Analysis of Air Draught Influence on the Local Ventilation Efficiency Through CFD Modelling

Rota R, Canossa L, Nano G
Politecnico di Milano, Dip. Chimica Fisica Applicata, Milano, Italy

In many industrial premises local ventilation, that usually provides a better control with the use of a lower air flow rate than general ventilation, is often required. In particular, several industrial processes use open surface tanks which may contain harmful substances whose evaporation in the workplaces has to be controlled. This can be done using different devices, such as lateral suction slots or push-pull systems. Lateral exhaust slots may be used for small tanks since they become prohibitively expensive for tank width exceeding about 0.6 m (1). The reason is that the air speed decreases very rapidly with the distance from the hood since the air flow is non-directional. In the push-pull ventilation system a jet of air (whose flow is highly directional and keeps its effects longer) is blown from one side of the tank and it is sucked in by a hood on the opposite side. Such a jet captures the pollutants and carries them into the exhaust hood.

Design guidelines for these ventilation systems are mainly based on practice and experiments, giving recommendations for a restricted range of operative and environmental parameters. While useful, these guidelines do not account in a clear way for the effect of different air draughts. Consequently, the main aim of this work has been to investigate the behavior of local ventilation systems in the presence of significant air draughts using mathematical models developed in the frame of the Computational Fluid Dynamics (CFD) to deduce quantitative guidelines for such conditions.

The influence of an environmental air current on the efficiency of a lateral suction slot has been investigated experimentally by Régnier et al. (2) using a full-scale model of an open surface tank located in a wind tun-nel with controlled air draught intensity. This study showed that, using reasonable values for both the environmental air velocity and the exhaust flow rate pulled by the lateral hood, the capture efficiency ranges from about 100% to 50%. The same study also evidenced that different values of both the velocity of the air draught (V_D) and the exhaust flow rate

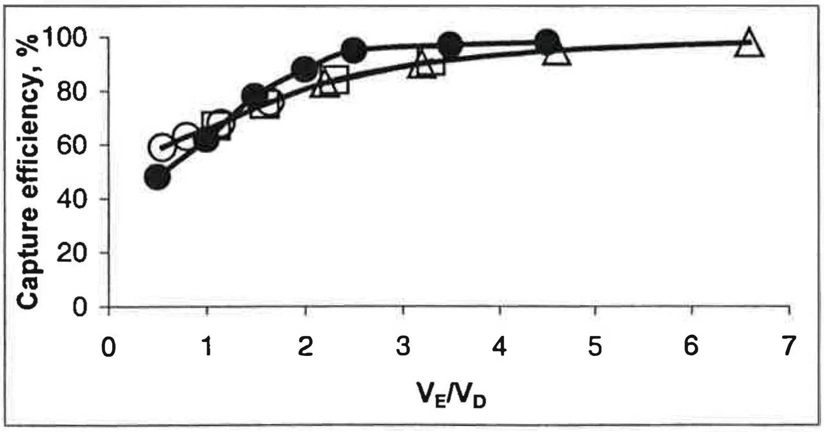

Figure 1. Capture efficiency as a function of the ratio V_E/V_D. (•) experimental data (2). Empty symbols are CFD model predictions: (O) $V_D = 1$ m/s; (□) $V_D = 0.5$ m/s; (Δ) $V_D = 0.25$ m/s.

lead to similar values of the capture efficiency when the ratio V_E/V_D is the same (V_E is the ratio between the exhaust flow rate and the surface of the tank), as summarized in figure 1.

The same figure also reports the predictions of the CFD model for different values of both V_E and V_D. We can see that not only model predictions (which are indeed true predictions, that is, no parameters of the model have been tuned on these experimental data) compare favorably with the experimental results, but also that the model predicts almost the same efficiency value for different values of V_E and V_D when leading to the same ratio V_E/V_D. This is an important point that adds confidence to the mathematical model, thus allowing for its use in simulating different conditions as well as in getting more insights on the reasons of the efficiency drop. The analysis of the velocity field over the tank surface (see figure 2) shows that since the air draught blows in the opposite direction of the exhaust flow there exists a region where the flow direction changes. When this region is over the tank, a portion of the pollutant emitted cannot be captured and the capture efficiency decreases. It has been found that increasing the V_E/V_D ratio this region moves outside the tank surface, thus leading to efficiency values close to 100%. Moreover, it has been also found that this region is located in the same position for configurations with the same efficiency, regardless the single values of V_E and V_D.

A similar analysis has been carried out for a push-pull ventilation system. Also in this case the basic design fulfilling the suggestions of (1) results in an almost complete capture of the pollutant as long as the velocity of the air draught is low (that is, lower than about 0.3 m/s). As expected the performance of the push-pull system is excellent in this standard situation. When the air draught velocity is increased up to about 0.4 m/s the capture efficiency decreases to about 80%, clearly showing that the push-pull system is becoming sensitive to the presence of air draught.

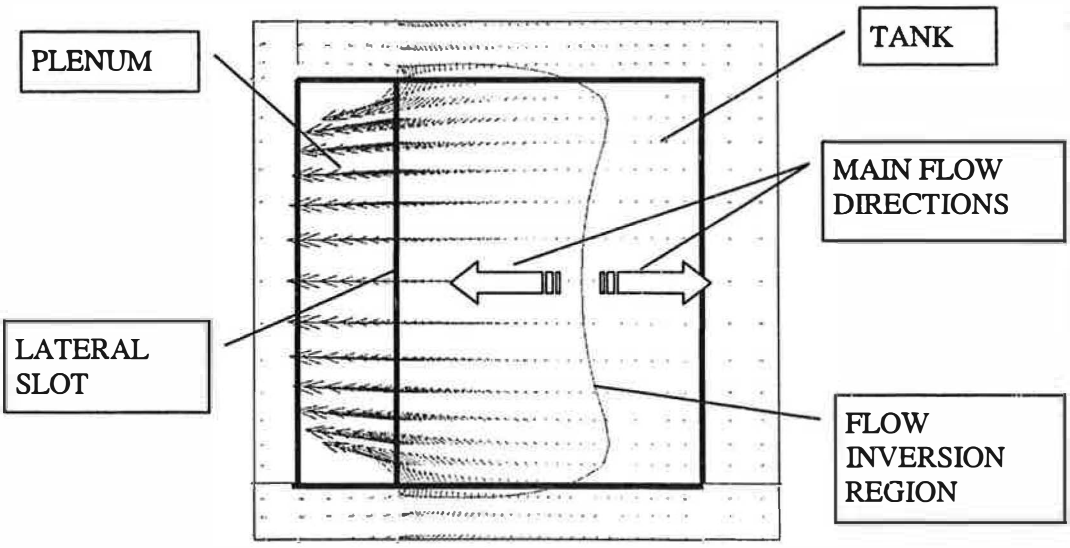

Figure 2. Velocity field over the tank computed by the CFD model.

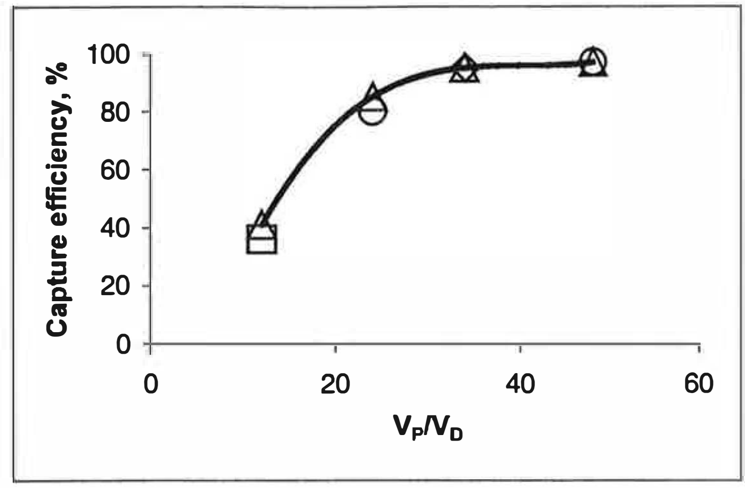

Figure 3. Capture efficiency as a function of the ratio V_P/V_D. (Δ) $V_D = 0.2$ m/s; (◊) $V_D = 0.3$ m/s; (O) $V_D = 0.4$ m/s; (□) $V_D = 0.8$ m/s.

As in the previous case, the effect of the air current velocity can be deduced from the air velocity field showing that the air jet from the push nozzle to the exhaust hood can be broken by the antagonistic air draught, leading to a fall of the capture efficiency. In this case, to increase the capture efficiency in the presence of high air velocity the push supply, and consequently the pull air flow rate to which it is related, has to be increased.

Figure 3 shows that, similarly to the previous situation involving only a lateral suction slot, different values of the velocity of the push jet (V_P) and of the air draught (V_D) leading to the same ratio V_P/V_D result in almost equal capture efficiency values. This is true not only for high values of the capture efficiency but also for situations with capture efficiency of the order of 40%.

In conclusion, the use of a CFD simulation model to examine the influence of air draught on the efficiency of local ventilation systems leads to the following guidelines. Once designed the ventilation system without considering any significant air draught (this can be done using well established guidelines such as (1), which account for air draught velocity up to about 0.3 m/s) the exhaust flow rate computed for a lateral suction slot has to be multiplied by (V_D/0.3), being V_D the estimated air draught velocity in m/s. However, when a push-pull system is considered, the velocity of the push supply has to be multiplied by the same value (V_D/0.3). In this last case, also the exhaust hood flow rate and geometry have to be recomputed using standard guidelines with the new value of the push flow rate.

References

1. Industrial Ventilation. A manual of recommended practice, 22nd ed., ACGIH, Lansing (MI), 1995
2. Régnier R., Dessagne J. M., Bonthoux F. Cuve de traitement de surface. Performances de fentes d'aspiration latérales, Cahiers de Notes Documentaires 1996; 165:425–440