Transient Diffusion Modeling of Methane Plume and Source Localization

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Abstract

Introduction:
Methane detection and quantification is of great importance due to its natural abundance, potential to cause explosions and known greenhouse effect. It's primarily released from the walls of coal mines and anaerobic decomposition of landfill garbage. Hence it is omnipotent to localize those landfill gas sources to avert any potential threat. Leak detection and concentration monitoring at source is highly challenging as CH4 is odorless and colorless. This can be performed mounting sensor network over a potential diffusion area. But it requires optimal positioning of those sensor nodes to localize the source and estimate concentration for early warning and forecasting. That needs comprehensive simulation and numerical analysis of the gas diffusion behavior starting from a source. Primarily this work is comprised of the simulation study and numerical analysis for the transport behavior of methane plume to facilitate in optimal positioning of sensor network by estimating the concentration profile of that plume and the concerned threat zone. Moreover it also demarcates the threshold concentration beyond which potential threat might take place.

Use of COMSOL Multiphysics® software:
The transient behavior of gas diffusion profile based on Fick's law was simulated in COMSOL 5.0 using transport of diluted species interface tool inside a cubical geometry of 0.5m side. The time varying concentration field of methane gas diffused through a point mass source of 20 mol/s (assumed) located just above the center of XY plane in isotropic medium (air) was observed. The total simulation time for simulation was 1200 sec to avoid deflection from boundary.
The observation will be extended to the estimation of the diffusion profile for non-isotropic medium and subsurface source with different grades of medium through which it will disperse. By using mathematical particle tracking interface, computing the trajectories of particles dispersing through a geometry will become more accurate which in turn optimizes the positioning of sensor nodes in the network. The gas plume profile under the influence of wind can be superiorly estimated using Lagrangian dispersion modelling.

Results:
The diffusion follows an upward hemispherical trajectory from source as time progresses

with layers of concentration profile. Surface concentration diffusion profile view from X-Y plane was shown in figure 1, whereas figure 2 shows concentration diffusion profile through the slices of geometry after 1200 sec. The diffusion follows Gaussian probability distribution profile (pdf) as shown in figure 3. The amplitude of the pdf decreases and variance increases with increase in time due to random movement of gas particles.
Conclusion:
The simulation demonstrates transient concentration diffusion profile of methane in a cubical atmosphere using COMSOL® software for a point mass source in isotropic medium. It was observed that the diffusion profile followed a hemispherical trajectory. Therefore to localize the source point, an optimally positioned sensor network can be deployed.

Reference

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Figures used in the abstract

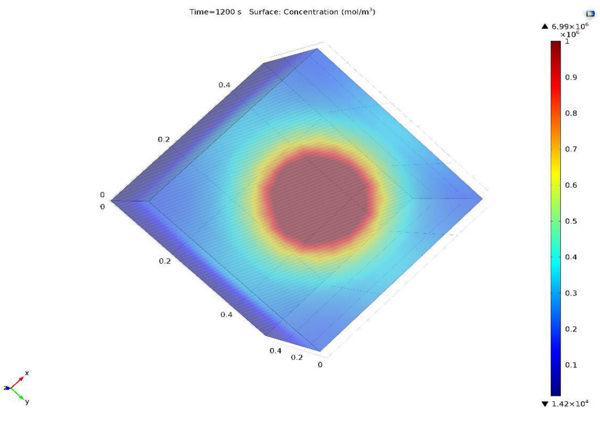

Figure 1: Surface concentration diffusion profile after 1200 sec Figure 2:

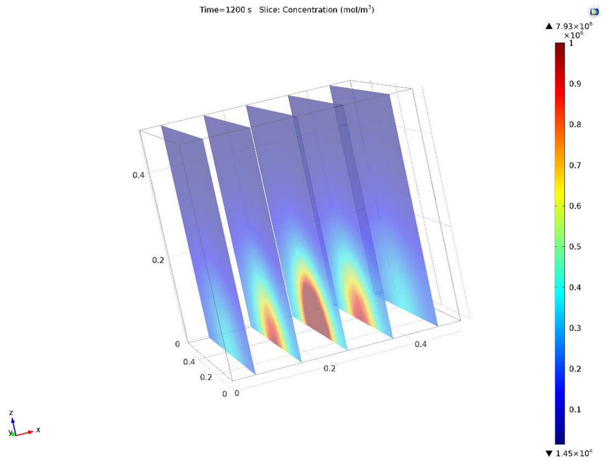

Figure 2: Slice concentration diffusion profile after 1200 sec

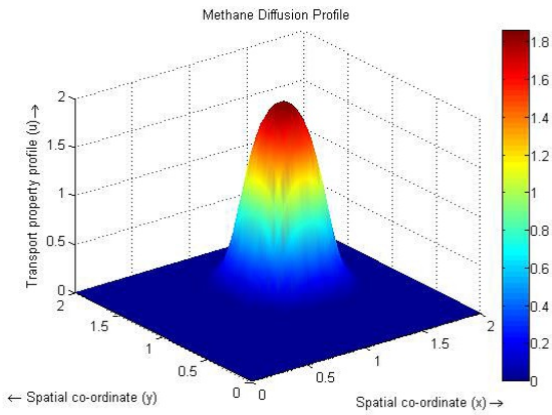

Figure 3: PDF of methane diffusion profile