Reducing power consumption of local exhaust ventilation systems

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Abstract. Local exhaust ventilation systems have become the most popular choice for capturing and containing releases of gas-borne dust contaminants in various fields of human activities. Energy conservation techniques have to be developed for these systems while ensuring that their contaminant capture efficiency is not compromised. This study summarizes our developments in the field of energy-saving techniques relying on the properties of detached, twisted and recycled flows of dust-laden air.

Introduction

Local exhaust ventilation [1,2] is the most reliable means of contaminant removal in various industries across wide range of personnel activities and workplaces. Local exhaust ventilation designs and layouts affect the indoor air quality and, consequently, occupants’ health. A local exhaust device is the core component of the local exhaust ventilation system. The device must maintain an airflow high enough for air in the contaminant release area to reach the required velocity for their entrapment. Excess velocity translates into waste of electricity by the local exhaust ventilation system. This calls, on the one hand, for improving the precision of data on the airflow velocity field in the area serviced by local exhaust, and on the other hand, for investigating options for increasing airflow velocity in the contaminant origination area without an added power-consumption overhead.

Our goal in this study is the development of technical proposals for increasing the efficiency of local exhaust ventilation systems and their operational energy savings.

Research Method

Flows within the reach of local exhaust systems are computed using the potential flow method [3] with additional reliance on the perfect fluid jet theory [4] as well as Navier-Stokes equations for viscous media, facilitated by state-of-the-art computational fluid dynamics (CFD) software [1,2]. Among the methods used for computing potential flows, the most productive are the conformal mapping method and Nikolay Ye. Zhukovsky’s method [4] for determining outlines of flow separation areas, although they are not applicable for manifold areas and are only operational in planar approximation. It is noted in [3] that the conformal mapping method can sometimes yield a more accurate solution than CFD. The method of boundary integral equations [2,5] enables the velocity field to be determined for any complex area boundaries in 2D or 3D, albeit without accounting for flow separation. The discrete vortex method (DVM) with its track record of flow computations for airplane and helicopter airfoil, propulsion screws, buildings and structures [6] and airplane vortex streets has been tailored successfully for solving aerodynamics problems in ventilation systems [2]. For example,
non-stationary discrete vortices are used for computations of flow separation at exhaust hood inlet. In a stationary setting this method was used in [7] to calculate flow separation at the inlet of a circular exhaust hood. Methods used for obtaining the results stated above include DVM in a stationary setting, CFD [1,8], and methods for solving differential equations [2].

**Results and Discussion**

Major consumers of electric power in dust removal systems include forced-draft units (fans, smoke exhausters). The power draw of motors in these exhaust devices is directly proportional to the product of the total flow rate of air removed by the fan and the drag exerted by the trunk exhaust network (air ducts, dust traps, discharge piping) and inversely proportional to the efficiency factor of the fan and transmission.

That said, options for operational power savings in local exhaust ventilation systems are mainly investigated along the following three lines: a) minimizing the volume of evacuated air while maintaining contaminant capture efficiency; b) minimizing pressure losses in aspiration network components; c) improving fan efficiency.

1.1. Reducing the flow rate of leaked-in air

The effect of jet detachment from thin hoods (Fig. 1a) can be used to reduce the flow rate of air coming in through leaks in closed-type local suction devices, thereby also minimizing the volume of air sucked in. The wider the detachment zone at the inlet of a suction duct, the greater will be the local drag coefficient of the cowl inlet and the smaller will be the flow rate of air leaked in. Assuming a fixed length of a vertical baffle \( d_0 \) with varying distance \( r \) to the horizontal buffer, the width of the separation zone can be seen to reach its maximum in the range \( 0.55 < r < 0.75 \) for the flat setting of the problem or \( 0.3 < r < 0.35 \) for the axisymmetric setting. The efficiency of this approach was confirmed experimentally in [9]. The study considered the effect of horizontal, vertical, slanting and dihedral impermeable plants (hoods) on the LDC at the inlet of a leakage opening (Fig. 1b). It was shown that fitting the leakage opening with a horizontal hood having a length of 0.5-0.7 gauge (the gauge understood as the height of the leakage opening) and an L-beam 1 gauge high and 0.5 gauge wide at a distance of 0.5 to 1 gauge away from the hood enables an airflow rate reduction in excess of 17%.

![Figure 1](image1.png)

**Figure 1:** Using detached flow properties for minimizing air leakages into the exhaust cowl: a – streamlines at inlet of slotted opening; b – a device reducing air leakage into the slotted opening: 1 – hood, 2 – L-beam, 3 – airflow-stabilizing walls, 4 – bolted joint, 5 – long side of the L-beam, 6 – short side of the L-beam, 7 – exhaust cowl wall.

1.2. Shaping along identified vortex zone boundaries

Edge shaping along the boundaries of *in situ* vortex zones enables a reduction of pressure losses in the exhaust network by virtue of reduction of energy losses on overcoming local drag. Discrete vortex [2,
vortex ring [7] and vortex polygon methods were used for determining the boundaries of vortex zones at exhaust duct inlets. For example, by determining the boundaries of a vortex zone (Fig. 2) and shaping the exhaust ducts along these boundaries, the local drag coefficient can be reduced by as much as 98%, with a concomitant reduction in pressure losses in the exhaust ventilation system [11].

Other formed members of exhaust ventilation systems can also be shaped to reduce pressure losses. Separated flows in a sharp-pointed elbow featuring a dead-end recess were studied in a two-dimensional setting in [12]. For a range of recess depths, vortex zone boundaries were determined and shaping was performed along these boundaries. A shaped elbow was found to feature 30% to 50% lower drag than a sharp-edged one. A numerical simulation study [13] considered junction of flows in a Y-piece. Shaping was performed using vortex zone boundaries determined for a flow detached from the inner edge of a Y-piece. Shaped Y-pieces were found to confer a threefold benefit in terms of drag losses than regular designs.

Aerodynamic computations for shaped vs. unshaped ducts of a local exhaust ventilation system (10,000 m³/h, 10 funnel-shaped exhaust ducts) suggest a 35% reduction in pressure losses resulting in a 21% decrease in electricity consumption.

Figure 2: Suction hood with a 180° opening angle: a – first vortex zone; b – second vortex zone; c – hood shaped along vortex zone boundaries determined using DVM

1.3. Air-jet baffling

Even as airflow rates are brought down, air velocity at the exhaust opening must not be allowed to fall, as contaminant trapping efficiency would be compromised otherwise. Therefore power saving is guided by the need of maintaining an optimum airflow velocity near the exhaust opening while minimizing the overall flow rate of air approaching the opening. Options include aerodynamic/mechanical deflection and improving the geometric shape of exhaust devices. Aerodynamic deflection or activation involves the use of jet currents of air. An air jet directed to a local exhaust device will improve its efficiency dramatically. The velocity of approaching air may also be boosted with the use of an oncoming air jet emanating from the end face of the hood. Helicoid-shaped jets provide a further enhancement to the efficiency of local exhaust devices (Fig. 3) as a result of air approaching the exhaust hood at an increased speed.
Flow twisting can be effected by means of a rotary exhaust cylinder with disks mounted on it [15].

1.4. Reducing ejected airflow

The flow rate of air entrained by loose material is the main contributor to the performance of local exhaust ventilation systems removing air from loose material handling locations. A promising direction of ejected airflow reduction is to use the properties of recycling flows. Air recycling is ensured by means of a bypass chamber [2] coupled aerodynamically with the inner space of the loading chute (Fig. 4). A bypass chamber with a transit air interchange is provided around the porous circular pipe between cowl of the handling facility with aspirated lower cowl. A significant drop in the flow rate of ejected air is proved by solving the resulting differential equations for the ejected air dynamics and recycle air dynamics. Experimental studies validate theoretical findings. The flow rate of air entrained by loose material can be reduced as much as 80%.

Forced recycling is also possible [16]. Computer simulations show that recycled jet should be supplied to the loading chute at an angle against the flow of loose material; the greater the angle toward the flow, the greater will be the reduction in ejection flow rate. At a supply angle of 60° the flow rate of ejected air is reduced by more than 70% with the ratio of recycled airflow to ejected airflow exceeding 0.8 (Fig.5).
Figure 4: Dust removal layout for a loose material handling facility (6) equipped with upper (1) and lower (2) exhaust cowls, a perforated chute (3) with a bypass chamber (4), and a flow-shaping chamber (5) in the lower cowl.

Figure 5: Layout of recycled air supplied to the chute: a – isosurface of full pressures; b – isosurfaces of velocities, c – streamlines
Conclusion

Our findings may contribute to the design of energy-efficient local dust removal ventilation systems. Topics of studies include:
- Studying separated flows at inlet of slotted and rectangular exhaust hoods, determining the effect of incident air flows, cross-flows and dust particles suspended in air, and evaluating the impact of process equipment located within the operating range of the local exhaust hood.
- Evaluating various exhaust hood shapes in terms of dust particle capture efficiency, including shapes matching determined separation zone outlines.
- Creating a multi-variable model of a baffled local exhaust device and determining properties ensuring optimal performance.
- Experimental-scale deployment of loading devices and aspirated cowls with recycled airflows in the field.

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