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Paper Authors

K. Pujakrishnamurali, A. Kameswara Rao, A. Chandra Kala

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Dispersion Coefficients For Puff at Different Stability Conditions

K. Pujakrishnamurali* and A. Kameswara Rao, A.Chandra Kala

Department Of Civil Engineering, GAYATRI VIDYA PARISHAD COLLEGE OF ENGINEERING
(Autonomous) Madhurawada visakhapatnam-53004.

*Email: 18131d9106@gvpce.ac.in chandrakalaadireddy@gvpce.ac.in

Mobile: +91 8106193783

+91 9618614903

Abstract: Slade gave 3 sets of dispersion coefficients for puff i.e, for Unstable, Neutral & Very Stable conditions for 100m and 4000m spread along wind direction. These dispersion coefficients were adopted for stabilities B,D&F respectively. The dispersion coefficients for the remaining 3 stabilities i.e, A,C&E were arrived at by comparing the puff dispersion with the corresponding plumes Pasquill-Gifford had given curves for the different plume spread during A to F stabilities in the same way dispersion curves for puff are plotted for stabilities A to F.

Key words: Air pollution; Gaussian plume model; Gaussian puff model; Mathematical modelling.

Introduction

A plume is a continuous emission from a stack. Plume goes along direction of wind (x-axis) and gets dispersed along the direction traverse to the direction of wind (y-axis) and along the vertical direction (z-axis). A plume is regarded as number of puffs ejected out in quick succession. A plume is discredited into segments and the segmented plume is considered as a puff. Gaussian plume model is used to find out the concentrations of the pollutants. Martin dispersion coefficients are used for plume. Slade's dispersion coefficients of puff are taken at 100m and 4000m. A relationship is established between plume and puff for different stability conditions [1].

For any air pollution model, there are certain assumptions that are to be considered. The meteorology places a key role for modeling. All the meteorological factors like wind velocity, wind direction, solar radiation, cloud cover, stability, mixing height etc are to be considered. The criteria are briefly discussed in air pollution engineering manual [2].

One the first dispersion models in older days (later known as ALMANAC) gives

information about the height of stacks or chimneys to be placed to avoid the ground level concentrations [3]. The information regarding the weather conditions were also briefly discussed.

Atmospheric dispersion modeling system (ADMS) is a model created to find out the concentration of pollutants released from stack. By giving the data of meteorology, the concentration can be calculated. This model can be used for both plume and puff. This model helps in knowing the concentrations of air pollutants easily by taking the input data [4]. The work book of atmospheric dispersion estimates the concentration of pollution emitted from continuous sources for a particular period of time. The hand book states about the estimation of stack height and concentration estimation for point, line and area sources [5]. The parameters required for atmospheric dispersion model are stated. The dispersion coefficients required for the modeling are studied [6].

The box model is used for finding out the concentration of air pollutants emitted

from a city. The whole city is considered as a box. The amount of pollutants entering and leaving the city is collected. And the concentration is found out to know the pollutant level in the city [8]. Gaussian plume model is widely used air pollution model for finding out the concentrations of the pollutants as it gives relatively better results. The dispersion coefficients are required to use the Gaussian model. So the dispersion coefficients given by pasquill are used. And the maximum concentrations are found out [9,10]. The dispersion of air pollutants generally takes place in the wind direction. In any model, x-axis is considered as wind direction. The concentration of pollutants gets dispersed as the pollutants move away from the stack. The change of concentration with distance is given by martin [11].

The dispersion of the pollutants depends on the stability conditions prevailing at the particular time at a particular place. There are six stability conditions. Plume has dispersion coefficients for all the six stability conditions. Puff has dispersion coefficients only for three stabilities. And there is no much research done on puff. The major difference between plume and puff is puff has a time factor, but plume has no time factor[12].

Case Study

Bhopal gas tragedy:

The Bhopal disaster, also known as the 'Bhopal Gas Tragedy', was a gas leak incident in India, considered as the world's worst industrial disaster. This industrial disaster not only causing air pollution, it is also responsible for loss of lives. The industrial disaster occurred on the night of 2.12.1984 in Bhopal. A poisonous gas called methyl isocyanides (MIC) leaked from a tank in pesticide manufacturing factory. The factory is owned by Union Carbide India Ltd. By 10 p.m water started entering into tank no.610 containing 42 tonne initiating an exothermic

reaction raising the temperature to 200c and also raising the pressure. By 10.30 p.m the gas started leaking into the tank resulting in the formation of huge cloud of MIC. The MIC gas was blown in the S-W direction over the old city. It travelled 5-7 km spreading over an area of 25 km². People woke up with burning sensation in their lungs. More than 20,000 people were died. And more than 3 lakh people were affected by gas. Even today i.e. 2 decades after the tragedy 1, 50,000 are in need of medical attendance and one person a day dies because of the gas exposure related decease. The disaster took place on winter night and temperature inversion engulfed the entire area preventing vertical dispersion. Horizontal spread rapidly occurred over an area of 40 km² and radical to distance of 5 to 8 km. Air pollution episodes occur only during night time and that too in winter[17,18].

Visakhapatnam Gas Leak:

LG Polymers were setup in Venkatapuram village near Gopalapatnam on the outskirts of Visakhapatnam, Andhra Pradesh, India, in 1967 in an area free from human habitation. Mushroom growth of housing colonies with no norms or regulation occurred during the last 53years. The industry expanded its production with new units producing hazardous intermediate products with or without the knowledge of the city planning trust. The Visakhapatnam gas leak was an industrial accident that occurred at the lg polymers chemical plant in R.R.Venkatapuram village near Gopalapatnam on the outskirts of Visakhapatnam, Andhra Pradesh, India, during the early morning of 7 May 2020. The resulting vapor cloud spread over a radius of about three kilometers, affecting the nearby areas and villages. As per the National Disaster Response (NDRF) the death roll was 11, and more than 1000 people became sick after being exposed to gas. Disasters occur either due to negligence or

lack of proper maintenance. The industries should be well equipped to meet industrial hazards emergency that is accidental release of any hazardous and inflammable gases. Chembur of Mumbai has clear air today which was a gas chamber earlier. We expect our cities to have industries to feed a few mouths but should not kill many by letting off hazardous wastes. Gaseous pollutants including particulate matter may spread over the entire city with varied range of concentration. People may co-exist with these air pollutants within safe limits. It is the job of the city administration and industrial management to see that the public are not

Fig:1 A Plume

Atmospheric Stability

Stability is the tendency of the atmosphere either to resist or to enhance vertical motion or turbulence of air. It controls vertical dispersion of the air pollutants[19].

Table1: Types of stabilities

Intensity	Stability
Highly unstable	A
Moderately unstable	B
Unstable	C
Neutral	D
Stable	E
Moderately stable	F

Stability A: It is supposed to occur during the Day time with clear sky. When strong or

affected because of these pollutants. To assess the concentrations of the pollutants at different places from the source a number of models are available. A relative study of the most acceptable models is here with studied[18].

Plume:

A plume is a continuous emission out of the industrial stack. It goes along the direction of wind (X-axis) and gets dispersed along a horizontal direction transverse to the direction of wind (Y-axis) and along the vertical direction (Z-axis).The dispersion coefficients for different distances from the source are given by Pasquill-Gifford curves[7].

moderate solar isolation occurs around the noon of summer, this stability is seen. The wind velocity will be $< 3\text{m/s}$. Temperature falls at more than 1.9°C per 100m rise of altitude. It is highly desirable condition as the pollutants are made to drift away from the stack, emitting them and dispersed and diluted over a longer height of infinite atmosphere. However its duration is much short lived, spreading for about 1 to $1\frac{1}{2}$ hour on either side of noon in summer.

Stability B: It occurs during the clear, sunny day time when strong or moderate solar insolation with the velocity of the blowing wind at 1 to 5m/s . Its temperature gradient lies between -1.9 to $-1.7^\circ\text{C}/100\text{m}$ rise.

Stability B is likely to occur for most part of the day i.e. before and after stability A for double its duration on sunny day.

Stability C: It occurs during the day time when moderate insulation and a wind velocity between 3 to 7m/s and slight solar isolation but wind velocity is between 2 and 5m/s . Temperature gradient lies between -1.7°C to $-1.5^\circ\text{C}/100\text{m}$ rise. Stability C precedes stability B at dawn and succeeds it at dusk for 1 to $1\frac{1}{2}$ hour.

Stability D: When ELR is very close to DALR, the stability is said to be Neutral.

While unstable conditions cannot occur during night and stable conditions may not occur during day time – Neutral stability may occur any time i.e. both during day and night.

Stability E: When ELR is more than DALR this situation occurs. It occurs because of sub adiabatic lapse rate and the lapse rate is said to be weak indicating minimum vertical dispersion. It occurs only during nights when the sky has >50% clouds with wind velocity between 2 and 3m/s and sky had less than 40% clouds with wind velocity of 3 to 5m/s. The temperature gradient is -0.5°C to 1.5°C/100m.

Stability F: It occurs when <40% of clouds spreading in sky with a velocity of wind between 2 and 3m/s. Temperature gradient is 1.5°C to 4°C/100m rise i.e. inversion. The dispersion of air pollutants is confined to horizontal plane at a low phase and no vertical dispersion occurs.

Meteorology

Pollutants in air travel depending on the moments of air in the atmosphere. This is called as dispersion of pollutants. The dispersion of pollutants depends on the weather patterns called meteorology. In the study air quality, it is important to measure the following factors that help in understanding the mode of dispersion that occur in the atmosphere such as Wind speed and direction, Solar radiation, Temperature, Atmospheric stability, Mixing height[16].

Plume Dispersion Curves

Fig 2: Graph between distance and σ_y

Fig 3: Graph between distance and σ_z

$$\sigma_y = a \cdot X^b$$

$$\sigma_z = c \cdot X^d + f$$

martin analysed them numerically[7,20].

Table 2: Martin's Dispersion Coefficients:

Stability Class	$X < 1\text{Km}$				$X > 1\text{Km}$		
	A	C	D	F	C	D	F
A	213.00	440.80	1.941	9.27	459.70	2.094	-9.6
B	156.00	106.60	1.149	3.30	108.20	1.098	2.00
C	104.00	61.00	0.911	0.00	61.00	0.911	0.00
D	68.00	33.20	0.725	-1.70	44.50	0.516	-13.00
E	50.50	22.80	0.678	-1.30	55.40	0.305	-34.00
F	34.00	14.35	0.740	-0.35	62.60	0.180	-48.60

Puff:

Puff is an instantaneous intermittent emission whose dispersion is related to time unlike a plume. The dispersion coefficients of a puff are different and smaller values of a plume. It may be because of closed shape of the puff compared to the free expanding conical diverging shape of the plume of infinite length[13,14].

Fig 4: Puff dispersion

- ☐ A puff is a closed figure expanding in all the three directions as it spreads.
- ☐ A puff is a 3-D mass expanding over a centre which travels along a trajectory.
- ☐ A puff is an instantaneous ejection whose time of emission is less compared to time of travel.
- ☐ A puff shall be emerging out after the explosion of a tank containing the vaporous fluid.

Table 3: Slade's dispersion coefficients of puff

Stability	Dispersion coefficient at 100m		Dispersion coefficient at 4000m	
	p (m)	q(m)	p(m)	q(m)
Unstable	10	15	300	220
Neutral	4	3.8	120	50
Very stable	1.3	0.75	35	7

Methodology

A Plume of dispersion coefficient, σ_y along y axis and σ_z along z axis is segmented at intervals of $u \cdot dt$ where u is wind velocity (a constant) and dt is the time interval (variable with distance) volume = $\pi \sigma_y \sigma_z u \cdot dt$

Its volume is equated to a corresponding volume of puff of ellipsoidal shape of dispersion coefficient of p along X and Y axis and q along Z axis = $(4/3) \cdot \pi \cdot p \cdot p \cdot q$

The three values given by Slade were adopted for stabilities B, D and F as in after assuming exponential propagation. i.e. $p=a \cdot x^b$ and $q=c \cdot x^d$ [15].

Table 4: Dispersion Coefficients for Puff.

STABILITY	For $x > 1km$	For $x < 1km$
B	$p = 83.55 \cdot x^{0.922}$	$p = 83.55 \cdot x^{0.922}$
	$q = 80.197 \cdot x^{0.728}$	$q = 80.197 \cdot x^{0.728}$
D	$p = 30.13 \cdot x^{0.922}$	$p = 30.13 \cdot x^{0.922}$
	$q = 19.04 \cdot x^{0.7}$	$q = 19.04 \cdot x^{0.708}$
F	$p = 10.124 \cdot x^{0.893}$	$p = 10.124 \cdot x^{0.895}$
	$q = 3.014 \cdot x^{0.6055}$	$q = 3.014 \cdot x^{0.606}$

To assess the dispersion coefficients for the other three Stabilities parameters for respective plumes are taken into account. Assuming stability C to lie between stability Band

stability D, its dispersion coefficients are analyzed. Similarly, assuming dispersion coefficients of E to lie between those of D and F they are found out. Having found out the dispersion coefficients of C and those of B already available, dispersion coefficients of A maybe analyzed by assuming them to lie away from B and far away from C [16].

Table 5 : Dispersion Coefficients for remaining three stabilities

Stability	For $x > 1km$	For $x < 1km$
A	$p = 157.9 \cdot x^{0.941}$	$p = 157.9 \cdot x^{0.941}$
	$q = 1039.23 \cdot x^{1.04}$	$q = 1039.23 \cdot x^{1.019}$
C	$p = 55.7 \cdot x^{0.922}$	$p = 55.7 \cdot x^{0.922}$
	$q = 40.01 \cdot x^{0.711}$	$q = 40.01 \cdot x^{0.717}$
E	$p = 24.78 \cdot x^{0.908}$	$p = 24.78 \cdot x^{0.908}$
	$q = 9.75 \cdot x^{0.653}$	$q = 9.75 \cdot x^{0.6401}$

puff has an additional advantage of involving time factor unlike a plume ,it had an additional advantage of spreading through greater length than of a plume. The plume had different dispersion coefficients for different stabilities of A to F which are plotted graphically by Pasquill-Gifford

Results

Table 5: A to F stabilities Correlation between plume and puff ($x > 1km$)

Stability	For $x > 1Km$	For $x < 1Km$
A	$p = 157.9 \cdot x^{0.941}$	$p = 157.9 \cdot x^{0.941}$
	$q = 1039.23 \cdot x^{1.04}$	$q = 1039.23 \cdot x^{1.019}$
B	$p = 83.55 \cdot x^{0.922}$	$p = 83.55 \cdot x^{0.92}$
	$q = 80.197 \cdot x^{0.728}$	$q = 80.197 \cdot x^{0.7282}$
C	$p = 55.7 \cdot x^{0.922}$	$p = 55.7 \cdot x^{0.922}$
	$q = 40.01 \cdot x^{0.711}$	$q = 40.01 \cdot x^{0.717}$
D	$p = 30.13 \cdot x^{0.922}$	$p = 30.13 \cdot x^{0.922}$
	$q = 19.04 \cdot x^{0.7}$	$q = 19.04 \cdot x^{0.708}$
E	$p = 24.78 \cdot x^{0.908}$	$p = 24.78 \cdot x^{0.908}$
	$q = 9.75 \cdot x^{0.653}$	$q = 9.75 \cdot x^{0.6401}$
F	$p = 10.124 \cdot x^{0.893}$	$p = 10.124 \cdot x^{0.895}$
	$q = 3.014 \cdot x^{0.6055}$	$q = 3.014 \cdot x^{0.606}$

Stability A

$$\sigma_y = 213 * x^{0.894}$$

$$\sigma_z = (459.7 * x^{2.094}) - 9.6$$

$$p = 157.94 * x^{0.941}$$

$$q = 1039.23 * x^{1.04}$$

Table 6: Correlation for stability A at X>1km

x (km)	sig y	sig z	p	q	u.dt
1	213	450.1	157.9	1039.23	360.3513
2	395.8224	1952.998	303.1457	2136.893	338.7054
3	568.756	4577.798	443.9696	3257.75	328.8368
4	735.5653	8369.322	581.9968	4393.939	322.3461
5	897.9637	13359.98	717.9809	5541.668	317.4976
6	1056.931	19575.38	852.3588	6698.676	313.6285
7	1213.102	27036.82	985.4155	7863.459	310.4118
8	1366.917	35762.54	1117.351	9034.94	307.6615
9	1518.701	45768.56	1248.315	10212.31	305.2612
10	1668.705	57069.16	1378.422	11394.93	303.1333
11	1817.124	69677.24	1507.761	12582.3	301.2232
12	1964.118	83604.6	1636.408	13774	299.4915
13	2109.818	98862.07	1764.423	14969.69	297.9082
14	2254.333	115459.7	1891.858	16169.06	296.4505
15	2397.757	133406.9	2018.757	17371.87	295.1004
16	2540.17	152712.5	2145.157	18577.89	293.8434
17	2681.643	173384.6	2271.091	19786.94	292.6678
18	2822.235	195431.2	2396.589	20998.83	291.564
19	2962.002	218859.5	2521.676	22213.42	290.5239
20	3100.99	243676.8	2646.375	23430.57	289.5407

Here the horizontal dispersion of pollutants in x direction are considered below 1km.

Stability A

$$\sigma_y = 213 * x^{0.894}$$

$$\sigma_z = (440.8 * x^{1.941}) + 9.27$$

$$p = 157.94 * x^{0.941}$$

$$q = 1039.23 * x^{1.019}$$

Table 7: correlation for stability A at X<1km

x (km)	sig y	sig z	p	q	u.dt
0.1	27.18815	14.31942	18.09223	112.9092	111.5141
0.2	50.52431	28.65835	34.73452	201.5864	223.9603
0.3	72.59823	51.86258	50.87018	304.7181	279.2437
0.4	93.89041	83.71577	66.68537	408.5176	308.1642
0.5	114.6196	124.0701	82.26648	512.8166	325.4023
0.6	134.9108	172.8135	97.66354	617.5154	336.8427
0.7	154.845	229.8555	112.9092	722.5478	345.0738
0.8	174.4786	295.1207	128.0265	827.8666	351.3638
0.9	193.8529	368.544	143.0324	933.4365	356.3936
1.0	213	450.07	157.94	1039.23	360.5579

Graphs:

Fig 7. Graph between distance (x) and p

Fig 8-graph between distance(x) and q

Table 8: Correlating u.dt values for different stability conditions of puff x>1km

x (km)	A	B	C	D	E	F
1	360.3513	43.4194	26.08882	10.75931	7.386536	0.865325
2	338.7054	65.5392	43.876	21.00629	13.6737	1.532619
3	328.8368	83.171	59.46966	31.73083	20.52638	2.267279
4	322.3461	98.4202	73.79034	42.79775	27.75473	3.042647
5	317.4976	112.117	87.23324	54.13955	35.2865	3.850443
6	313.6285	124.694	100.0156	65.71337	43.07845	4.686029
7	310.4118	136.411	112.2737	77.48902	51.10052	5.546251
8	307.6615	147.439	124.1001	89.44394	59.33015	6.428764
9	305.2612	157.899	135.5615	101.5605	67.74959	7.331726
10	303.1333	167.88	146.7082	113.8244	76.34442	8.253643
11	301.2232	177.447	157.5792	126.2242	85.10267	9.193268
12	299.4915	186.655	168.2056	138.7498	94.01414	10.14954
13	297.9082	195.544	178.6126	151.3929	103.0701	11.12155
14	296.4505	204.15	188.8211	164.1463	112.2629	12.1085

15	295.1004	212.501	198.8488	177.0037	121.5858	13.10968
16	293.8434	220.62	208.7106	189.9595	131.0328	14.12447
17	292.6678	228.529	218.4194	203.0086	140.5986	15.1523
18	291.564	236.244	227.9864	216.1467	150.2784	16.19267
19	290.5239	243.78	237.4213	229.3697	160.0677	17.24511
20	289.5407	251.152	246.7329	242.6741	169.9626	18.30919

Table 9: Correlating u, dt values for different stability conditions of puff $x < 1 \text{ km}$

$x \text{ (km)}$	A	B	C	D	E	F
0.1	111.5141	9.244245	4.575668	1.635796	1.242937	0.168638
0.2	223.9603	16.00871	7.727396	2.72177	2.01257	0.26926
0.3	279.2437	21.13224	10.49925	3.783559	2.745355	0.358624
0.4	308.1642	25.39125	13.05004	4.821638	3.44994	0.441175
0.5	325.4023	29.10902	15.44813	5.841204	4.133453	0.518958
0.6	336.8427	32.45037	17.73115	6.845964	4.800425	0.593126
0.7	345.0738	35.51145	19.92272	7.838505	5.453893	0.66441
0.8	351.3638	38.35372	22.03893	8.820695	6.096008	0.73331
0.9	356.3936	41.01916	24.09139	9.793936	6.728363	0.80019
1	360.5579	43.5379	26.08882	10.75931	7.35218	0.865325

It may be noticed that u, dt values for different stabilities were following a regular pattern for distances 0 to 20km either increasing or decreasing with distance also they followed a decreasing pattern from stability A to stability F.

Conclusions:

Under different stability conditions puff may be conveniently adopted to get detailed dispersion particulars of a plume when segmented under different stability conditions. the segmentation is adopted at different time intervals of dt . a segmented plume form an individual puff. Dispersion coefficients for stabilities A to F of puff are derived analytically. graphical dispersion of puff are drawn accordingly for dispersion of stabilities A to F. puff had an additional advantage of involving time factor unlike a plume it has an additional advantage of spreading for greater length than as plume.

Often in accidents, the releases are essentially instantaneous and no plume develops.

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