

ENVIRONMENTAL IMPACT SIMULATION OF A DOMESTIC WASTE INCINERATOR

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Abstract

The *fluidyn* family of software is giving extensive solutions for the assessment (for example through the dispersion modelling of toxic emissions) and reduction (for example through the design optimisation) of municipal solid waste incinerator pollution.

In this article, we develop a methodology based on fluid numerical simulation through two examples. The air quality impact analysis of dioxins and particulate emissions is shown through the example of an actual incinerator located in France and is carried out using *fluidyn*-PANEIA.

Once the assessment has been performed and if this assessment shows the need for improvement, the incineration process is analysed. The design optimisation is highlighted here through the example of optimisation of deflectors using *fluidyn*-NS.

Keywords

Incinerator, pollution, assessment, optimisation, fluid.

Introduction

Waste incineration is the process of destruction of wastes through the application of heat within a controlled combustion system. It can however give rise to pollutants emissions in air, land and water and as such, incinerators are linked with many health risks. In particular, air emissions can include acid gas, particulate matter, heavy metals, highly toxic trace organic compounds and dioxins. Therefore, the ambient air quality impact analysis is one of the major criteria for the selection of a site for an incineration facility.

In this article, we develop a methodology based on fluid numerical simulation in order to assess and reduce the air quality impact of an incinerator through the *fluidyn* family of software. Two cases related to waste incineration were investigated here : the first one deals with the environmental impact assessment of the incinerator. The second one shows an example of reduction of pollution emission through design optimisation. The first case is the example of an actual incinerator located in France and was carried out using *fluidyn*-PANEIA. Once the assessment has been performed and if this assessment shows the need for improvement, the incineration process is analysed. The design optimisation is highlighted through the example of optimisation of deflectors using *fluidyn*-NS. Deflectors are used mainly to enhance the heat transfer by better distribution of gas and to reduce erosion and corrosion of the walls at the bottom of the third chamber.

Materials and Methods

The *fluidyn* code family uses the computational fluid dynamics tools in a finite volume based approach to solve the Navier-Stokes equations governing mass, momentum, and energy transfer for both laminar and turbulent flows. The

equations for the two cases differ primarily in the form and magnitude of the transport coefficients. Eddy hypothesis is used to compute the turbulent contribution to the exchange coefficients. A SIMPLE type pressure-momentum coupling is used for implicit treatment of acoustic terms in the momentum equations. Turbulence is treated by $k-\epsilon$ models. Micrometeorological parameters are evaluated using similarity theories. The density variation are taken into account using the buoyancy model.

Air quality impact modelling

The first case, concerning the pollution from a domestic waste incinerator, is comprised of 4 steps : (1) numerical terrain modelling (2) windfield calculations (3) dispersion simulation.

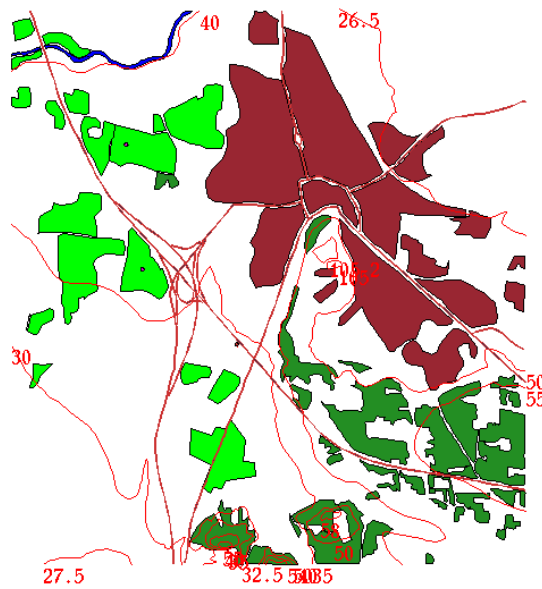


Figure 1. Numerical terrain model

The detailed numerical terrain modelling is important because the wind pattern near the ground surface depends mainly on the frictional resistance of the surface features and hence meticulous modeling of their influence becomes necessary. For this study, an area of nearly 86 km² has been outlined for the study. The altitude contours representing the terrain undulations vary from a minimum of 30 m to 105 m (curves in red in figure 1). The vegetation like fields and forests is featured through light and dark green objects. The urban areas are shown in brown colour. Based on the stack parameters (stack height : 34 m; volumetric flow rate: 45 000 m³/h; emission temperature: 270°C), the domain height is calculated as 700 m. Concerning the meteorology, the nearest weather station to the incinerator yielded the relative humidity (75%) and the average temperature (15°C). The main objective of the study was to assess the pollution affecting the human health as well as the crops in case of dioxins. Hence in order to consider the worst meteorological conditions, the average wind blowing towards the sensitive areas was taken into account. Two weather conditions, for the two main sensitive areas, were singled out (see table 1). The wind velocity and stability class were chosen in such a way as to maximise the pollutants concentrations.

Table 1: Weather parameters

Parameters	Scenario 1	Scenario 2
Mean wind speed (at 10 m)	3 m/s	6 m/s
Wind Direction (at 10 m)	160 °	340 °
Pasquill Stability Class	C	D

The pollutant species considered for this study are heavy metals and dioxins. The emission data from the stack monitoring experiments were used for this study (table 2).

Table 2: Pollutants emission concentrations at the stack exit

Dioxins	155 ng/m ³
Cadmium	2.82 E-03 µg/g
Mercury	7.34 µg/g
Zinc	6.2 E-02 µg/g

Once the computational domain and the terrain features have been defined, a 3-D mesh is automatically generated. The mesh is cartesian in x-y directions and body fitted in the z direction so as to map the terrain undulations (figure 2).

Design of deflectors in the incinerator

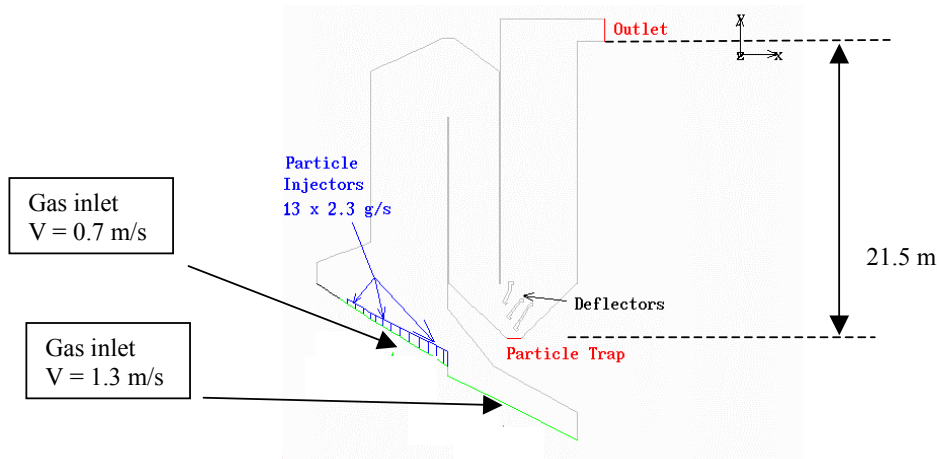


Figure 3: Schematic of the incinerator chambers

Hot gases generated as a result of incineration process flow through three chambers (shown in figure 3). In between the second and third chamber, there is a filter through which gas passes, leaving the suspended particles behind. Three deflectors are fitted with the filter guiding the flow towards the third chamber. To optimise the number of deflectors, the flow field is studied for the following three scenarios : without deflectors, with two deflectors and with three deflectors. The temperature inside the chamber is equal to 1295K. The flow is modelled as steady, compressible and viscous perfect gas. The walls are supposed adiabatic. The solver scheme is a Roe FDS with the Weis-Smith preconditioner.

Results and Discussion

Air quality impact modelling

Before carrying out the dispersion calculations, *fluidyn*-PANAIR establishes the windfield over the computational domain by considering the topographical features and selected stability class. The wind deviates from the set direction at the places where the terrain undulations are significant and in the vicinity of obstacles (buildings, etc.).

The dispersion of pollutants was then simulated by allowing the emission from the stack. The simulation was carried out until stabilisation occurred. The results are shown in figure 4 as concentrations isocontours at man height (1.5 m) for the two wind directions. The example shown here is the example of dioxins. The maximum concentrations for the 4 pollutants and the 2 wind directions are compared in table 3 with the available toxicity limit values specified by the WHO (World Health Organisation). From these concentrations, the ground deposition was calculated on crops and vineyards. The results show a Cadmium concentration above limits. Mercury on the other hand is well below the WHO limits. No threshold is available concerning the maximum allowable air concentration of dioxins and zinc. However, dioxins are toxic through ingestion so their concentration should be as small as possible on ground level.

Table 3 : Maximum Concentration of the species

Pollutant	Max Conc. Scenario 1	Max Conc. Scenario 2	Limits
Dioxins	1.273 E-3 ng/m ³	2.581 E-3 ng/m ³	---
Hg	3.350 E-5 µg/m ³	6.810 E-5 µg/m ³	1 E-3 mg/m ³
Cd	1.287 E-5 µg/m ³	2.616 E-5 µg/m ³	5 E-6 mg/m ³
Zn	2.830 E-4 µg/m ³	5.752 E-4 µg/m ³	---

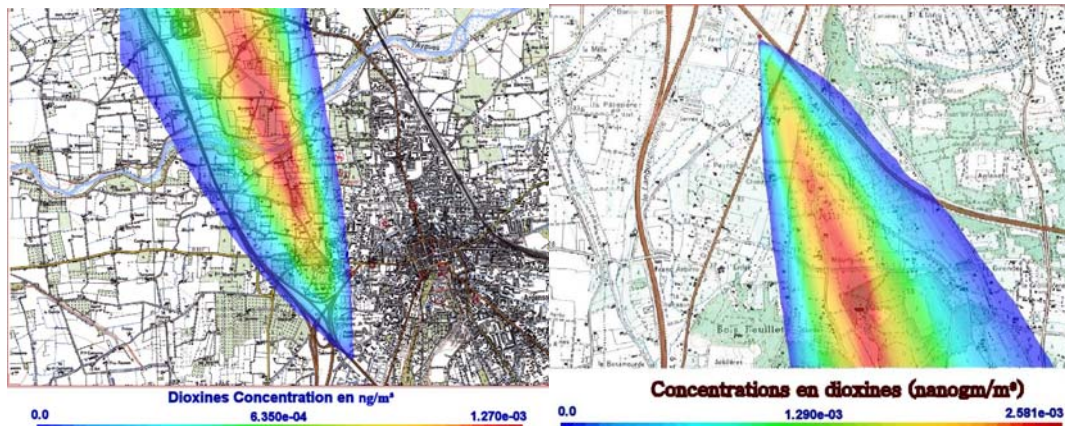


Figure 4. Contours of Dioxin at 1.5 m (3m/s, 160° on the left, 6m/s, 340° on the right)

Design of deflectors in the incinerator

The above assessment study has shown the need for improvement of the incineration process in order to reduce the pollution. This has been done in this study through the study of the influence of deflectors in the so-called Hopper region (between the 2nd and the 3rd chamber).

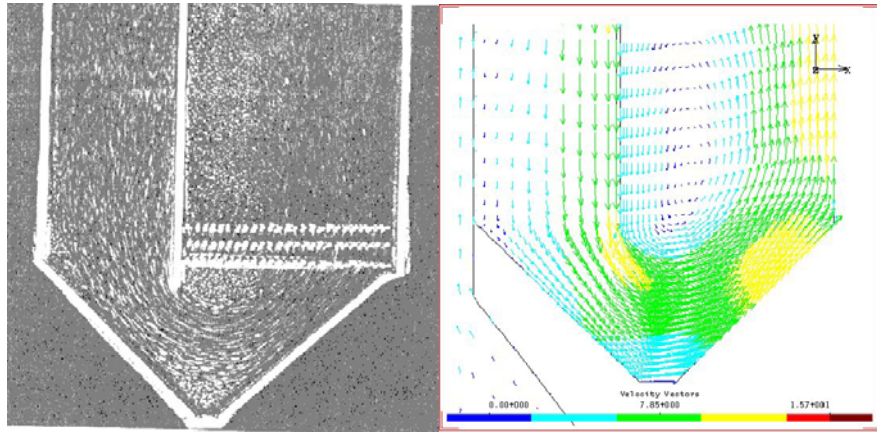


Figure 5 : Velocity in the Hopper region without deflectors (experimental on the left and numerical on the right)

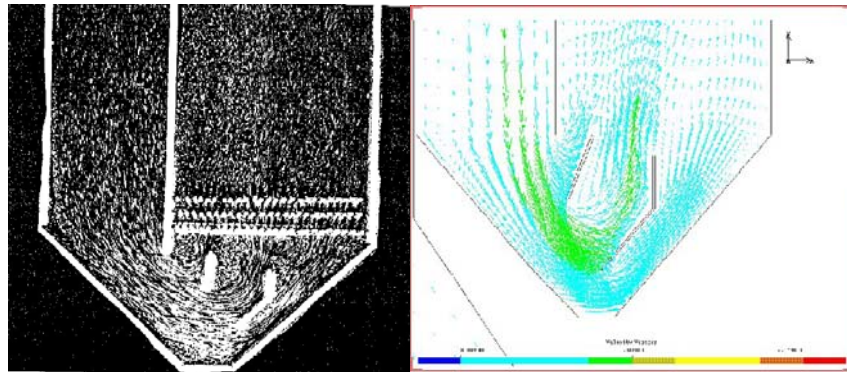


Figure 6 : Velocity in the Hopper region with 2 deflectors (experimental on the left and numerical on the right)

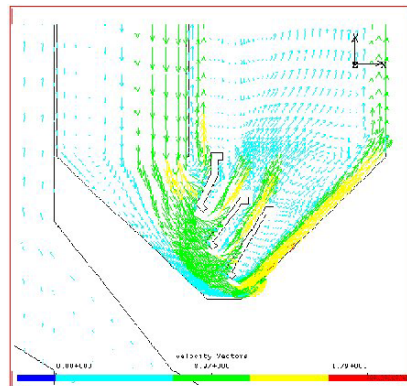


Figure 7. Velocity in the Hopper region with 3 deflectors

The figures 5, 6 and 7 show the three configurations studied. The image on the right represents the velocity vectors in a vertical slice through the incinerator obtained by simulation. The left hand side image shows the experimental study shows the streamlines of the gas obtained by tomography on seeding. These experimental pictures have been provided by the incinerator operator.

These results show clearly that the best configuration is the one with two deflectors. The first one (no deflector) presents a dead zone at the bottom where the gas gets trapped and increases the wall temperature locally.

In the three deflector geometry, the gas seems to hit the bottom wall of the third chamber where degradation is very important. The floating ashes get deposited in the deflectors and so blocks the deflectors.

Conclusions

Computational fluid dynamics can be a powerful tool to increase the environmental friendliness of domestic waste incinerators, both by assessing the pollution emitted by the stacks and by reducing the pollution emitted through a better design of the incineration process. As examples, two case studies were carried out using the *fluidyn* family software. The first case study simulated the dispersion of pollutants outside a domestic waste incinerator using *fluidyn*-PANAIR. Both the air quality around the incinerator and the ground deposition of the heavy metals and the dioxins were estimated.

The second study concerned the flow analysis inside the combustion chambers of the incinerator in order to analyse the effects of the deflectors used in the superheater section and improve the process. This study helped define a better design in order to reduce pollutant formation.

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