Capture Envelope of an Exhausted Opening Under Cross Draft –An Experimental Approach

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Introduction

The exterior hood has been used extensively in the local exhaust devices to capture a variety of comtaminats generated in a working-site(1). The performance of a hood can be measured by either how well it captures the comtaminants or how far away it can perform an effective capture.

It has been known theoretically that in the presence of an uniform cross draft a capture envelope will form in front of an exhausted opening(2, 3). All streamlines inside an envelope will lead into the opening; otherwise, those outside the envelope will lead to infinity downstream. Therefore, a comtaminant inside the envelope tends to be captured by the opening.

In this study, the capture envelope formed under the combination of exhuat airflow generated by an exterior hood and a uniform cross draft is observed in a wind tunnel.

Experimental Facilities

A low speed wind tunnel as shown in Figure 1 is built and generates an uniform cross draft at given velocity V_c. The test section has a length of 120 cm, and a cross section of 50 cm $\times$50 cm. It is surrounded by transparent acrylic plates for easy observation. The hood is installed at the center of the upper plate in the test section. The diameter of the opening D = 10 cm. A thin plate measured at 30 cm × 30 cm is served as a flange. The hood is imersed in the test section at 4 cm. A Fiber Flow® 2D Laser Doppler velocimetry (LDV) manufactured by Dantec™ is used to measure the flow velocities in the test section. Due to the limitation of the 2D LDV, only the airflow velocities on the central plane are measured.

As shown in Figure 1., a coordinate is defined on the center of the hood opening, with x-axis along the cross draft, and z-axis as the central axis of the opening.

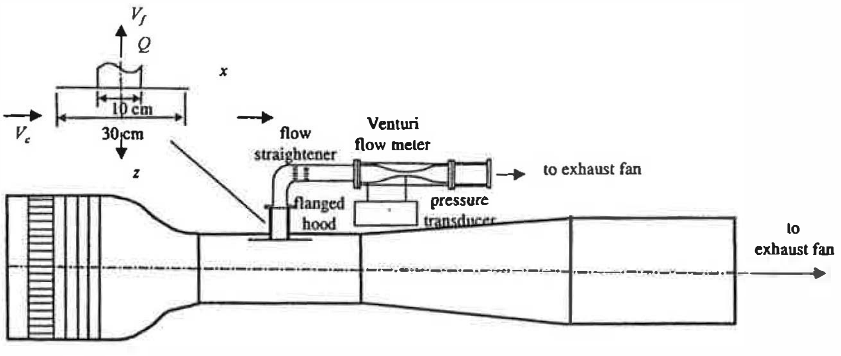


Figure 1. A low speed wind tunnel used in this study.

Limiting Streamlines

The experiments are conducted under three different exhausted airflows: 0.042, 0.057 and 0.079 m^3/s, which, respectively, give three average face velocity at the opening: 5.35, 7.26 and 10.1 m/s. The cross draft velocity generated by the wind tunnel ranges between 0.4 and 2.0 m/s. The ranges for the variation of the exhausted airflow and cross draft are determined from the condition whereby an exterior hood used in the working-site may operate.

At a given average face velocity at the opening V_f and cross draft velocity V_c, as shown in Figure 2, the flow velocity vetors on the central plane of the test sction are measured by the LDV. The streamlines then can be traced by interpolation on the vectors starting from any point upstream of the cross draft. Figure 2 also shows the capture envelope bounded by a limiting streamline. Once the limiting streamline is identified, the extent of the capture envelope is revealed.

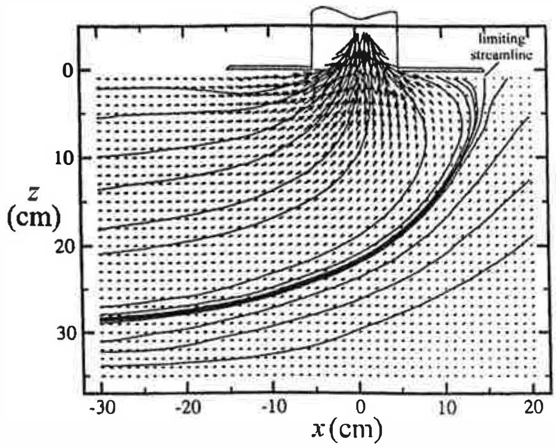
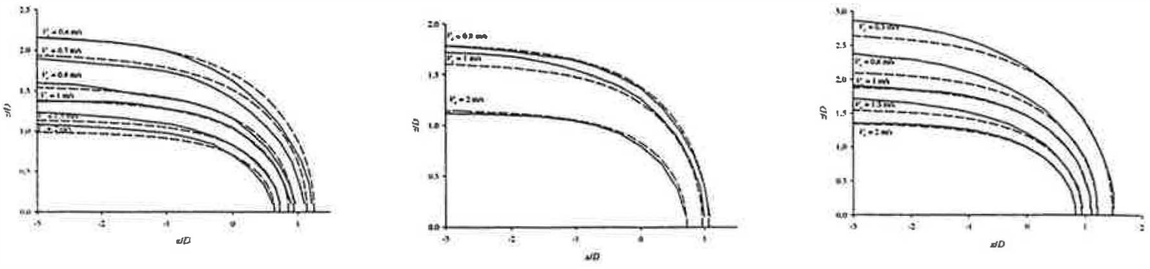


Figure 2. The streamlines can be trcaed by interpolating from the air flow vectors. A limiting streamline, which is located on the boundary of a capture envelope, then is revealed. The airflow vectors are measured at $V_f = 10.1$ m/s and $V_c = 0.5$ m/s.

Figure 3 shows the limiting streamlines, or the boundary of the capture envelope, determined from the flow vectors measured by the LDV at different V_f s and V_c s. The extent of the envelope increases while V_c decreases or V_f increases. In the other hands, the extent of the envelope decreases while V_c increases or V_f decreases.



(a) (b) (c)

Figure 3.The limiting streamlins, or the boundary of the capture envelope, at different V_f*s and* V_c*s: (a)* V_f *= 5.35 m/s; (b)* V_f *= 7.26 m/s; (c)* V_f *= 10.1 m/s. The solid lines are traced from the air flow vectors measued by the LDV; the dashed lines are the empirical fittings.*

The Geometry of the Capture Envelopes

The extent of the capture envelopes shown in Figure 3 is found to be controlled by three parameters: the extent of the envelope normal to the cross draft at infinite upstream, z_∞; the extent of the envelope normal to the cross draft along the opening axis, z_0; and the extent of the envelope on the flange downstream of the cross draft, x_s. It is also the location of a stagnation point where a limiting streamline meets with a flange. If a limiting streamline ends at a flange, the capture envelope in front of the opening is not expected to change significantly while the dimension of the flange changes, even though the flow field outside the envelope changes dramatically. Therefore, x_s can also be a parameter to regard a flange as an infinite one.

As shown in Figure 4, All z_∞ / D, z_0 / D and x_s / D are function of V_f / V_c only, and can be fitted empirically by

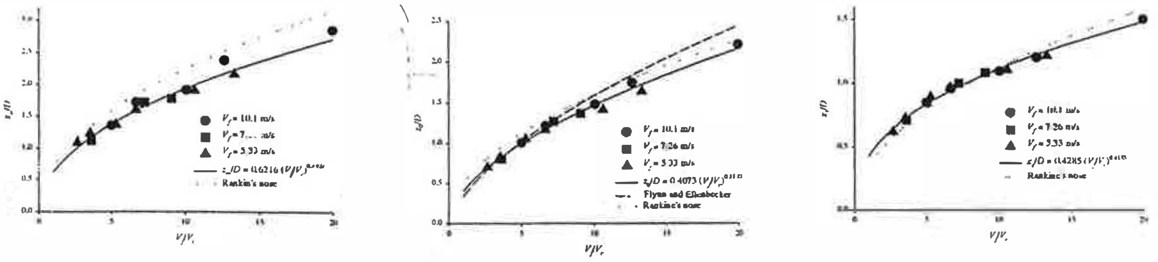
$$\frac{z_\infty}{D} = 0.6216\left(\frac{V_f}{V_c}\right)^{0.4924}, \tag{1}$$

$$\frac{z_0}{D} = 0.4073\left(\frac{V_f}{V_c}\right)^{0.5533}, \tag{2}$$

and

$$\frac{x_s}{D} = 0.4285\left(\frac{V_f}{V_c}\right)^{0.4135}, \tag{3}$$

respectively.



(a) (b) (c)

Figure 4.The fitting of the extent of the capture envelope in term of V_f/V_c*: (a)* z_∞/D*; (b)* z_0/D*; (c)* x_s/D*. The symbols are experimental results. The dotted lines define the extents for Rankine's nose, as given by Eqs.(1)-(3). The dashed line in (b) is an empirical fitting presented by Flynn and Ellenbecker.*

In an early study, by fitting the capture efficiency of the hood against the trace gas, Flynn and Ellenbecker gave the extent where 50% of the capture efficiency is accomplished(3). Their results are also shown in Fig. 4(b) for comparison.

As modified from the classical "Rakine's nose" problem, the geometry of the envelope on the center plane is given by(4)

$$\frac{x}{D}=\frac{x_s}{D}\frac{1-\left(\dfrac{z/D}{z_0/D}\right)^2}{\sqrt{1-\left(\dfrac{z/D}{z_\infty/D}\right)^2}}\quad. \tag{4}$$

By substituting Eqs.(1) to (3) into Eq.(4). as shown in Figure 3, the empirical fitting generally agrees with the limiting streamlines determined from the LDV measurements. Some greater deviationss are observed because z_∞/D has a more scattering relation with V_f/V_c(as seen in Figure 4(a)), otherwise, the empirical fitting shows an excellent agreement with the experiment. However, the greatest error of z_∞/D is still under 10%, which is generally acceptable for the purpose of hood design.

Acknowledgement

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