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Atmospheric gaussian dispersion modeling for central region of Iran

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Abstract

This paper describes the atmospheric dispersion modeling using radionuclides for a hypothesis plant in the central region of Iran. pollutants concentration is estimated by using a mathematical Gaussian plume model in Meso Scale based on 5-year meteorological data such as speed and direction wind, temperature, absolute humidity, stability classes and mixing layer height. This modeling is done first time in central region of Iran. Meteorological data has measured directly from automatic meteorology station in 2003 to 2008. The computation points are done up to 50 km in 16 geographical directions. The results indicate pollutants concentration is under the authorized limit and there is not any threat for people and environment.

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Introduction

Over 3 decades have passed since the air pollution modeling in Mediterranean region. Primitive steps were done by Gaussian plume emission model. It was combination model by using of Meso Scale model and 3 dimensional emission models. In recent decade, such models by using of advanced computers are widely used in the management of the impact of pollutant emissions on environment.

Dispersion modeling uses mathematical formulations to quantify the atmospheric processes that disperse a pollutant emitted by a source. Based on emissions and meteorological inputs, dispersion models can be used to predict concentrations at selected downwind receptor locations.

Also, environmental assessment and pollution effects estimation on the environment are necessary to establish an industrial plant. One of the most important compounds of environment is air quality. Pollutants released amount and their move directions based on meteorology conditions is considered to air assessment.

As industrial plants usually release their pollution to atmosphere via a high stack therefore, pollution concentration prediction based on meteorological conditions is unavoidable.

In this study pollution concentration amount by using of Gaussian mathematical model and CAP is calculated. This software is designed based on EPA (Environmental Protect Agency) standards and verified by DOE. (Department Of Energy).

Methods

Gaussian model is one of the most famous of atmospheric dispersion models that simulates behavior of plumes and estimates pollution concentration emitted from stack-height sources.[4] In this model, emission source such as stack is considered a point source and pollutant concentration is estimated in downwind source. (In a point source, physical dimension of source respect to dispersion dimension is very small).

Stack is assumed on origin of coordination system and pollution air is moved along wind and dispersed along y and z directions. Coordination system of Gaussian model is represented by the schematic shown in Figure 1.

Plume Rise

In order to establish the effective emission height the plume rise must be accounted for upon leaving the stack, the plume usually encounters a crosswind, which causes the plume to bend over. Eventually, the plume will cease rising, and the plume rise is added to the actual stack height to determined the effective emission height. Then, it is usual to write the effective emission height as the sum of the actual height of the stack h_s and the plume rise Δh as, $H = h_s + \Delta h$.

So, pollutants is emitted from point (H, 0, 0)

Where:

h_s = Stack height

Δh = Plum rise

H = Effective height

There are numerous methods for calculating Δh. Here it is calculated by Holland equation:

$\Delta h = V_s\, d / u[1.5 + 2.68 * 10^{-3} P d(T_s - T_a)/T_s]$

Where:

Vs= exit gas velocity from stack (m/s)

D= inner diameter (m)

U= wind speed (m/s)

P= air pressure (mb)

T_s=gas temperature at the stack exit (°k)

T_a=air temperature (°k)

Correction factor is considered for unstable classes (A, B, C) and stable classes (D,E,F) 1.1 and 0.8 respectively.

Model description

By considering figure1,Gaussian plume essential equation to estimate of pollution concentration which can be defined as:

$$\bar{C}(x,y,z) = \frac{Q}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left[-0.5\left(\frac{y^2}{\sigma_y^2}\right)\right]\left\{\exp\left[-0.5\left(\frac{(z-H)^2}{\sigma_z^2} + \frac{(z+H)^2}{\sigma_z^2}\right)\right]\right\}$$

Where:

$\overline{C}$ = mean concentration

Q= emission source strength or emission rate (g/s)

H = Effective source release height

$\overline{u}$ = mean wind speed (m/s)

σ_y=horizon emission coefficient

σ_z= vertical emission coefficient

y = crosswind distance

z = receptor height.

To compute long-term averaged ground level concentration, above equation is integrated in the crosswind direction.

Accurate estimates of the dispersion of pollutants in the atmosphere require knowledge of the frequency distribution of wind direction as well as wind speed. So by considering wind direction and speed changing in long term, we use windroses. It is a graphic diagram of wind data. It is drawn on polar coordinates by soft ware. It shows frequencies of various observed wind directions and speeds in different stability classes. It shows them in 16 geographical directions include of north, west, south and east(N,W,S, E) and N,NNE,NE,...,NNW.

If y=0 and z=0, the concentration is calculated on ground level.

Dispersion pattern with lid mixing height effect

The basic models employ the idea of complete reflection from the diffusion lid as in the case for the plume contacting the ground. Now that plume is trapped between lid and bottom, multiple reflections are allowed for in the model. Thus, dispersion model

Become

$$\bar{C} = \int_0^\infty \frac{C}{L} dz$$

Here L is lid mixing height

$$\bar{C}=\frac{1}{L}\int_0^\infty \left(\frac{Q}{\pi\sigma y\sigma zu}\right) \exp\left(\frac{-z^2}{2\sigma z^2}\right)\exp\left(\frac{-z^2}{2\sigma y^2}\right)dz$$

Atmospheric Dispersion Coefficient

Dispersion coefficients or sigma values must be determined by measurement. There have been many significant transport and dispersion studies carried out in the atmosphere and reported and analyzed in the literature by Slade (1968),Pasquili and Smith (1983). At the plant of interest, the meteorological parameters are required to determine the sigma values. To estimate σ_y and σ_z, the stability class must first be determined. The techniques proposed of Pasquill-Gifford and Turner are the most widely used. A series of curves or formulas are referenced to find values for σ_y and σ_z as a function of stability class and downwind distance. Brigg's (1973) shows analytical formulas for dispersion coefficients, which use the Pasquill stability classes. (Table 1).

Input parameters

The required data for calculation dispersion by CAP soft ware at this plant are:

- meteorological parameters
- Stack physical parameters

Meteorological parameters including mean temperature, absolute humidity, precipitation and mixing layer height during (01/01/2005-30/12/2008) have been used from meteorology automatic station in central region of Iran. (Table2) Wind rose diagram at 16- direction for the same period is presented in Figures 2, 3. Data on stack physical parameters is shown in Table 3.

Emitted pollutants from stack

Information on type of pollutants to be released from stack including the quantity of annual released and is shown in Table 4.

Results and Conclusions

By inputting of calculated meteorological parameters from the available data, stack physical parameters and emission source into the CAP code, the atmospheric dispersion at different distances up to 30 Kmradiusin 16 directions for day and night, is calculated and is shown inTables 5 and 6.

Discussion

Based on diurnal and nocturnal windroses (figure2,3), 28% of daily winds are blown with 3.5 to 15.5 m/s speed from west and south west and others are blown in different directions. Also nocturnal windrose shows 27% of them with 5.5 to 15.5 m/s is blown from east and south east and others are in different directions.

Table 1. Briggs's Dispersion Coefficient for Rural and Urban Regions.

Pasquill stability category	σ_z (m) - Urban	σ_z (m) - Rural
A	$0.24x(1+0.001x)^{0.5}$	0.2x
B	$0.24x(1+0.001x)^{0.5}$	0.12x
C	0.2x	$0.08x(1+0.0002x)^{-0.5}$
D	$0.14x(1+0.0003x)^{-0.5}$	$0.06x(1+0.0015x)^{-0.5}$
E	$0.08x(1+0.0015x)^{-0.5}$	$0.03x(1+0.0003x)^{-1}$
F	$0.08x(1+0.0015x)^{-0.5}$	$0.016x(1+0.0003x)^{-1}$

Table 2. Meteorological Parameters.

Parameter	Value
Mean Ambient Temperature	15 (°C)
Absolute Humidity	5.2 g/m^3
Annual Precipitation	27 cm
Mix Height	800m

Table 3. Stack Physical Parameters.

Parameter	Value
stack height	80 m
Inner diameter	1.2 m
Outer diameter	1.5m
Exit gas velocity	14 m/s

Table 4. Radionuclide Characteristics.

Radionuclides	Activity (MBq/year)
^{60}Co	1.50E+01
^{95}Zr	2.37E-01
^{59}Fe	1.46E+00
^{51}Cr	3.72E-01
^{131}I	6.54E+03
^{132}I	1.70E+04
^{133}I	4.84E+04
^{134}I	1.62E+04
^{135}I	3.56E+04
^{85m}Kr	2.25E+03
^{87}Kr	4.12E+03
^{88}Kr	5.11E+03
^{133}Xe	1.72E+04
^{135}Xe	1.69E+03
^{137}Cs	1.26E-01
^{134}Cs	2.04E-01
^{14}C	7.98E+03
^{41}Ar	2.48E+08

Table 5. Daily Distribution of Concentration (s/m3) Within 30 Km Radius from Stack.

Dir.	100	200	300	400	500	600	700	800	1000	3000	10000	20000	30000
N	2.08E-10	3.43E-07	8.79E-07	1.03E-06	9.74E-07	8.63E-07	7.47E-07	6.45E-07	4.91E-07	1.04E-07	2.24E-08	9.55E-09	5.82E-09
NNW	1.50E-10	2.23E-07	5.74E-07	6.79E-07	6.51E-07	5.79E-07	5.02E-07	4.33E-07	3.30E-07	7.44E-08	1.65E-08	7.09E-09	4.35E-09
NW	7.12E-11	1.30E-07	3.59E-07	4.47E-07	4.48E-07	4.15E-07	3.72E-07	3.31E-07	2.63E-07	6.43E-08	1.33E-08	5.60E-09	3.41E-09
WNW	4.11E-11	7.13E-08	2.02E-07	2.59E-07	2.64E-07	2.47E-07	2.23E-07	2.00E-07	1.65E-07	5.06E-08	1.15E-08	4.85E-09	2.95E-09
W	2.49E-11	4.23E-08	1.26E-07	1.69E-07	1.79E-07	1.71E-07	1.58E-07	1.44E-07	1.22E-07	4.07E-08	9.66E-09	4.12E-09	2.52E-09
WSW	9.90E-12	2.16E-08	6.50E-08	8.55E-08	8.67E-08	7.99E-08	7.12E-08	6.33E-08	5.17E-08	1.70E-08	4.21E-09	1.87E-09	1.18E-09
SW	3.07E-12	9.79E-09	3.05E-08	4.00E-08	4.15E-08	3.95E-08	3.65E-08	3.37E-08	2.96E-08	1.24E-08	2.94E-09	1.26E-09	7.83E-10
SSW	2.19E-12	1.21E-08	4.00E-08	5.22E-08	5.39E-08	5.14E-08	4.72E-08	4.30E-08	3.63E-08	1.35E-08	3.13E-09	1.33E-09	8.17E-10
S	1.57E-11	3.02E-08	8.26E-08	1.02E-07	1.01E-07	9.31E-08	8.41E-08	7.57E-08	6.26E-08	2.06E-08	4.69E-09	1.98E-09	1.20E-09
SSE	1.47E-11	3.84E-08	1.09E-07	1.34E-07	1.31E-07	1.18E-07	1.03E-07	8.95E-08	6.94E-08	2.05E-08	5.22E-09	2.33E-09	1.46E-09
SE	4.87E-11	7.49E-08	2.08E-07	2.62E-07	2.58E-07	2.34E-07	2.04E-07	1.78E-07	1.37E-07	3.35E-08	7.85E-09	3.55E-09	2.25E-09
ESE	2.08E-10	2.14E-07	5.18E-07	6.02E-07	5.71E-07	5.05E-07	4.36E-07	3.74E-07	2.81E-07	5.46E-08	1.23E-08	5.63E-09	3.58E-09
E	5.60E-10	5.59E-07	1.28E-06	1.42E-06	1.32E-06	1.15E-06	9.93E-07	8.53E-07	6.40E-07	1.26E-07	2.86E-08	1.27E-08	7.96E-09
ENE	2.84E-10	5.04E-07	1.25E-06	1.37E-06	1.25E-06	1.07E-06	8.99E-07	7.58E-07	5.54E-07	9.70E-08	2.14E-08	9.42E-09	5.83E-09
NE	1.24E-10	3.21E-07	8.48E-07	9.50E-07	8.69E-07	7.49E-07	6.36E-07	5.40E-07	4.01E-07	7.65E-08	1.67E-08	7.19E-09	4.40E-09
NNE	1.49E-10	3.34E-07	8.53E-07	9.44E-07	8.59E-07	7.39E-07	6.28E-07	5.36E-07	4.04E-07	8.73E-08	1.96E-08	8.24E-09	4.96E-09

Table 6. Nightly Distribution of Concentration (s/m3) Within 30 Km Radius from Stack.

Dir.	100	200	300	400	500	600	700	800	1000	3000	10000	20000	30000
N	4.58E-15	9.00E-10	1.99E-08	5.64E-08	8.31E-08	9.59E-08	1.01E-07	1.03E-07	1.07E-07	7.01E-08	1.87E-08	7.58E-09	4.58E-09
NNW	4.49E-15	9.96E-10	2.22E-08	6.32E-08	9.67E-08	1.16E-07	1.24E-07	1.28E-07	1.33E-07	8.55E-08	2.27E-08	9.19E-09	5.56E-09
NW	6.84E-21	3.11E-10	1.75E-08	6.06E-08	1.01E-07	1.26E-07	1.39E-07	1.46E-07	1.57E-07	1.07E-07	2.84E-08	1.15E-08	7.01E-09
WNW	1.33E-12	2.65E-09	1.43E-08	4.01E-08	7.00E-08	9.42E-08	1.13E-07	1.30E-07	1.65E-07	1.48E-07	4.05E-08	1.68E-08	1.03E-08
W	6.48E-20	3.97E-10	1.56E-08	4.92E-08	8.08E-08	1.04E-07	1.24E-07	1.47E-07	1.95E-07	1.85E-07	4.96E-08	2.01E-08	1.22E-08
WSW	1.35E-12	2.67E-09	1.25E-08	2.85E-08	4.26E-08	5.27E-08	6.19E-08	7.32E-08	1.02E-07	1.12E-07	2.78E-08	1.09E-08	6.65E-09
SW	1.41E-14	1.56E-09	8.42E-09	1.63E-08	2.57E-08	3.35E-08	3.82E-08	4.09E-08	4.59E-08	5.72E-08	1.66E-08	6.87E-09	4.34E-09
SSW	4.53E-15	6.19E-10	8.50E-09	2.30E-08	3.66E-08	4.68E-08	5.34E-08	5.77E-08	6.62E-08	7.57E-08	2.11E-08	8.58E-09	5.35E-09
S	4.60E-15	7.69E-10	1.33E-08	3.64E-08	5.80E-08	7.50E-08	8.73E-08	9.75E-08	1.19E-07	1.30E-07	3.48E-08	1.40E-08	8.59E-09
SSE	1.37E-12	2.97E-09	1.88E-08	4.72E-08	7.78E-08	1.01E-07	1.16E-07	1.27E-07	1.49E-07	1.34E-07	3.54E-08	1.43E-08	8.78E-09
SE	9.45E-15	2.19E-09	3.51E-08	9.13E-08	1.41E-07	1.73E-07	1.89E-07	1.97E-07	2.02E-07	1.22E-07	3.17E-08	1.32E-08	8.16E-09
ESE	1.28E-12	1.66E-09	3.01E-08	8.66E-08	1.36E-07	1.65E-07	1.78E-07	1.82E-07	1.83E-07	1.09E-07	2.86E-08	1.19E-08	7.32E-09
E	9.54E-15	2.01E-09	4.65E-08	1.32E-07	1.97E-07	2.30E-07	2.40E-07	2.38E-07	2.25E-07	1.18E-07	3.02E-08	1.23E-08	7.47E-09
ENE	5.37E-13	5.19E-09	3.03E-08	7.54E-08	1.12E-07	1.29E-07	1.32E-07	1.29E-07	1.18E-07	5.38E-08	1.37E-08	5.63E-09	3.43E-09
NE	1.86E-14	2.21E-09	2.07E-08	5.12E-08	7.50E-08	8.70E-08	9.07E-08	9.04E-08	8.66E-08	4.34E-08	1.06E-08	4.25E-09	2.56E-09
NNE	1.28E-20	2.21E-10	1.04E-08	3.27E-08	5.06E-08	6.00E-08	6.41E-08	6.61E-08	6.87E-08	4.17E-08	1.07E-08	4.31E-09	2.60E-09

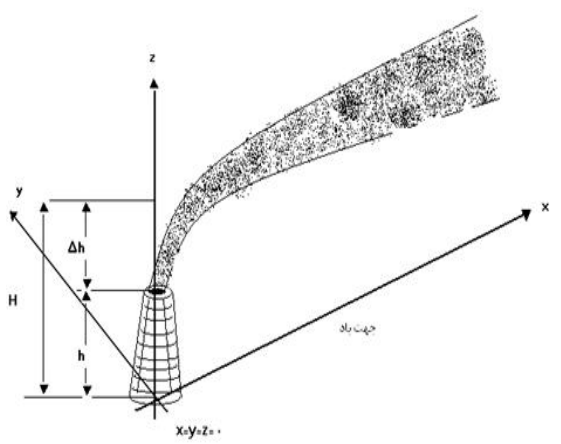

Fig. 1. Coordination system of Gaussian Plume.

Wind intensity and variety of directions are caused pollution is dispersed in all of directions during day and night. In other hand, as there is just 7% calm condition. It shows that the region atmosphere is very unstable and air pollution accumulation potential is very low. Also mixing layer mean height is high; therefore air pollution is mixed very well. Besides by considering low mean temperature and humidity, this station is located in semi-dry and cold region. So probability of combination pollutant and formation of secondary pollution is small. These results are confirmed by CAP software output. By comparing them with safety limits, the plant selection is good and there is no threat for people and environment.

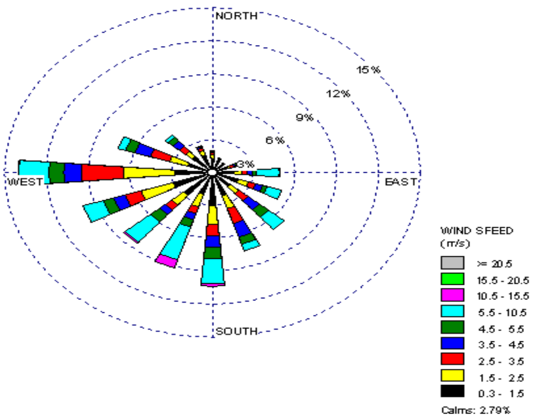

Fig. 2. Annually Day time Wind Rose.

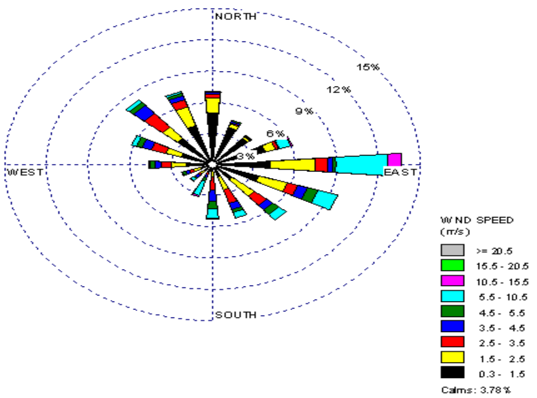

Fig. 3. Annually Night time Wind Rose.

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