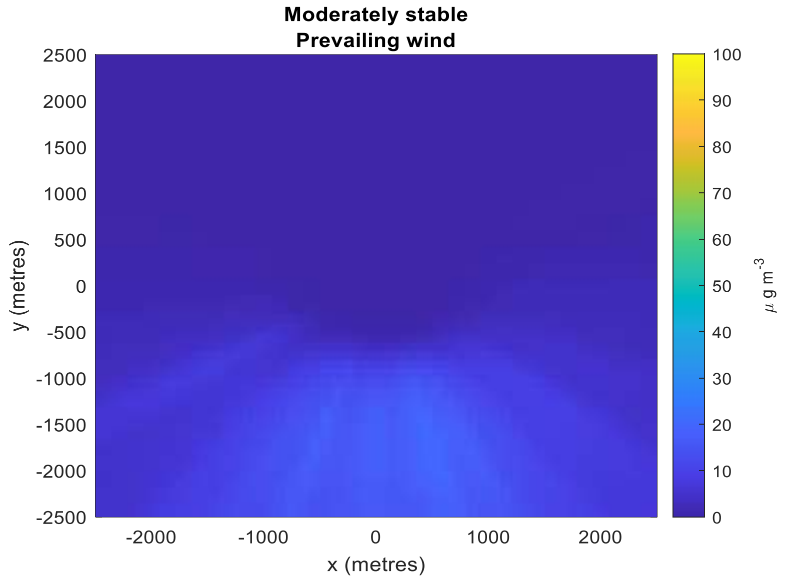

Figure 9: Distribution of the Gaussian plume :moderately stable case

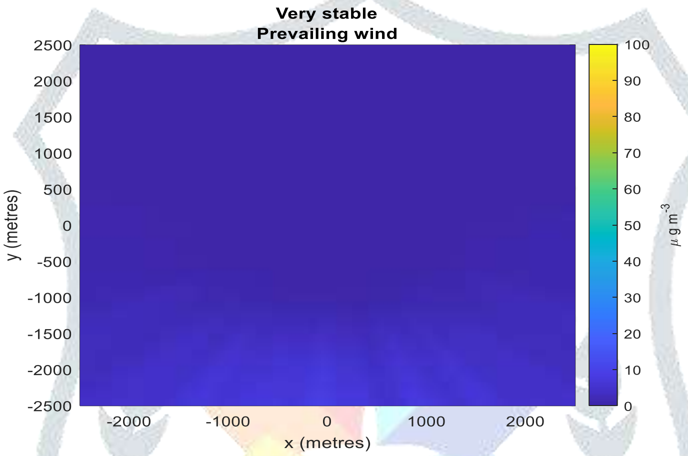

Figure 10: Distribution of the Gaussian plume: Very stable case

6.2 SIMULINK RESULTS

6.2.1 open loop system response

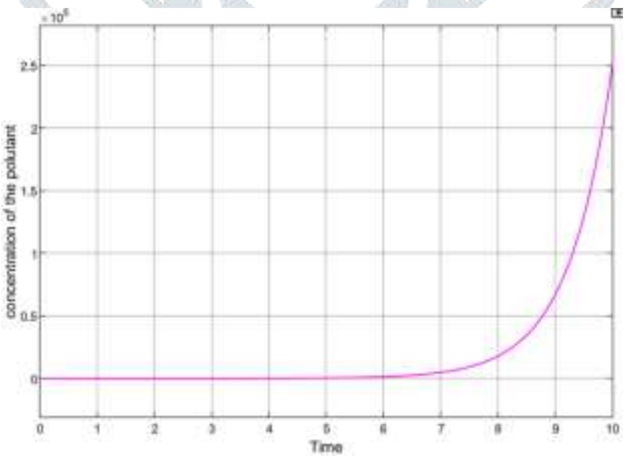

Figure 11: open loop system response

6.2.2 step response of pid controller

The PID control parameters considered are shown in table 3

Parameter	Proportional	Integral	Derivative
Value	103.26	94.23	-2.38

Table 3: PID control parameters

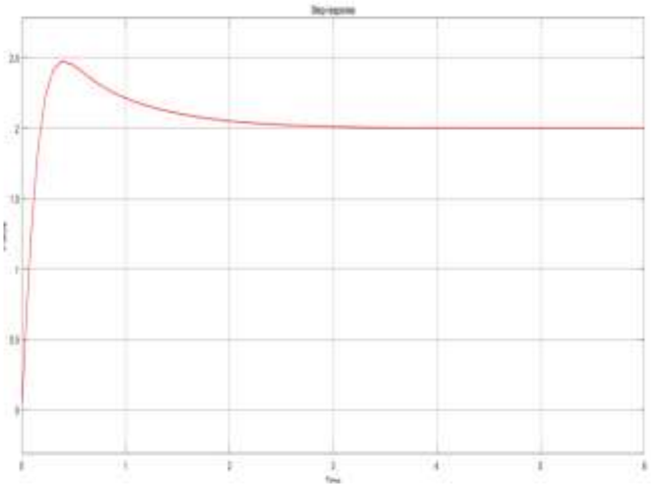

Fig 12: Step Response of the PID System

6.2.3 step response of fuzzy pid control system

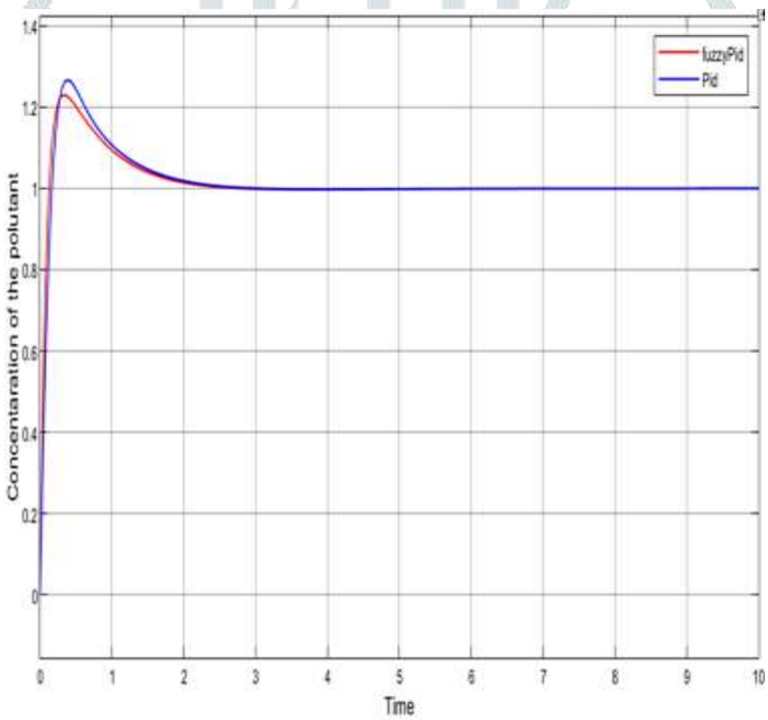

Figure 13: Step response of Fuzzy PIDsystem

7 ADVANTAGES, DISADVANTAGES AND APPLICATIONS

7.1 ADVANTAGES

- Consistency of Performance.
- More realistic to the practical scenario
- Low initial cost
- Easy to design
- Low pressure drop
- Low maintenance cost
- Dry and continuous disposal of solid particles
- Reduced amount of operator errors
- Continuous working of 24/7
- Cost effectiveness

7.2 DISADVANTAGES

- Limited flexibility Precise programming needed
- When computer system fails, it will cause breakdown
- Less collection efficiency
- .Only large size particles are collected

7.3 APPLICATIONS

- To remove pollutants from laboratory fume hoods and batch production facilities, wet scrubbers should be utilized.
- To remove sulphur dioxide (SO2) from non-condensable exhaust gases, packed bed scrubbers should be used.

8 CONCLUSION AND FUTURE SCOPE

8.1 CONCLUSION

A three-dimensional simulation Matlab program is presented in this project for the propagation of multiple pollutants from an industrial pile. Gaussian plume Model is implemented in the program approach. The project depicts meteorological characteristics such as wind velocity, atmospheric stability, relative humidity, and their impact on pollution dispersion. The PID and Fuzzy PID controllers are implemented using mass balance equations. The performance of Fuzzy PID controller with respect to rising settling time(s), rising time(s), overshoot (%) is better than PID Controller and best suited for air pollution monitoring system.

8.2 FUTURE SCOPE

Air pollution is a very big problem for the modern society. By estimating the pollutants impact on certain point of interest, predictive actions need to be taken to reduce the impact with suitable control actions. This work helps to extend new ways and ideas towards the sustainable development in monitoring air pollution. The program can be used as tool in studying the effect of various parameters on air pollution monitoring

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