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POLLUTANTS EMISSION AND DISPERSION FROM ELEVATED GAS FLARE: C.S. OF AGHAJARY

SAMAD JAFARMADAR[1] AND ALIREZA SHAYESTEH NEZHAD[2]

[1] Department of Mechanical Engineering, University of Urmia, Urmia, Iran
[2] Oil & Gas Department, National Iranian South Oil Company, Ahwaz, Iran

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ABSTRACT

The purpose of this research is to study the emission and dispersion of hydrogen sulfide gas (H_2S) from elevated flare in Aghajary compression station. This flare is used only during shut-down or start-up. This flare has ignition system, when the feed gas discharged to the flare will be ignited by sparks. It is very likely that the ignition system does not work or ignition is delayed. In this situation H_2S may come down to the ground level and if it's concentration be greater than 8 ppm it can endanger human health and lead to death. Gaussian-based dispersion models are widely used to estimate local pollution levels. The accuracy of such models depends on stability classification schemes as well as plume rise equations. A general plume dispersion model for a point source emission, based on Gaussian plume dispersion equation, was developed. A mathematical model formulated in a computer program written in Pascal language was utilized in finding the ground level concentrations of H_2S emitted from the elevated flare and final results compare with PHAST software results.

INTRODUCTION

Air pollution is dangerous problem facing humans, and it caused great harmful which may cause death especially when it is higher than the critical environmental limits of pollutants. Oil and gas activities is one of the most important pollution source and very toxic gas emitted in environment in this industry. A large number of oil reservoirs have hydrogen sulfide gas in their components. H_2S during the oil processing is separated from oil, if there are processing facilities sent to refinery otherwise discharge to flare for burning, as well as in shut down and stat up usually gas sent to flare. The flares system is safety equipment necessary in petroleum plants. Flares are designed to avoid the uncontrolled emissions. It is used for two cases related strongly with safety, one of them is during the unstable operations such as start-up, shutdown of unit operations; the second case is to management the waste gases discharged from routine production operations. Elevated flare is a one type of flares, it is a vertical pipe opened from its top sup-

*** Corresponding author's email :** Shayestehnezhad.a@gmail.com

plied with igniters.

The waste or discharged gases are burned with atmospheric air at the tip of flare stack.Aghajary compression station is located in south of Iran, it's flare is elevated type with ignition system and during uncontrolled process or in shut down and start-up is used.In this investigation dispersion of H_2S emitted from this flare at ignition failure has been study. Gaussian model written in Pascal language and PHAST software is used for gas dispersion study . The programmed model and software model takes into consideration the meteorological conditions (wind speed, ambient temperature, and atmospheric stability) which may take place at the study region. According to OSHA standard the maximum H_2S allowable ground level concentration(MGLC) for 8 hours working is 8 ppm and for 10minutes is 20-50 ppm and 100 ppm dangerous for life Health immediately. Table1 shows the feed gas composition and specifications of flare and ambient condition are shown in Table 2.

One of the research at this case belong to Hatam Asal Gzar and Khamaal Muhsin Kseer (2009) in this research they studied pollution emission and dispersion from several flare in Iraq by using Gaussian model. Seema Awasthi, Mukesh Khare and Prashant Gargav (2006) studied the pollution dispersion of power plant flare by using Gaussian model.

Theoretical Basis of dispersion air pollutants emitted from flares

Mathematical model formulating in a computer program written in Pascal language using Gaussian equation is utilized to investigate the dispersion process and distribution of pollutants (H_2S) emitted from the elevated flare. With Gaussian equation(1) the ground level concentrations of H_2S is determined.

$$C = \frac{Q}{2\pi u\sigma_y\sigma_z}\exp\left[-\frac{y^2}{2\sigma_y^2}\right]\left\{\exp\left[-\frac{(H-z)^2}{2\sigma_z^2}\right]+\exp\left[-\frac{(H+z)^2}{2\sigma_z^2}\right]\right\} \quad (1)$$

Where,
C : Air pollutant concentration in mass per volume (g/m^3)
Q : Pollutant emission rate in mass per time (g/s)
u : Wind speed at point of release (m/s)
y : Crosswind direction standard deviation of the concentration distribution at downwind distance x
z : Vertical direction standard deviation of the concentration distribution at downwind distance x
y : Horizontal distance from plume centerline (m)
H : Effective height of the centerline of the pollutant plume
z : Vertical distance from the ground level (m)

The Maximum Ground Level Concentration (MGLC) is usually of interest. It will occur at some downwind distance right below the centerline of the plume (y = 0, z = 0) then Eq. (1) is reduced to:

$$\left(\frac{Cu}{Q}\right)_{ground} = \frac{1}{\pi\sigma_y\sigma_z}\exp\left[-\frac{(H)^2}{2\sigma_z^2}\right] \quad (2)$$

Table 1. feed gas composition and specifications of flare

Composition/spec.	Mas fraction
C1	0.8327
C2	0.0692
C3	0.0316
C4	0.104 +
N2	0.0210
CO2	0.0263
H2S	0.0088
T(C)	38
MW	19.67
Height of flare(m)	70
Diameter(mm)	1067
FLOW RATE(MMSCFD)	620

Table 2. Ambient condition

Parameter	Quantity
Average ambient temperature (°C)	24.5
Average ambient wind velocity (m/s)	4
Average ambient humidity(%)	46

Correlation for MGLC

Using Eq. (2) to calculate MGLC requires one to generate repetitious solution. In order to approximate MGLC, without calculating Eq. (2), many times a correlation formula has been generated by using the MGLC graph presented in the Workbook is been used]. The values of the constants are listed in Table 3.

$$\left(\frac{Cu}{Q}\right)_{max} = \exp\left[a + b(\ln H) + c(\ln H)^2 + d(\ln H)^3\right] \quad (3)$$

Where,
(Cu/Q)max : maximum ground level concentration
a,b,c,d : Coefficients for a given stability condition

H : Effective height of the centerline of the pollutant plume (m)

Calculating the distance correspond to MGLC, xmax is also important. Eq.(4) for xmax are developed using the same regression and format of equation as Ranchoux's book.

$$x_{max} = \exp\left[a + b(\ln H) + c(\ln H)^2 + d(\ln H)^3\right] \tag{4}$$

Table 3. Values of the coefficients for Ranchoux's equation

Stability Class	Coefficients			
	a	b	c	d
A	-1.0563	-2.7153	0.1261	0
B	-1.8060	-2.1912	0.0389	0
C	-1.9748	-1.9980	0	0
D	-2.5302	-1.5610	-0.0934	0
E	-1.4496	-2.5910	0.2181	-0.0343
F	-1.0488	-3.2252	0.4977	-0.0765

Numerical simulation method

The modeling of dispersion of air pollutants from an industrial source can be broken down into the following steps:

1. Describing the geometry of the domain.
2. Introducing appropriate boundary conditions
3. Introducing of sources, sink*s and the dispersion characteristics for the entire domain.
4. Selection of values for parameters in the model.
5. Division of the domain into cells and solution of the finite difference equations.
6. Visualization of results.

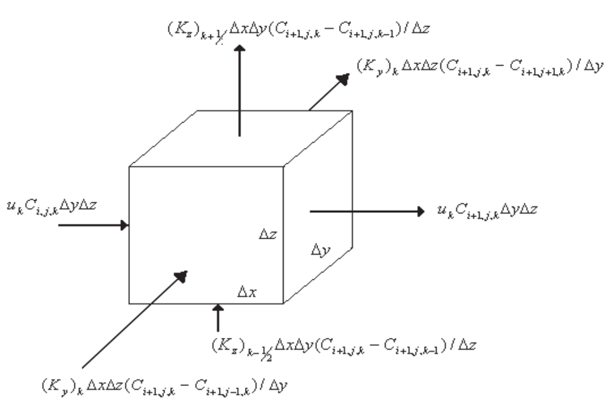

Fig. 1 Mass balance for an unknown cell

In this study a Multiple Cell Model was used for pollution dispersion from an industrial stack emissions. Figure (1) shows the mass balance for an unknown cell.

$$\frac{\partial C}{\partial t} = -\frac{\partial(uC)}{\partial x} - \frac{\partial(vC)}{\partial y} - \frac{\partial(wC)}{\partial z} + \frac{\partial}{\partial x}(K_x\frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(K_y\frac{\partial C}{\partial y}) + \frac{\partial}{\partial z}(K_z\frac{\partial C}{\partial z}) + E_s - (k_{1_s} + k_{2_s})C + Q_s(c_1, c_2, \ldots, c_q), \quad s = 1,2,\ldots,q \tag{5}$$

Five major physical and chemical processes are to be considered when an air pollution model is developed. These processes are: (i) horizontal transport (advection), (ii) horizontal diffusion, (iii) deposition (both dry deposition and wet deposition), (iv) chemical reactions plus emissions and (v) vertical transport and diffusion. The mathematical description of these processes leads to a system of partial differential equation:

Where,

C : the concentration of the chemical species involved in the model

u, v and w : wind velocities

K_x, K_y and K_z : diffusion coefficients

E_s : the emission sources

K_{1s} and K_{2s} : deposition coefficients (for the dry deposition and the wet deposition, respectively)

$Q_s(c1, c2, \ldots, cq)$: chemical reactions.

Assumptions

For this kind of systems, the following assumptions are employed:

1. Steady state condition
2. v=w=0
3. Transport by bulk motion in the x-direction exceeds diffusion in the x- direction ($K_x=0$)
4. There is no deposition in system ($K_{1s}=K_{2s}=0$)
5. There is no reaction in system ($Q_s=0$)

By applying the above assumptions, Eq. (5) reduces to:

$$\frac{\partial(uC)}{\partial x} = \frac{\partial}{\partial y}(K_y\frac{\partial C}{\partial y}) + \frac{\partial}{\partial z}(K_z\frac{\partial C}{\partial z}) + E_s \tag{6}$$

Initial and Boundary Conditions

For solving Eq. (6), the following initial and boundary conditions are used:

at x = 0, $C(0,j,k)=0$

at y = 0, $\dfrac{\partial C}{\partial y} = 0$

at y = W, $\dfrac{\partial C}{\partial y} = 0$

at z = 0, $\dfrac{\partial C}{\partial z} = 0$

at z = mixing length , $\dfrac{\partial C}{\partial z} = 0$

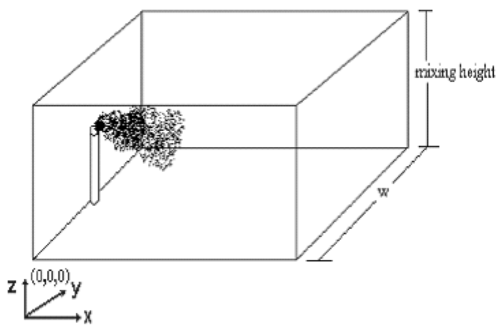

Fig. 2 Domain used in simulation for flare stack

For solving the mathematical model, the finite difference method is used. We express derivatives in terms of central differences around the point (i+1,j,k) using the counters i for the x-direction, j for the y-direction and k for the z- direction.

$$\left.\frac{\partial C}{\partial x}\right|_{i,j,k} = \frac{1}{2\Delta x}\left(C_{i+1,j,k} - C_{i-1,j,k}\right) \tag{7}$$

$$\left.\frac{\partial^2 C}{\partial y^2}\right|_{i,j,k} = \frac{1}{\Delta y^2}\left(C_{i,j+1,k} - 2C_{i,j,k} + C_{i,j-1,k}\right) \tag{8}$$

$$\left.\frac{\partial^2 C}{\partial z^2}\right|_{i,j,k} = \frac{1}{\Delta z^2}\left(C_{i,j,k+1} - 2C_{i,j,k} + C_{i,j,k-1}\right) \tag{9}$$

$$Q = q\Delta y\Delta z \tag{10}$$

$$R = rC^m \tag{11}$$

By substitution in equation (2), we have:

$$\begin{aligned} &{U_x}_k C^s_{i+1,j,k}\Delta y\Delta z + (K_y)_k \Delta x\Delta z\left(C^s_{i+1,j,k} - C^s_{i+1,j+1,k}\right)/\Delta y \\ &+ (K_y)_k \Delta x\Delta z\left(C^s_{i+1,j,k} - C^s_{i+1,j-1,k}\right)/\Delta y \\ &+ (K_z)_{k+\frac{1}{2}} \Delta x\Delta y\left(C^s_{i+1,j,k} - C^s_{i+1,j,k+1}\right)/\Delta z \\ &+ (K_z)_{k-\frac{1}{2}} \Delta x\Delta y\left(C^s_{i+1,j,k} - C^s_{i+1,j,k-1}\right)/\Delta z = {U_x}_k C^s_{i,j,k}\Delta y\Delta z + E^s\Delta y\Delta z \end{aligned} \tag{12}$$

Where, values of wind speed and eddy diffusivity are presumed known. This is an explicit algebraic formula and may be unstable in some conditions. The stability condition for this system is;

$$\Delta x \le \frac{U_x}{2K_z\left(\dfrac{5}{\Delta y^2} + \dfrac{1}{\Delta z^2}\right)} \tag{13}$$

Atmospheric Parameters

Atmospheric conditions are a driving force in the formation, dispersion and transport of pollutant plumes. For solving Eq. (12) we need atmospheric parameters like, wind speed, plume rise, stability category, dispersion coefficients, surface roughness and other parameters. Required equations and values for determining that parameters are as:

Atmospheric Stability

Stability of the atmosphere varies hourly, but for modeling purposes, for short time periods (1-3 hr) a constant and representative atmospheric stability was assumed. In this research three classes of atmosphere stability, neutral, stable and unstable are considered. Atmospheric stability is calculated by using the following equation:

$$L = -\frac{{u^*}^3 C_p \rho T}{kgH_n} \tag{14}$$

In equation (14), u^* is friction velocity, C_p is specific heat of air, T is air temperature, k is Karman's constant (k=0.4), g is gravitational constant and H_n is net heat that enters the atmosphere. Hn for neutral atmosphere is 0, for stable atmosphere is -42 and for unstable atmosphere is 175. We see that L is simply the height above the ground at which the production of turbulence by both mechanical and boundary forces is equal.

Surface Roughness and Friction Velocity

It is convenient to introduce a drag coefficient, c_g, based on the geostrophic wind, u_g, such that

$$u^* = c_g u_g \qquad (15)$$

The geostrophic drag coefficient is a function of the surface Rossby Number ($R_0 = ug / fZ0$) and L, where *f* is the Coriolis parameter of the earth and Z_0 is surface roughness. Lettau suggests the following empirical relationship for a neutral atmosphere:

$$C_g = 0.16/[\log_{10}(R_0) - 1.8] \qquad (16)$$

For stable and unstable atmosphere it must be multiplied by 0.6 and 1.2, respectively. Values of Roughness length (Z_0) and friction velocity (μ*) for several different land surfaces are presented in Heinsohn. Table (4) defines values of Roughness length (Z_o) and friction velocity (μ*) for several different land surfaces.

Table 4. Roughness lengths and friction velocity

Surface	Z_0 (CM)	$\mu^{*(m/s)}$
Very smooth (ice, mud flats)	0.001	0.16
Snow	0.0001-0.005	0.17
Smooth sea	0.0001-0.02	0.21
Level desert	0.0001-0.03	0.22
Lawn, grass up to 1 cm high	0.1	0.27
Lawn, grass up to 5 cm high	1-2	0.43
Lawn, grass up to 50 cm high	4-9	0.60
Fully grown root crops	10-14	1.75
Tree covered	100	-
Low-density residential	200	-
Central dusiness district	500-10000	-

Plume Rise

When the air contaminants are emitted from a stack, they rise above the stack before drifting a significant distance downwind. The effective stack height H is

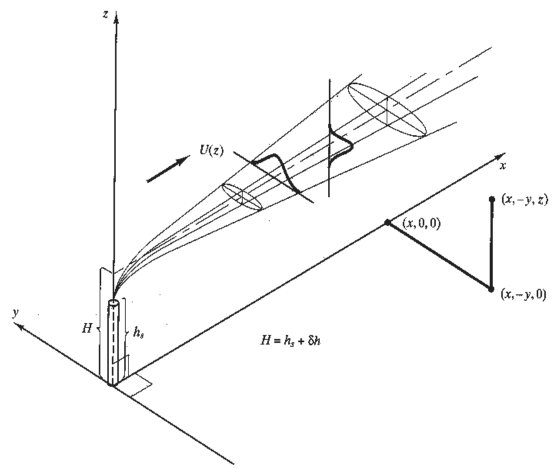

Fig. 3 Effective stack height

not only the physical stack's height hs but include also the plume rise (Fig. (3).

$$H = h_s + \delta h \qquad (17)$$

The stack height used in the calculations must be the effective stack height. Usually, Brigg's equation and Holland's equation are used for prediction of plume rise. Brigg's and Holland's equations are given by equations (34) and (35) respectively.

$$\delta h = \frac{114CF^{1/3}}{u}, \quad F = \frac{v_s g D^2 (T_s - T_a)}{4T_a}, \quad C = 1.58 \quad 41.4 \frac{\Delta\theta}{\Delta z} \qquad (18)$$

$$\delta h = \frac{v_s D}{u}\left(1.5 + 2.68 \times 10^{-3} PD \frac{(T_s - T_a)}{T_s}\right) \qquad (19)$$

Where,

v_s : stack exit velocity (m/s)
D : stack diameter (m)
u : wind velocity (m/s) measured or calculated at the height, hs
P : pressure (mbar)
Ts: stack gas temperature (K)
T_a: atmosphere temperature (K)

Wind Velocity and Dispersion Coefficients

The wind power law is used to adjust the observed wind speed, u_{ref}, from a reference measurement height, z_{ref}, to the stack or release height, hs. The power law equation is of the form:

$$u_s = u_{ref} \left(\frac{h_s}{z_{ref}} \right)^p \quad (20)$$

Where p is the wind profile exponent. Values of p may be provided by the user as a function of stability category and wind speed class.

RESULTS AND DISCUSSION

Comparison between computer program model and PHAST model is with neutral stability condition is presented in figure 5 and 6. There is good match between the two models and maximum deviation is about 11%. As is clear from these graphs after short distance from flare concentration become 1/3 and after that With a lower slope decreases As well as with increasing wind velocity mixing length decreases too.

Fig. 4 H_2S centerline concentration with u=4 m/s

Fig. 5 H_2S centerline concentration with u=8 m/s

As previously mentioned, it is very important we find MGLC for this purpose 32 different cases defined. Each case has special meteorological conditions with 45 and 70(m) flare height. We look for with which condition MGLC is greater than 8 ppm until necessary instruction to be considered. For reach our goal three stability condition, very unstable, neutral and very stable with various wind velocity are considered. All of these condition occur during the year. Tables 5 and 6 are shown MGLC and it's distance(x_{max}) for two flares.

As results at neutral condition for two flare MGLC is zero and in this condition operators have enough time to stop the operation and for other weather condition, A(very unstable) and G(very stable) MGLC not zero but concentration flare with 70 m height not greater than 8 ppm thus operator do not do any thing but it is better to end the operation for the first time. The height of Aghajary flare is 70 m and another flare with 45 m height consider for second alternative, if it is possible the height of flare reduced however, for second flare MGLC equal 8 and in situation 8 hours existing for reaction.

Other important result is, increasing wind velocity in very unstable(A) condition decrease the x_{max} and MGLC but in very stable(G) condition wind velocity increasing, decrease MGLC and increase x_{max}.

Table 5. Maximum ground level concentration for Aghajary flare

Case	Flare height	Weather category	Wind velocity	MGLC	x_{max}
01	70	A	4	5	345
02			8	3	308
03			10	3	268
04			20	5	284
05		D	4	0	—
06			8	0	—
07			10	o	—
08			20	0	—
09		G	4	7	640
10			8	3	10500
11			10	1	7200
12			20	0	—

Table 6. Maximum ground level concentration for flare with 45 m height

Case	Flare height	Weather category	Wind velocity	MGLC	x_{max}
13	45	A	4	5	335
14			8	3	300
15			8	10	160
16			8	20	105
17		D	0	4	—
18			0	8	—
19			0	10	—
20		G	20	0	—
21		G	4	8	3979
22			1	8	2000
23			1	10	5980
24			0	20	—

Contour of H_2S distributing at several cases are shown in following Figures.

Other results that can be achieved graphs about mixing length and downwind distance, at A,D and G weather conditions with increasing wind velocity mixing length is reduced but for cloud length at A condition reduction is seen and at D and G increasing. Generally, maximum cloud height in the neutral weather condition and minimum in the very stable condition, cloud height in the very stable condition is very greater than other conditions at a equal wind velocity an minimum was occurred at very unstable condition.

Because of the gas reached to the ground level at stability condition A and G, study other rang of wind velocity were important Therefore the problem was resolved for wind velocity less than 4 m/s and the

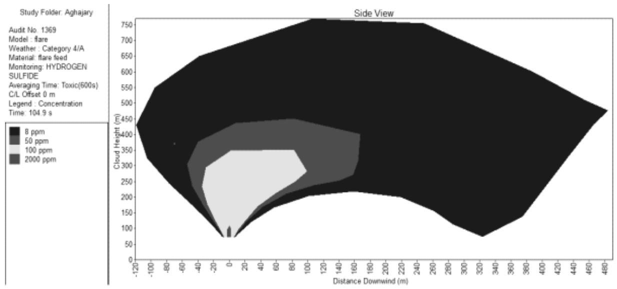

Fig. 6 H_2S distributing at case 01

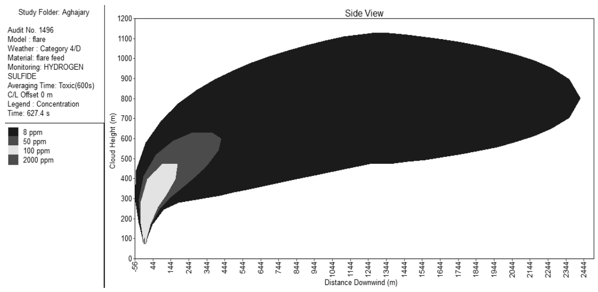

Fig. 7 H_2S distributing at case 05

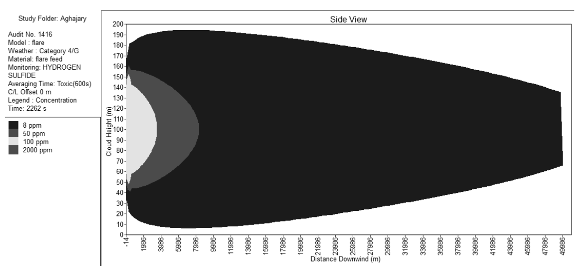

Fig. 8 H_2S distributing at case 09

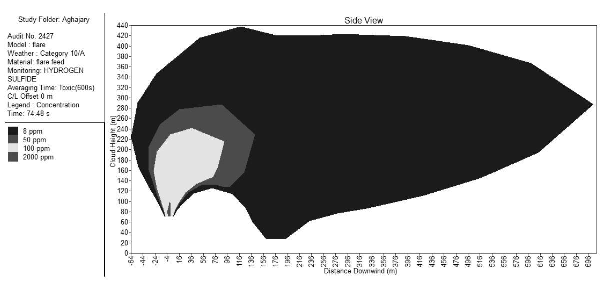

Fig. 9 H_2S distributing at case 03

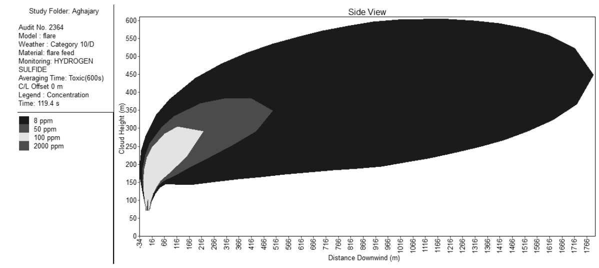

Fig. 10 H_2S distributing at case 07

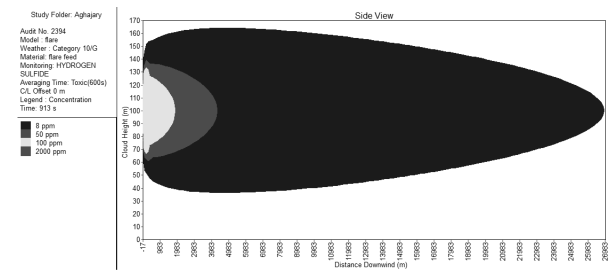

Fig. 11 H_2S distributing at case 11

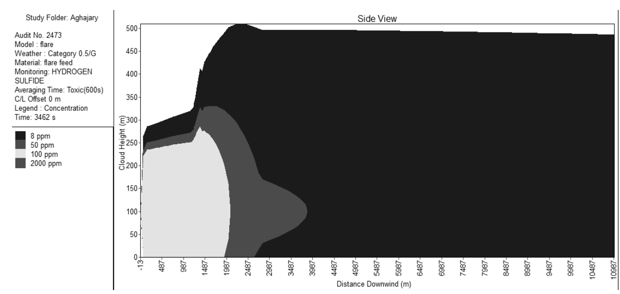

Fig. 12 H_2S distributing at case 25

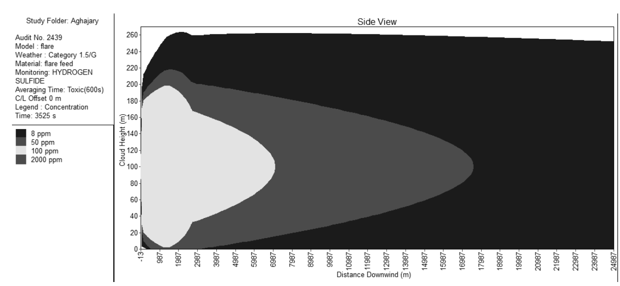

Fig. 13 H_2S distributing at case 26

results are shown in Table 7.

As is clear from the results at stability condition A with decreasing wind velocity MGLC decreased and x_{max} increased but the important results obtained at th G stability. In very stable condition with decreasing wind velocity MGLC increase quickly and very close to the flare (x_{max}=49 m) MGLC be 100 ppm and this mean is death for each alive creature.

For further information some contour from critical cases are given below.

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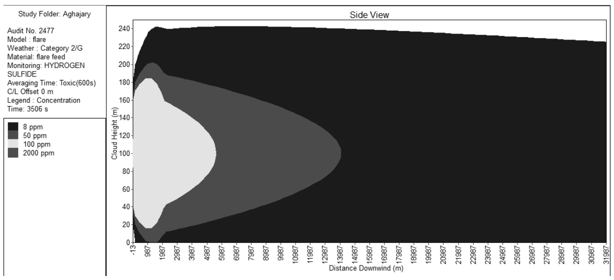

Fig. 14 H_2S distributing at case 27

Fig. 15 H_2S distributing at case 28

Table 7. Suspicious critical cases for Aghajary flare

Case	Flare height	Weather category	Wind velocity	MGLC	x_{max}
25	70	G	0.5	100	49
26			1.5	50	437
27			2	50	937
28			3	8	1650
29			0.5	1	420
30	70	A	1.5	1	670
31			2	1	692
32			3	1	725

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REFERENCES

Briggs, G.A. 1973. Diffusion estimation for small emissions in environmental research laboratories, Air Resources Atmospheric Turbulence and Diffusion Laboratory, Annual Report of the USAEC,Report ATDL-106, National Oceanic and Atmospheric Administration Oak Ridge, TN.

Briggs, G.A. 1984. Plume rise and buoyancy effects, In: *Atmospheric Science and Power Production*, ed. D. Randerson, U.S. Department of Energy, DOE/TIC 27601 : 327Y366.

Benarie, M.M. 1987. The limits of air pollution modelling. *Atmos. Enviro. Atmos. Environ*. 21 (1) :1-5.

Beychok, M.R. 1979. How accurate are dispersion predictions. In: *Hydrocarbon Processing* (Gulf Publishing, Houston, TX.

Beychok, M.R. 1995. *Fundamentals of Stack Gas Dispersion*, Published by the author, Irvine, CA.

Carrascal, M.D., Puigcerver, M. and Puig, P. 1993. Sensitivity of gaussian plume model to dispersion specifications. *Theor. Appl. Climatol*. *Theor. Appl. Climatol* . 48 : 147-157

Davenport, A.G. 1961. The application if statistical concepts to the wind loading of structures. *Proc. Inst. Civil Eng*. 19 : 449Y473.

EPA, 2001. Appendix H: Recommendations for Estimating Concentrations of Longer Averaging Periods from the Maximum One-Hour Concentration for Screening Purposes. U.S. Environmental Protection Agency, Research Triangle Park, NC, USA.

Ghadianlou, F. 2011. Flare. (Andishehsara Iran:basic book)

Grigoras, G., Cuculeanu, V., Ene, G., Mocioaca, G. and Deneanu, A. 2012. Air pollution dispersion modeling In: *A Pollutedarea of Complex Terrain From Romania*. Romanian Reports in Physics, 64 (1) : 173-186.

Goyal, P. and Ramakrishna, T.V.B.P.S. 2002. Dispersion of pollutants in convective low wind: a case study of Delhi. *Atmos. Environ*. 36 : 2071 - Y2079.

Hatam Asal Gzar and Khamaal Muhsin Kseer, 2009. Pollutants emission and dispersion from flares: A gaussian case – study in Iraq. *Journal of Al-Nahrain University*. 12 (4) : 38-57.

Heinsohn, R.J. and Kabel, R.L. 1999. *Sources and Control of Air Pollution*. Prentice Hall, New Jersey, 696.

Hurley, Peter J. 2005. The Air Pollution Model (TAPM) Version 3. Part1: "Technical Description",CSIRO Atmospheric Research Tehnical Paper No.71, Australia, 2005.

Hanna, S.R., Briggs, G.A. and Hosker Jr., R.P. 1982. *Handbook on Atmospheric Diffusion, Atmospheric Turbulence and Diffusion Laboratory*, NOAA, USA Technical Information Centre, US Department of Energy.

Kahforoshan, D.and Fatehifar, E. 2008. Modeling and evaluation of air pollution from a gaseous flare in an oil and gas processing area. (Paper presented at the *WSEAS Conferences*, Spain).

Khare, M. and Sharma, P. 2002. *Modelling Urban Vehicle Emissions*. WIT Press, Southampton, Boston.

Lakshminarayanachari, K., Sudheer, K.L., Pia, M. and Siddalinga Prasad, Pandurangappa, C. 2013. A two dimensional numerical model of primary pollutant emitted from an urban area source with meso scale wind, dry deposition and chemical reaction. *Atmospheric Pollution Research*. 4 : 106 -116.

Lettau, H.H. 1959. Wind profile, surface stress and geostrophic drag cofficients in the atmospheric surface layer. *Advances In Geophysics*. 6 : 241 -257.

McMullen, R.W. 1975. The change of concentration standard deviation with distance. *JAPCA*. 25 : 1057-

1058.

Nikmo, J., Tuovinen, J.P., Kukkonen, J. and Valkama, I. 1999. A hybrid plume model for local-scale atmospheric dispersion. *Atmos. Environ*. 33. 4389Y4399.

Pasquill, F. and Smith, F.B. 1983. *Atmospheric Diffusion*, 3rd edn (Wiley, New York, 1983) p. 437.

Peavy, H. S. and *et al*., 1985. *Environmental Engineering*, Mc Grow Hill Inc.

Rahnama, K. 2012. Plume Dispersion: A New Flare Combustion and Plume Rise Model. (Chemical and Petroleum Engineering Department Calgary, Alberta)

Ranchoux, R.J.P. 1976. Determination of maximum ground level concentration. *Journal of The Air Pollution Control Association.* 26 (11) : 1088-1089

Schnelle, K.B. and Dey, P.R. 1999. *Atmospheric Dispersion Modelling Compliance Guide* (McGraw-Hill, Europe.

Seema Awasthia, Mukesh Khareb and Prashant Gargava, 2006. General plume dispersion model (GPDM) for point source emission. *Environmental Modeling and Assessment*. 11 : 267-276.

SENES Consultants Limited 2007. *Sour Gas Well-test Flaring.* (Vancouver, British Columbia: basic book).

Turner, D.B. 1994. Workbook of Atmospheric Dispersion Estimates: *An Introduction to Dispersion Modelling,* Lewis Publishers, Boca Raton, FL.

Willmott, C.J. 1981. On the validation of models. *Physical geography.* 2 (2) : 184-194.

Zannetti, P. 1990. *Air Pollution Modeling: Theories, Computational Methods and Available Software*, (Van Nostrand Reinhold, New York)