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THE IMPORTANCE OF CONSIDERING BUILDING DOWNWASH WHEN ASSESSING THE NEED TO HEIGHTEN STACKS OF EXISTING SMALL- AND MEDIUM-SIZED INDUSTRIES

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This short communication intends to share the authors' experience on the modeling of atmospheric pollutant dispersal and on the importance of building downwash considerations when assessing the need to heighten stacks of small- and medium-sized industrial enterprises (SMEs). In order to understand the reasons that make industrial companies, especially SMEs, consider stack heightening, in section 2 the existing Portuguese legislation on air quality and the stack heightening rules are briefly commented upon. New legislation that ought to appear soon (new Portuguese Air Act) is also commented upon and compared critically with the existing legislation. Then section 3 characterizes Portuguese industry in terms of the ambient quality problems related to stack height. The adequacy of the stack heightening legislation to the particularities of the Portuguese case is discussed. In section 4 the authors' experience in the specific study of stack heightening is presented. The methodology considered in these studies is discussed and compared with the application of existing and soon to appear legislation on stack height calculation. Finally, section 5 presents the conclusions, and the need for an increased awareness on the pollutant dispersal problem is discussed.**[AuQ1]**

Keywords: Dispersion modeling; Building downwash; Stack height

INTRODUCTION

Atmospheric pollutant dispersal is a complex phenomenon that requires the use and interconnection between several distinct sciences. It is questionable that any simple set of rules can be used to assess the risk that certain specific emissions of atmospheric pollutants will cause on the environment; nevertheless, it is through the use of a simple set of rules that most countries enforce the implementation of a "regulatory model" for the maintenance of acceptable ambient air quality. Portugal is no exception, and since 1990, a Portuguese Air Act has existed, establishing the basic principles of Portuguese air control and monitoring.

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Despite the tight interconnection that exists between pollutant emission flow, stack height, and location, on one hand, and pollutant ambient air concentration, on the other hand, the regulatory model implemented in Portugal, recently reviewed (Gomes, 2004), sets up independent limits for maximum ambient air pollutant concentrations along with limits for maximum pollutant flow emissions and also limits for minimum stack height. This methodology points operators in two directions regarding ambient air control and often forces them to take action leading to process chances (in order to reduce pollutant emissions) and/or stack heightening**[AuQ2]**. From an environmental point of view the reduction of pollutant emissions should be the preferred way to achieve ambient pollution abatement; in many cases, however, economic reasons dictate a compromise solution, and frequently, stack heightening is used as a way to "improve" ambient air quality.

In Portugal, since the introduction of the Portuguese Air Act in 1990, several existing operators had to review their stack heights. The recent revision of Portuguese ambient air pollutant limits, which imposes stricter limits, and a growing social awareness of ambient air pollution issues contribute also to an increase in the number of operators that may have to review their stack heights. The Instituto de Soldadura e Qualidade, an accredited laboratory that analyses the compliance of pollutant emissions and monitors ambient air pollutant concentrations, also has vast experience on stack height evaluation that spans back to 1986. Over 30 studies on the need to heighten stacks have been performed based on the use of a (long/short-term) Gaussian model and building downwash considerations.

PORTUGUESE AIR QUALITY LEGISLATION: A BRIEF OVERVIEW

The 1990 Portuguese Air Act established the basic principles of Portuguese air control and monitoring. From the beginning, three concomitant fields subject to control were established: (1) ambient air pollutant concentration, (2) pollutant flow emissions, and (3) stack height.

Regarding ambient air, the adopted pollutant concentration limits were the ones adopted by the European Union at the beginning of 1990, which were transposed into Portuguese law from the respective European Directives. Both air limits and recommended values for total suspended particulate, sulfur dioxide, nitrogen dioxide, lead, and carbon monoxide were considered, however, these values were enforced only in 1993 due to a disagreement between the Portuguese authorities on the environment on one hand, and on the industry on the other hand. As in the correspondent European Directives, the main criteria for adopting ambient air pollutant limits was public health protection, and a monitoring system was introduced so that compliance with these values could be evaluated and measures could be derived afterward. An Air Quality National Network was established for monitoring these pollutants in a series of stations, encompassing critical areas in terms of ambient air quality and rural areas.

Since 2002, a revision of the ambient air limits was introduced. This revision considered the adoption of new and stricter ambient pollutant concentration limits, deriving from the current European values, for pollutants such as PM_{10}, $PM_{2.5}$, sulfur dioxide, nitrogen oxides, carbon monoxide, ozone, and benzene. Regarding emissions from stationary sources, and according to the 1990 Portuguese Air Act, pollutant emissions to the atmosphere are subject to specific limits, according to the specific industrial sector and the specific emitting source. For nonspecified facilities, general emission limits must be used. Although these principles were described in 1990, for the same reason stated above for ambient air, the emission limits were only issued in 1993. They included the European emission limits already published for incinerators and large combustion units and also other limits specific to the Portuguese industrial units. As the emission limits fixed in 1993 resulted both from the measured values of the emission inventory on the Portuguese industry and also the best available technologies at that time, it is quite understandable that a revision of these emission limits is urged as the situation has considerably changed since then**[AuQ3]**. Also, the need to adopt, in Portugal, the new European Directives on air quality issued since 1993 forced the publication of other laws and regulations, such as specific limits regarding VOC emissions, emissions from large combustion units, and alterations of the monitoring and management system for ambient air.

Nowadays, the Portuguese legislation on air quality is dispersed among a series of laws and regulations and will soon be subject to a revision, resulting in a new air act. This revision will consider (1) new emission limits for particulates, sulfur dioxide, and nitrogen oxides, deriving from the European limit values already defined for large combustion facilities; (2) new emission limits for specific pollutants, applicable to the Portuguese industrial units, resulting from a revision of the previous emission limits issued in 1993; and (3) new methodologies regarding self-control monitoring and reporting procedures for operators. In this revision, special attention will also be given to air quality in critical areas.

Regarding stack height, its calculation was ruled in the 1990 Portuguese Air Act. A minimum height of 10 m was specified, and Eq. (1) should be used whenever nearby buildings or other structures are present:

$$Ac = a + 1.5l \tag{1}$$

where Ac stands for the stack height measured above soil (m), a stands for the nearby building or structure height measured above soil (m), and l stands for the smallest dimension (height or width) of the nearby building or structure (m). This calculation can only be overridden if specific technical studies are presented and approved.

Until now, no other regulation has been issued, despite the fact that with the issuing of the new Portuguese Air Act (in preparation), this methodology will be altered, and a new one inspired on the French regulations is to be used. Regarding the existing stack height computation method described above, it can be said that it does not take into consideration pollutant flow volume, upward thermal forces, or background pollutant concentration and presents a quite crude way of dealing with the presence of buildings or structures near the stacks.

Comparing this method with the new methodology (to appear in Portuguese legislation), which takes into account pollutant flow volume, upward thermal forces, and pollutant background concentration and improves and clarifies the way nearby buildings or structures should alter stack height, a significant improvement toward a better stack height calculation can be expected.

CHARACTERIZATION OF THE PORTUGUESE INDUSTRY SECTOR: STACK HEIGHT-RELATED PROBLEMS

A way of studying the Portuguese industry that is especially useful for relating atmospheric pollutant emission problems to stack height is one that considers the division between large- and small- to medium-sized industrial enterprises, being the later SMEs, those with less than 50 workers. For large industry, and regarding atmospheric pollutant emissions, it can be said that the implementation of the Portuguese Air Act and of the related monitoring mechanisms has had a very beneficial effect on the lowering of pollutant emissions. This success is, however, more difficult to assess regarding stack height.

In the authors' opinion, except for a few very large industry plants (*e.g.*, thermoelectric, incinerator, or cement plants), where very tall stacks conform with the legislation, in general, the stack height of Portuguese industrial facilities does not conform with legislation, as stated in Eq. (1). This is usually due to the plant layout, where large buildings or structures are commonly adjacent to the stacks. As a consequence, Eq. (1) results in very tall stacks. These common nonequilibrated results produce, in common practice, a generalized discredit of the 1990 Portuguese Air Act stack height computation for most industrial plants. In some cases, enterprises decide to support stack height calculations based on technical studies rather than on the legislation. Problems remain, however, when downwash is not correctly assessed, especially when poor plant layout planning results in complex roof geometry and a great number of stacks dispersed throughout the plant site.

Regarding SMEs, the success brought by the Portuguese Air Act to the pollutant emissions abatement is more questionable, and this can be attributed, in part, to generalized lower technical and human resource capabilities when comparing SMEs and large industrial enterprises. According to Gomes (2004), who analyzed the pollutant emission compliance of about 400 sources belonging to Portuguese SMEs and large industrial facilities, it was found that compliance was higher in larger facilities, despite a significantly larger volume flow of atmospheric releases. This result is somehow disturbing if it is taken into account that the majority of the Portuguese industry sector is composed of SMEs. The fact that Eq. (1) does not take into account the pollutant flow emission makes its implementation even more difficult to support in SMEs that can emit very small pollutant flow volumes.

The disproportionate heights that can be attained with the use of Eq. (1), along with the limited compliance verification actions by the competent governmental bodies, results in an actual risk of high pollutant concentration at soil level due to disrespect of minimum stack heights and nonconsideration of downwash effects.

Another problem that has emerged recently is related to the demographic growth around Portuguese main cities and the consequent approximation of residential areas to traditional industrialized areas. The disrespect for urban planning has resulted in the construction of multistory buildings near several pollutant-emitting industrial facilities.

It can be concluded therefore, in regard to stack height, that there is a need for a revision of the current legislation that introduces adequate stack height calculation rules and a more efficient enforcement of the existing legislation. Regarding this last subject, it could also be useful to invest in pedagogy of the atmospheric pollutant dispersal problem near industry and nonenvironmentally related governmental and municipal institutions.

ATMOSPHERIC POLLUTANT DISPERSION MODELING: THE AUTHORS' EXPERIENCE

Experience in atmospheric pollutant dispersion modeling applied to over 30 Portuguese industrial facilities has been gathered by the authors since 1986. The great majority of these studies result from the need to assess, given certain pollutant emission values, stack height compliance with ambient air quality legislation. There are, however, some cases where the study results from actual complaints by a nearby population or workers in the facilities. The methodology followed in the studies of atmospheric dispersion is presented in the flowchart of Figure 1.

1. Site visit

2. Building downwash analysis

3. Long / short - term atmospheric pollutant dispersion modelling

4. Ambient air modelling results and legislation limits comparison and compliance analysis

5. Recommendations on stack heightening or other plant layout changes

FIGURE 1 Methodology used in atmospheric pollutant dispersion studies.

The methodology presented in Figure 1 starts with a site visit. This is a very important step since it enables us to gather information not only about the geometry and pollutant emissions, but also about the way workers understand atmospheric pollutant dispersal. Often, there is a generalized lack of understanding of the mechanics of pollutant dispersal and pollutant trapping in buildings or other structures**[AuQ4]**. With informal and simple conversations with the facility staff, very useful information on pollution events actually experienced is known. This information can be very helpful for assessing unforeseen problems or confirming the main pollutant dispersal problems. With the plant layout data and the information from the site visit, a preliminary analysis on the airflow patterns around the main buildings can be performed. This analysis intends to identify possible regions of recirculating flow downwind of the buildings and the danger that stacks are emitting pollutants inside or near these regions. This situation can be quite common in facilities with several stacks spread along the plant and with complex roof geometry. To attain an estimate of the recirculating flow region dimensions, expressions from Schulman *et al*. (1998) for recirculating cavity (near-wake) dimensions of different building shapes are used as depicted in Figure 2 (Schulman *et al*., 1998). These expressions enable the assessment of the need to heighten stacks due to building downwash and pollutant trapping in the recirculating regions.

To study the compliance with ambient pollutant concentration limits, a simple long- and short-term Gaussian dispersion model is used to determine ambient pollutant concentrations that result from specific maximum emissions, stack geometry, and location (near large buildings) and meteorological data. The Gaussian long-term model used is based on the TCM-2b model (Texas Climatological

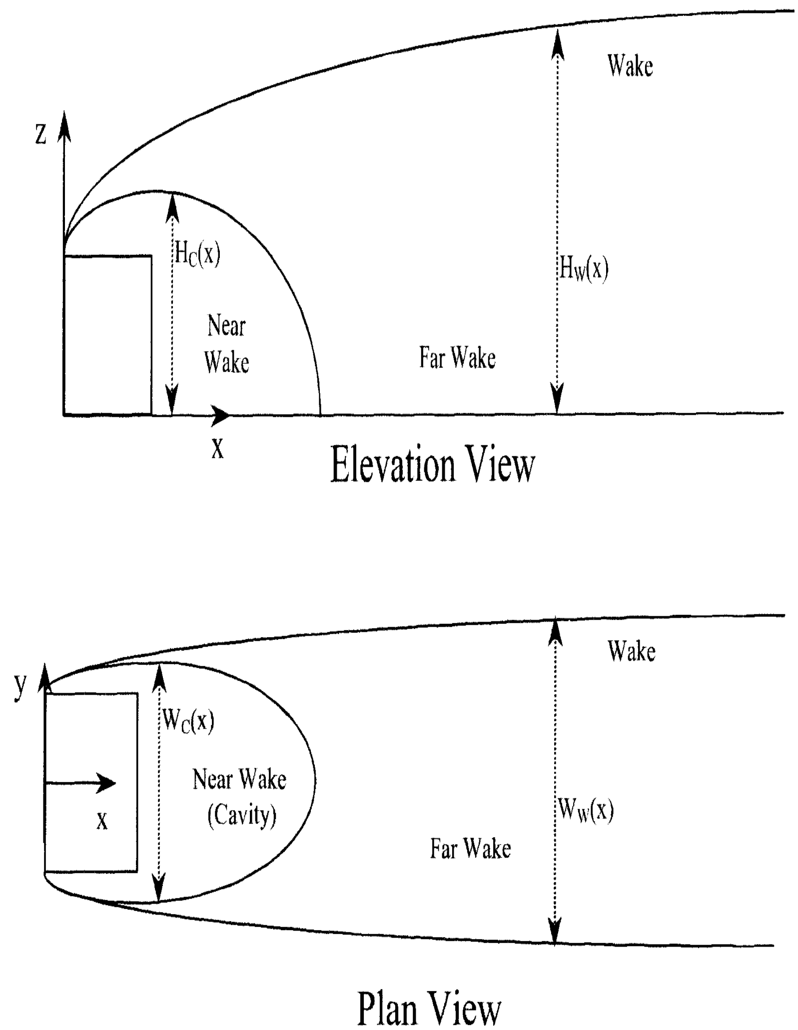

FIGURE 2 Near and far wake geometry (Schulman *et al.*, 1998).**[AuQ7]**

Model, 1980). The average annual, winter, summer, or hourly modeling results are compared with existing limits for different pollutants for compliance assessment. The authors' experience shows that for the pollutant flow volumes emitted by small- to medium-sized industrial facilities, pollutant dispersal problems are mainly associated with building downwash or specific meteorological phenomena. This conclusion stresses the importance of an analysis of airflow patterns around main buildings and of the recirculating cavity dimension calculations. For larger industries, with larger pollutant flow volume emissions and a more planned typical large industry layout, the simpler Gaussian dispersion models become more appropriate to predict possible air quality problems near the industrial facility.

An analysis of the results from the downwash and Gaussian modeling studies enables us to recommend alterations to stack height, stack location, and plant layout and can even justify cost-effective process improvements.

CONCLUSIONS

The maintenance of adequate air quality is a very important issue, and legislation that imposes limit values on pollutant emissions and stack height along with limits of ambient pollutant concentration can contribute effectively to air quality control. The actual applicability of this legislation to the existing industry particularities should be, however, stressed. When this is not the case, a real danger of not considering the use of the legislations occurs.

This is perhaps what is happening in Portugal with the 1990 Portuguese Air Act stack height calculation rule, which proves inadequate for the majority of SMEs. A methodology for atmospheric pollutant dispersal modeling, such as the one used by the authors, is considered adequate. This methodology considers, along with simple Gaussian dispersion modeling, building downwash, which is of great importance in the analysis of SME air quality problems.

The lack of understanding of atmospheric pollutant dispersal would perhaps suggest the need for increased sensibilization actions near industry and nonenvironmental governmental and municipal institutions. This sensibilization would certainly prove very useful, along with a revision of the Portuguese legislation on stack heightening.

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