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Theoretical and experimental study of Gaussian Plume model in small scale system

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Abstract

Atmospheric dispersion pollution modelling is of great and actual concern in the scientific international community. Many dispersion models have been developed and used to estimate the downwind ambient concentration of air pollutants from sources such as industrial plants, vehicular traffic or accidental chemical release. Among them, Gaussian model is perhaps the most commonly used model type. It is often used to predict the dispersion of air pollution plumes originated from ground-level or elevated sources. In this research an experimental campaign was carried out in the wind tunnel of the Industrial Engineering Department of University of Catania. It was tested an emission plume of particulate matters and the concentrations of PM_{10} were evaluated in several points downwind beyond the emitter. Both the wind velocity and PM_{10} mass flow were varied in order to test the differences in terms of PM10 concentrations in the sampling points. A Gaussian plume mathematical model was developed according the boundaries conditions of the experimental campaign. The results of the model were compared with experimental ones in order to identify the limits and the advantages of this model in such a small scale system.

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1. Introduction

The dispersion of air pollution both in urban areas and open spaces is becoming of great concern in the scientific community. In last decades the normal levels of air pollution have increased [1] and many countries have started to focus to develop monitoring systems for air pollution. With the European directive 2008/50/CE all European countries have declared to adopt a standardized way to control, monitor and study air pollutants in urban areas. In such scenario, many air quality models to predict, study and evaluate the pollution dispersion have been studied and implemented [2]. Air quality models are able to predict the pollutant gases or aerosol trajectories in atmosphere. Generally, these pollutants cab be emitted by industrial sources [3], hazard chemical released due to accidents or natural events [4], and vehicular urban traffic [5, 6]. The evaluation and calibration of dispersion models is of a crucial importance, because their results often influence decisions that have large public-health and economic consequences. Obviously there are different types of models and their performances depend on many variables. The classification of these models may refer about the source type (point source, line source, area source), the adopted scale (large or small scale), the input type (deterministic models and stochastic models), the dynamic conditions (steady or unsteady state), the pollutant sources (gases or particles). Many reviews [7, 8] have already classified and studied these models, trying to focus about performance in respect with the variables stated before. Among all these possible models the most used are probably Lagrangian and Gaussian models. Both of them are able to estimate the downwind ambient concentration of air pollutants from different sources types. Lagrangian models work well both for homogeneous and stationary conditions over the flat terrain [9] and unstable media condition for the complex terrain [10] but they usually suffer for computational calculation and they cannot be used for real time applications. Gaussian models are widely used in atmospheric dispersion modelling, usually in regulatory purposes because of their easy implementation and their near real-time responds. They generally are used in large scale applications [11] and although they have been shown to over-predict concentrations in low wind conditions [12], since the plume models are calculated with steady state approximations they do not take into account the time required for the pollutant to move from the source to the receptor. In this research a Gaussian plume model was implemented and tested in small scale scenario thanks to experimental campaigns carried out in a wind tunnel. The performances of this model in such a small scale set up were then studied by comparing model results with experimental ones.

Nomenclature

L	Height of the emitter [mm]
D	Diameter of the emitter outlet [mm]
$\dot{m}_{PM10}$	Mass flow rate of PM_{10} [μg/s]
C_{PM10}	PM_{10} concentration [μg/m^3]
V_e	Emitter outlet velocity [m/s]
U	Wind tunnel velocity [m/s]

2. Gaussian Plume Model

The greatest advantage of Gaussian Plume models is that they have an extremely fast, almost immediate response time. Their calculation is based only on solving a single formula for every receptor point, and the model's computational cost mainly consists of meteorological data pre-processing and turbulence parameterization. Depending on the complexity of these sub-modules, the model's runtime can be extremely reduced enabling its application in real-time and near real-time decision support software. Gaussian dispersion models have become a uniquely efficient tool of air quality management for the past decades, especially in the early years when high performance computers had an unreachable price for environmental protection organizations and authorities. Their fast responds depend basically on several assumptions that make them useful for just some applications. The main important assumptions are:

- The emission rate of the source is constant;