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Modelling atmospheric dispersion during oil and gas extraction activities

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ABSTRACT

There exists a great interest to evaluate the environmental impact every time that a accident occurs. This phenomenon are transient in their behaviour and in general very dangerous to nature.

Field observations show that emergency planning may not be reliable if only if a single wind observation is made, and can often be completely unreliable if the wind observation site is located 10 Km or more from the hazardous gas release point. As an alternative to a full three-dimensional model, many engineers and researchers are using puff models based on wind fields derived from interpolated wind observations.

The concentration downwind of the source or sources is estimated using a gaussian puff trajectory model for non-dense emmissions. The model can also handle multiple receptors. It is not expected to be valid for very dense gases close to the source, but is useful for many types of hazardous gas release with nearly neutral or slight positive bouyancy.

The mass of pollutant is given by Q_i. Dispersion coefficients (Pasquill, Irwing) derived for plumes are used because they are based on extensive experimental evidence. The rate of dispersion can change with time as atmospheric stability changes.

The model is used to evaluate a sudden break of a pipe that carried H_2S. The results allows the prediction of the dilution, the height of the cloud above the ground and the concentration of the gas downwind of the emission. Concentrations values for a region cover by ten receptors are presented for three diferents dispersion algorithms. Maximum concentratios are evaluated as a function of position and time.

INTRODUCTION

The release of hazardous material is a problem that should be considered very careful due to the environment damage that it causes.

The purpose of this paper is to discuss some of the issues involved in modelling of the accidental release of hydrogen sulfide H_2S during oil and gas extraction activities.

The focus is on pipeline ruptures that leads to large release of sour gas.

Characteristics such as the rate of release, the H_2S content and duration of release and that most sour gases streams are less dense of its environment (air) are importants in the modelling process.

One important issue is that of lift-off, since one has to pay attention to whether a buoyant plume that is initially on the ground will in fact lift off. For plumes that are marginally bouyant (e.g after dillution during an initial jet phase), lift off is unlikely.

Releases from wellhead blowouts have the following characteristics: (i) initially, they are high momentum jets which can be vertical or horizontal; and (ii) generally, their effective molecular weight is less than the air.

In general, the total mass released when a pipeline ruptures happens is limited by the quantity of gas between emergency shutdowns valves. The valves are typically 1 Km to 3 Km apart.

In our case study the quantity t_d which is the time taken for 99 % of the pipeline contents to be depleted is equal to 110 minutes. At time equal to cero de mass release rate is 825 g/sec.

One way to evalate the problem of concentration of the hazardous material is by means of mathematical model. In this particular type of problems they should incorporate some features as: initial momentum jet modeling, subsequent buoyant rise, whether a nominally bouyant plume that is initially on the ground will in fact lift off and transition to a subsequent Gaussian passive modelling phase.

Then a jet model that incorporate density effects should be chossen. The model used in this paper is of Gaussian type. The Gaussian puff equation determine the distribution of each puff and is given by the following expression.

$$C = (Q_i/(\sqrt{2}\pi^{3/2}{\sigma_r}^2\sigma_z))\ \exp(-0.5r^2/{\sigma_r}^2)\ \exp(-0.5{z_e}^2/{\sigma_z}^2)$$

para $\sigma_z < 0.8$ MLH

$$C = (Q_i/(2\pi{\sigma_r}^2 h))\ \exp(-0.5r^2/{\sigma_r}^2)$$

para $\sigma_z > 0.8$ MLH

where $r^2 = (x - ut)^2 + y^2$, ${\sigma_r}^2 = {\sigma_y}^2 + {\sigma_x}^2$, C is the pollutant concentration at x, y, z, and Q_i is the emission rate. The total contribution from all the puff is summed at each receptor after each time step.

The model is capable of estimating pollution dispersion under unsteady and nonuniform flow. Pollution dispersion within the puff is assumed to be Gaus-

sian and meteorological conditions within a time step are assumed to be spatially and temporally uniform.

The diffused material is assumed to be stable over a long period of time.

As long as the variations in meteorological conditions are not simulated to any finer resolution than 3 to 10 minutes periods, the use of plume characterizations of dispersion may still be reasonable.

The most important difference between Gaussian-Plume models and this model is that it can handle changing meteorological conditions, whereas typical Gaussian-Plume model assume spatial and temporal uniformity in the meteorology.

The plume initial dispersion at the source is modeled by specifyng the initial horizontal and vertical dispersion parameters, σ_{ro} y σ_{zo}. For tall stacks these parameters, generally, have little influence on downwind concentration. However, if the source is close enough to the ground, initial size is important in determining ground level concentrations near the source.

For long travel time the dispersion parameter used in the model satisfy the diffusion theory of Taylor (1921). The dispersion parameter can be written as,

$$\sigma_{y,z}{}^2 = \overline{2(vw)'^2} \int_o^{T_d} R(\tau) \int_o^t d\tau dt$$

where $R(\tau)$ is the Lagrangian autocorrelation.

The dependence on the location of the puffs in relation to the mixing layer height (MLH) is taken into account depending whether the puff is below of above this height. If the MLH collapses, as it does most evenings, the model assumes that the puff remains well mixed through the MLH, that existed prior to collapse.

Model Characteristics

General and Meteorological Characteristics

The mathemetical model is a Gaussian integrated puff model with a wide range of applications. The implied modeling scale is from tens of meters to ten kilometers. The model is capable of addressing the release of substance over several minutes, or of modelling the more typical continuous plume from a stack.

Computations in the model can be made for multiple point sources at up to 100 receptors locationss. In practice, however, the number of receptors locations should be kept to a minimum to avoid excessive run time. The model is primaraly designed to model a single event during which one meteorological transition period may occur, such as going to from afternooon to evening conditions. Up to 144 separate meteorological periods of the same length may used to characterize the meteorology during the event; this provide a time resolution that range from minutes to hour. The user has the option of specifying the wind field for each meteorological period at up to 100 grid location or allowing the model to default to a homogeneous wind field.

Dispersion Characteristic

For short time travel the model used two dispersion algorithms for dispersion downwind of the emmission source: the Pasquill-Gifford scheme, as discussed

by Turner [1970] and the on-site scheme of Irwing [1983]. The on-site scheme, requieres specification of the variance of the vertical and lateral wind direction. It is a synthesis of work performed by Draxler [1976] and Cramer [1976].

For long travel time scheme a third dispersion algorithm is used in which the growth of the puff becomes proportional to the square root of time.

An initial dispersion algorithm handles the finite size of the release through the use of initial dispersion parameters. Once the puff leaves the source its growth is determined by the mentioned short travel algorithms. The P-G scheme characterizes dispersion as a function of downwind distance and the on-site which characterize dispersion as a function of travel time.

Initial Dispersion

The initial dispersion of the plume at the source is modeled by specifyng the initial horizontal and vertical dispersion parameters σ_{ro} and σ_{zo}. We know that if the source is large enough or close enough to the ground, then initial size is important in determining ground level concentration near the source. The form to calculate the initial horizontal and vertical dispersion are calculated as indicated in Petersen and Lavdas [1986].

This methods of accounting for the initial size of near ground level release gives reasonable concentration estimates at downwind greater than about five times the initial horizontal dimensions of the source.

Bouyancy Induced Dispersion

The buoyancy induced dispesion feature is offered because emitted plumes undergo a certain amount of growth during the plume rise phase, due to turbulent motions associated with the conditions of plume release and the turbulent entrainment of ambient air.

In general, bouyancy induced dispersion will have little effect upon maximum concentration unless the stack height is small compared to the plume rise. Alkso, it is most effective in simulating concentration near plume centerlines close to the source, where treating the emmission as a point source confines the the plume to a volume much more smaller than the actual plume. It should be clarified here that the bouyancy-induced dispersion close to the source is calculated using the gradual rise in the model, even through gradual plume rise is not being use to determined the effective plume height.

Gaussian Puff Methodology

When the model assumes $\sigma_y = \sigma_x$ the puffs remain circular throughout their lifetime. At a given time, puffs released are in different locations when the wind field is no homogeneous. Meaning that there is a change in the wind direction.

In a Gaussian puff algorithms, source emissions are treated as a series of puffs emitted into the atmosphere. Constant conditions of wind and atmospheric stability are assumed during a time interval. The diffusion parameters are function of the travel time.

During each time step, the puff centers are determined by the trajectory and the in-puff distribution are assumed to be Gaussian. Thus, each puff has a center and a volume which are determined separately by the mean wind, atmospheric stability and travel time.

Plume rise is calculated by the method of Briggs [1973]. These equations are based in the assumptions that plume rise depends on the inverse of the mean wind speed u and is directly proportional to the two third power of the downwind distance x from the source.

Many equations for $\Delta h(x)$ Zannetti [1990] have the following form

$$\Delta h(x) = const Q_h{}^a x^b u^c$$

where a, b, c are constants and Q_h is the heat emmission rate of the source and is given by

$$Q_h = Q_m c_p (T_s - T_a)$$

where c_p is the specific heat at constant pressure, T_s is the gas exit temperature, T_a is the ambient temperature and Q_m is the total mass emission rate.

MODEL APPLICATION

The case that had been studied consisted of a low level suddenly release of H_2S from a pipe. The emmision rate is variable, as shown in Table 1.

TABLE 1 EMISSION RATE

Time (sec)	Emission Rate (gr/sec)
0	825
600	562
1200	383
1800	261
2400	178
3000	121
3600	83
4200	56
4800	38
5400	26
6000	18
6600	12

RESULTS

The 2.0 hours average concentrations at receptors for all simulation periods due to the single source, are shown in table 2 for different dispertion algorithms. As should be expected the maximum concentrations are in receptor 3 and 8 due to the north location of the source indepedently of the algorithm used. It is clear that the maximum concetration occurs around receptor 8 and its value is equal to 26340 $\mu g/m^3$, for the P-G algorithm.

TABLE 2 RESULTS OF CONCENTRATIONS

	Receptor Coordinate X (Km)	Receptor Coordinate Y (Km)	Algorithm 1 Concentration ($\mu g/m^3$)	Algorithm 2 Concentration ($\mu g/m^3$)	Algorithm 3 Concentration ($\mu g/m^3$)
1	1.54	1.19	0.0	5.1	0.0
2	1.65	1.35	1.0	254.6	8.2
3	2.00	1.50	22960.0	2277.0	22740.0
4	2.35	1.35	0.0	132.9	0.0
5	2.46	1.19	0.0	1.1	0.0
6	1.08	1.38	0.0	0.1	0.0
7	1.30	1.70	0.0	97.1	0.0
8	2.00	2.00	26340.0	10480.0	24400.0
9	2.70	1.70	0.0	17.2	0.0
10	2.92	1.38	0.0	0.0	0.0

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