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Comparison Between Actual and Estimated Maximum Downwind Distance using Different Dispersion Parameters

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Abstract: In this study, the maximum downwind distance x_{max} was calculated according to the dispersion parameters and by using four methods the power law function, standard, Klug and Pasquill-Gifford method sat three effective heights of 5, 100 and 250 m, respectively. The maximum ground level concentration of air pollution that based on the Gaussian model can be calculated by using the estimated and actual values of the x_{max} for different stability classes. The estimated and actual x_{max} are summarized as 0-492 m in power law and standard method, also the percentage of the error between estimated and actual maximum downwind distance in the range of 0.005-14.2, respectively. Comparison between the results of estimated and actual x_{max} in case of power law and standard method with the previous work used Brigg method (Ronbanchob2015) is carried out.

INTRODUCTION

The main factor of air dispersion modeling is predicting the concentration of pollutant resulting from a point source or multi-sources under various meteorological conditions. These models are useful for studying the transmission of pollutants into the air[1].

The concentration of pollutant is function of many variables including the emission rate, the distance of the receptors from the source and the atmospheric conditions. The atmospheric air quality dispersion model is usually used to estimate the reduction occurring through the transportation of pollutant from any source[2]. The most common model for studying the air dispersion process is to improve air quality is generally based on Gaussian plume/puff formula. There are many parameters on the basis of empirical correlation and as function of distance were originally developed by pasquill and modified by Gifford. The lateral and vertical dispersion parameter, respectively σ_y and σ_y represent the turbulent parameter ization in this approach. They include the physical features that describe the dispersion progression[3].

In this study, the maximum concentration at ground level in center-line is predicted with the maximum downwind distance by using the dispersion parameters by two different methods. One of the most important methods is the power-law functionsin which plume dispersion coefficients are articulated according to downwind distance and atmospheric stability[4]. While the standard method is based on a single atmospheric stability firmed by vertical temperature gradient and the analytical expressions based on (P-G) curves[5]. A Comparison between the results of estimated and actual x_{max} in the case of the power law and standard method with the previous work used Brigg's method[6] is carried out.

MATERIALS AND METHODS

Mathematical model: The concentration in the downwind distance can be expressed as Eq. 1 according to Gaussian model[7]:

$$c(x,y,z,H)=\frac{q_q}{2\pi\sigma_y\sigma_z u}e^{-\frac{1}{2}\left[\frac{y}{\sigma_y}\right]^2}\left[e^{-\frac{1}{2}\left[\frac{z-H}{\sigma_z}\right]^2}+e^{-\frac{1}{2}\left[\frac{z+H}{\sigma_z}\right]^2}\right] \quad (1)$$

Where:

C (x, y, z, H) = The concentration in the downwind distance, crosswind and vertical distance at stack height
H, q_p = The emission rate at point source "p"
σ_y, σ_z = Are crosswind and vertical dispersion parameters
u = The wind speed (m sec^{-1})

Equation 1 can be reduced to simple term at the ground level in the plume centerline as follows:

$$c(x,0,0,H)=\frac{q_q}{\pi\sigma_y\sigma_z u}\left[e^{-\frac{1}{2}\left[\frac{H}{\sigma_z}\right]^2}\right] \quad (2)$$

where the variables σ_y, σ_z depends on the atmospheric stability classes. The maximum downwind distance and concentration can be derived from the principle of rough estimation by solving equation $\sigma_z \frac{H}{\sqrt{2}}$ [7] using estimated and actual methods, so we used two different methods such as power law and standard methods as follows:

Power-law functions: The variables and can be calculated as follows[8]:

$$\sigma_y = ax^b \quad (3)$$

$$\sigma_z = cx^d \quad (4)$$

where, a-d are constants values depending on the stability classes (Table 1)[9].

Standard method: This model is based on a single atmospheric stability which determined by the vertical temperature gradient, $\Delta T/Z\Delta$[10] and the dispersion parameters have the form:

Table 1: Constants for calculating lateral (σ_y) and vertical dispersion parameter (σ_z)

Constants stability	σ_y a	σ_y B	σ_z C	σ_z d
Very unstable	0.40	0.91	0.41	0.91
Unstable	0.36	0.86	0.33	0.86
Neutral	0.32	0.78	0.22	0.78
Stable	0.31	0.71	0.06	0.71

Table 2: A correspondence between $\Delta T/\Delta z$, σ_0, dispersion parameters and Pasquill stability classes

Pasquill classes	A	B	C	D	E
$\frac{\Delta T}{\Delta Z}\left(\frac{k}{100}m\right)$	<-1.9	-1.9 to -1.7	-1.7 to -1.5	-1.5 to -0.5	0.5-1.5
σ_0	25°	20°	15°	10°	5°
a (km)	0.927	0.370	0.283	0.707	1.07
s (m/km)	102.0	96.2	72.2	47.5	33.5
q	-1.918	-0.101	0.102	0.465	0.624
r (m/km)	250	202	134	78.7	56.6
p	0.189	0.162	0.134	0.135	0.137

A correspondence between $\Delta T/\Delta z$, σ_0, dispersion parameters and Pasquill stability classes

$$\sigma_y = \frac{rx}{\left(1+\frac{x}{a}\right)^p} \quad (5)$$

$$\sigma_z = \frac{sx}{\left(1+\frac{x}{a}\right)^q} \quad (6)$$

where, r, s, a, p and q are constants depends on the atmospheric stability (Table 2)[4]. Now, one estimates the values of crosswind and vertical standard parameters in power law and standard methods as follows:

Klug system: Klug studied a system of diffusion parameters that is applicable for short-term ground level release over terrain with a low surface roughness[1] as follows:

$$\sigma_y(x) = p_y x^{qy} \quad (7)$$

$$\sigma_z(x) = p_y x^{qz} \quad (8)$$

where, x is the source distance and the coefficient p and q are specified in Table 3 and 4.

Pasquill-gifford system: The combination of Pasquill and Gifford parameters is called P-G scheme. In this scheme and are obtained from graphs as a function of downwind distance x, for each stability classes[11]:

$$\sigma_y(x) = (a_1\ \text{In}x + a_2) \quad (9)$$

Table 3: Power law and standard method for prediction of σ_y and σ_z

Stability class	Power law σ_y (m)	σ_z (m)	Standard method σ_y (m)	σ_z (m)
A (very unstable)	$0.4x^{0.91}$	$0.41x^{0.91}$	$\frac{0.25x}{1+\frac{0.189x}{0.927}}$	$\frac{0.102x}{1-\frac{1.918x}{0.927}}$
B (moderately unstable)	$0.4x^{0.91}$	$0.41x^{0.91}$	$\frac{0.202x}{1+\frac{0.162x}{0.370}}$	$\frac{0.0962x}{1-\frac{0.101x}{0.370}}$
C (slightly unstable)	$0.36x^{0.86}$	$0.33x^{0.86}$	$\frac{0.134x}{1+\frac{0.134x}{0.283}}$	$\frac{0.0722x}{1+\frac{0.102x}{0.283}}$
D (neutral)	$0.32x^{0.78}$	$0.22x^{0.78}$	$\frac{0.0787x}{1+\frac{0.135x}{0.707}}$	$\frac{0.0475x}{1+\frac{0.465x}{0.707}}$
E (slightly stable)	$0.31x^{0.71}$	$0.06x^{0.71}$	$\frac{0.0566x}{1+\frac{0.137x}{1.07}}$	$\frac{0.0335x}{1+\frac{0624x}{1.07}}$

Table 4: Coefficients of Klug system for all stability classes (Vogt. 1977)

Coefficients	A	B	C	D	E	F
p_y	0.4690	0.3060	0.2300	0.2190	0.2370	0.2730
q_y	0.9030	0.8850	0.8550	0.7640	0.6910	0.5940
p_z	0.0170	0.0720	0.0760	0.1400	0.2170	0.2620
q_z	0.3800	1.0210	0.7270	0.7270	0.6100	0.5000

Table 5: Coefficients of Pasquill-Gifford system for all stability classes (Vogt. 1977)

Coefficients	Stability classes A	B	C	D	E	F
a_1	-0.0234	-0.0147	-0.0117	-0.0059	-0.0059	-0.0029
a_2	0.3500	0.2480	0.1750	0.1080	0.0880	0.0540
b_1	0.8800	-0.9850	-1.1860	-1.3500	-2.8800	-3.800
b_2	0.1520	0.8200	0.8500	0.7930	1.2550	1.4190
b_3	0.1475	0.0168	0.0045	0.0022	-0.0420	-0.0550

$$\sigma_z(x) = \frac{1}{2.15}\exp\left(b_1+b_2 Inx+b_2 \ln^2 x\right) \tag{10}$$

where the constants a_1, a_2, b_1, b_2 and b_3 depend on the atmospheric stability and thyeir values are presented in Table 5.

RESULTS AND DISCUSSION

The actual x_{max} of the Gaussian model is determined using programs as a mathmatica5 that finds the relation between the ground level concentration and the downwind distance such that there are three effective heights at 5, 100 and 250 m were evaluated using q_p and u of 3 g sec^{-1} and 3 m sec^{-1}, respectively. The percentage of relative error was calculated by:

$$\text{Relative error} = \left|\frac{\text{actual}x_{max}\text{-estimated}x_{max}}{\text{actual}x_{max}}\right| \tag{11}$$

Table 6: Calculation of x_{max}

Stability class	x_{max} power law	x_{max} standard method
A	$\left(\frac{H}{0.41\sqrt{2}}\right)^{\frac{1}{0.91}}$	$\frac{H}{0.144+2.07H}$
B	$\left(\frac{H}{0.41\sqrt{2}}\right)^{\frac{1}{0.91}}$	$\frac{H}{0.136+0.27H}$
C	$\left(\frac{H}{0.33\sqrt{2}}\right)^{\frac{1}{0.86}}$	$\frac{H}{0.102-0.360H}$
D	$\left(\frac{H}{0.22\sqrt{2}}\right)^{\frac{1}{0.78}}$	$\frac{H}{0.067-0.657H}$
E	$\left(\frac{H}{0.06\sqrt{2}}\right)^{\frac{1}{0.71}}$	$\frac{H}{0.047-0.58H}$

The calculation of x_{max} which depends on the dispersion parameters can be estimated from Table 6. The prediction of maximum values x_{max} depend on input values which are given in Table 7-10 one concludes that from four tables, the maximum value of downwind distance depends on stability classes and the effective height of point source, one finds that from thefourtables, there are well agreement between actual and estimated values of maximum downwind distance.

In power law, standard method, Klug and Pasquill-Gifford systems, one finds that the percentage of the error between estimated and actual maximum downwind distance in the range of 0-492, 0.005-14.2, 0.73-6.7 and 0.23-94.9, respectively. This research shows that when we used the method of the power law, standard method, Klug and Pasquill-Gifford system are better than Brigg's model method with respect to the presented error[6]. Then one can deduce that the best values for the estimation x_{max} be observed at the lower x_{max} value.

Figure 1 and 2 show the variation of the maximum estimated and actual downwind distance in power law and standard methods. We can conclude that the maximum estimated and actual downwind distances using standard method are better than using power law method but the power law method is a well agreement in all stabilities except stable condition.

Table 9 and 10 show that the estimated of c_{max} which depend on the maximum downwind distance, effective stack height and stability classes. One finds that the errors are in the range of 0-15.38 and 3.1-290 for power law function and standard method, respectively.

Figure 3 and 4 show the variation of absolute maximum estimated and absolute maximum ground

Table 7: Accuracy for the calculation of x_{max} by using power law function

Stability class	H = 5 actual x_{max}(m)	H = 5 estimated x_{max} (m)	H = 5 relative error (%)	H = 100 actua x_{max} (m)	H = 100 estimated x_{max} (m)	H = 100 actual error (%)	H = 250 relative x_{max}(m)	H=250 estimated x_{max}(m)	H = 250 relative error (%)
A	11	11	0	300	287	4.33	1000	786	21.4
B	11	11	0	300	287	4.33	1000	786	21.4
C	14	16	14.3	500	513	2.6	2000	1489	25.55
D	45	35	22.22	1400	1637	16.92	5000	5301	6.02
E	400	311	22.25	15000	21174	41.16	13000	76966	492

Table 8: Accuracy for the calculation of x_{max} bystandard method

Stability class	H = 5 actual x_{max}(m)	H = 5 estimated x_{max} (m)	H = 5 relative error (%)	H = 100 actua x_{max} (m)	H = 100 estimated x_{max} (m)	H = 100 actual error (%)	H = 250 relative x_{max}(m)	H=250 estimated x_{max}(m)	H = 250 relative error (%)
A	0.482	0.476463	1.15	0.483	0.482756	0.05	0.483	0.482957	0.005
B	3.50	3.34225	4.5	3.64	3.65818	0.5	3.66	3.66913	0.25
C	-2.90	-2.94464	1.54	-2.78	-2.78567	0.2	-2.78	-2.78093	0.03
D	-1.51	-1.55376	2.9	-1.52	-1.52362	0.24	-1.52	-1.52269	0.17
E	-1.71	-1.75254	14.2	-1.71	-1.725	0.87	-1.71	-1.7247	0.85

Table 9: Accuracy for the calculation of x_{max} by using Klug system

Stability class	H = 5 actual x_{max}(m)	H = 5 estimated x_{max} (m)	H = 5 relative error (%)	H = 100 actua x_{max} (m)	H = 100 estimated x_{max} (m)	H = 100 actual error (%)	H = 250 relative x_{max}(m)	H=250 estimated x_{max}(m)	H = 250 relative error (%)
A	51	47.83	6.2	449	419.27	6.6	872.5	814.43	6.7
B	47	45.33	3.6	882	852.33	3.4	2163	2091.05	3.3
C	79.5	78.92	0.73	2403	2384.12	0.79	6814.5	6761.56	0.78
D	83.5	84.9	1.7	5140.5	5230.1	1.7	18129	18445.2	1.7
E	92	97.02	5.5	12497.5	13173.9	5.4	56129.5	59166.3	5.4

Table 10: Accuracy for the calculation of x_{max} by using Pasquill-Gifford system

Stability class	H = 5 actual x_{max}(m)	H = 5 estimated x_{max} (m)	H = 5 relative error (%)	H = 100 actua x_{max} (m)	H = 100 estimated x_{max} (m)	H = 100 actual error (%)	H = 250 relative x_{max}(m)	H=250 estimated x_{max}(m)	H = 250 relative error (%)
A	9.85	10.20	3.6	132.6	122.76	7.4	231.7	213.71	7.8
B	31.05	30.98	0.23	667	645.73	3.2	1605	1542.80	3.9
C	40.40	40.80	1.0	1159.2	1145.19	1.2	3171	3107.56	2.0
D	64.55	67.42	4.4	2537.1	2607.76	2.8	7696.5	7864.84	2.2
E	101.10	102.28	1.2	6368.5	8285.11	30.1	41722.5	81308.53	94.9

Table 11: Accuracyof the calculation of C_{max} by using power law method

Stability class	H = 5 actual C_{max} 10^{-4} (g m^{-3})	H = 5 estimated C_{max} 10^{4}(g m^{-3})	H = 5 relative error (%)	H = 100 actua C_{max} 10^{-4}(g m^{-3})	H = 100 estimated C_{max} 10^{-4}(g m^{-3})	H = 100 actual error (%)	H = 250 relative C_{max} 10^{-4}(g m^{-3})	H=250 estimated C_{max} 10^{-4}(g m^{-3})	H = 250 relative error (%)
A	96	96	0	0.24	0.24	0	0.035	0.035	0
B	96	96	0	0.24	0.24	0	0.035	0.035	0
C	84	85.8	2.14	0.21	0.21	0	0.0307	0.03	2.28
D	60.3	64.37	6.74	0.1608	0.1609	0.06	0.0256	0.0256	0
E	17	18.12	6.58	0.039	0.0453	15.38	$9.21*10^{-7}$	$9.21*10^{-7}$	0

Table 12: Accuracy of the calculation of C_{max} standard method

Stability class	H = 5 actual C_{max} 10^{-4} (g m^{-3})	H = 5 estimated C_{max} 10^{4}(g m^{-3})	H = 5 relative error (%)	H = 100 actua C_{max} 10^{-4}(g m^{-3})	H = 100 estimated C_{max} 10^{-4}(g m^{-3})	H = 100 actual error (%)	H = 250 relative C_{max} 10^{-4}(g m^{-3})	H=250 estimated C_{max} 10^{-4}(g m^{-3})	H = 250 relative error (%)
A	1545.50	- 2950	290	159.253	42.783	73.13	1.56611	0.35898	77
B	1212.28	1249.9	3.1	38.9136	41.563	6.8	23.627	-26.807	213
C	368.313	324.175	11.98	16.3842	7.3607	55.07	1.27759	0.49106	61.5
D	1625.53	-1804.4	211	68.5025	-8.1635	111.9	45.7823	0.000718	99.9
E	1204.35	-1603.9	233	0.010702	-0.000968	109	$2.7*10^{-29}$	-5.25	$1.94*10^{-29}$

concentration 10^{-4} (g m^{-3}) in Power law and standard methods. We can conclude that the maximum estimated and absolute maximum ground concentration using power law method is better than using standard. This work shows that when we used the method of the power law, standard method, Klug and Pasquill-Gifford system are better than Brigg's model method with respect to the presented error[6]. Then one can deduce that the best values for the estimation x_{max} be observed at the lower x_{max} value (Fig. 5 and 6).

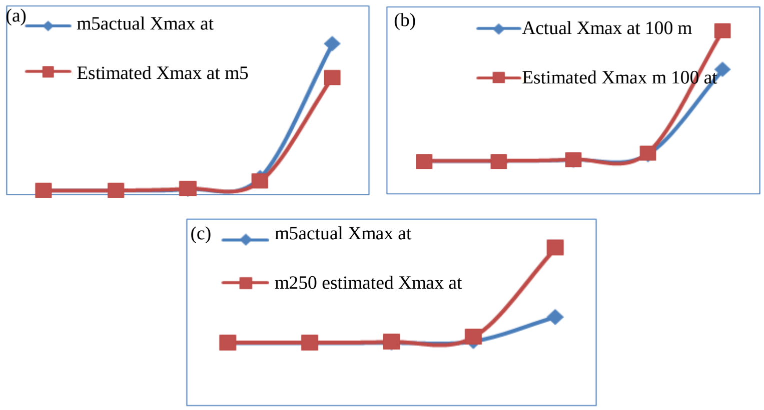

Fig. 1: The variation of the maximum estimated and actual downwind distance (m) using power law

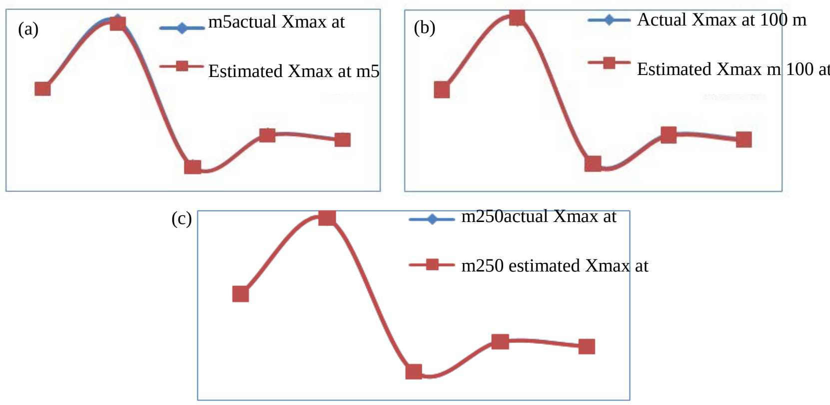

Fig. 2: The variation of the maximum estimated and actual downwind distance (m) in the standard method

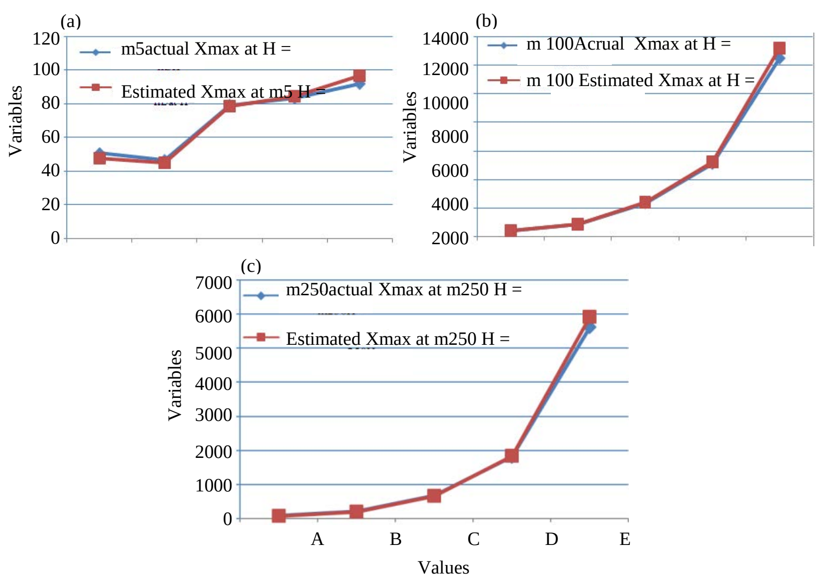

Fig. 3: The variation of the maximum estimated and actual downwind distance (m) in the Klug system

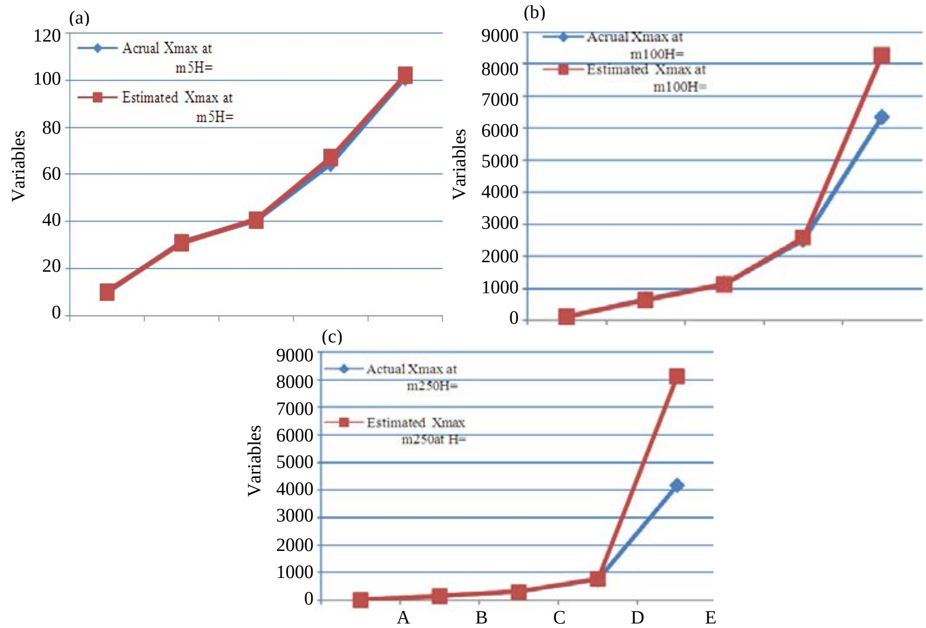

Fig. 4: The variation of the maximum estimated and actual downwind distance (m) in the Pasquill-Gifford system

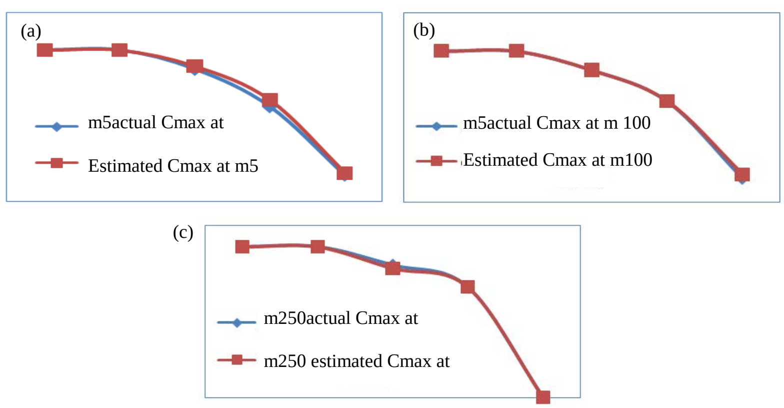

Fig. 5: The variation of absolute maximum estimated and absolute maximum ground concentration 10^{-4}(g/m^3) in Power law

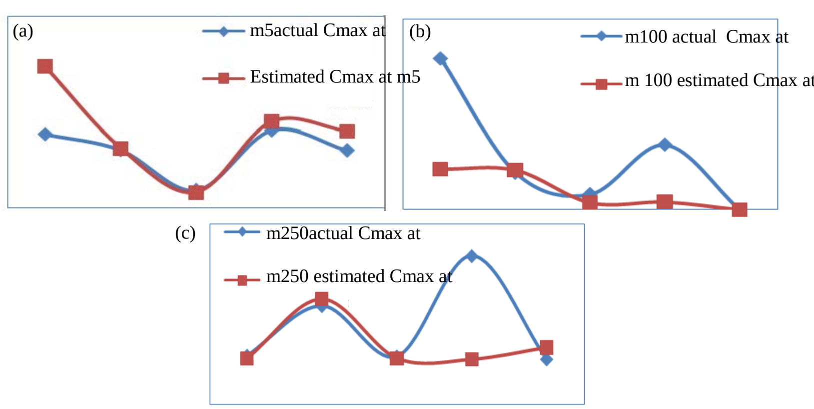

Fig. 6: The variation of maximum estimated and actual maximum ground concentration 10^{-4}(g/m^3) in standard method

CONCLUSION

In this study, the dispersion parameter and can be calculated by using four methods the power law, standard methods, Klug and Pasquill-Gifford systems at three effective height at 5, 100 and 250 m, respectively to calculate the maximum downwind distance and ground level concentration for the emission of air pollutants at point source based on Gaussian model. One finds that the percentage of the error between estimated and actual maximum downwind distance in the range of 0-492, 0.005-14.2, 0.73-6.7 and 0.23-94.9, respectively and the error in the previous work [6] in the range of 0-2713.3%. This work shows that when we used the method of power law, standard methods, Klug and Pasquill-Gifford systems are better than Brigg's model method with respect to the presented error. Then one can deduce that the best values for the estimation x_{max} be observed at the lower x_{max} value and vice versa.

For the maximum concentration, one finds that the errors are in the range of 0-15.38 and 3.1-290 in power law and standard methods respectively. Also from the figures, we conclude that the estimated and actual maximum downwind distances are in good agreement in all stabilities except stable condition for power law method than standard method.

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