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# An Introductory Study in Center Push-Pull Ventilation


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# Summary Reports

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## An Introductory Study in Center Push-Pull Ventilation

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**This report presents the results of a study on center push-pull ventilation for open surface tanks. The study was performed on a full-scale mock tank which had fixed dimensions. The objectives of the study were as follows: 1) to develop a curve for the minimum pull flow for a given push flow (called a match point curve); 2) to develop velocity profiles for one match point; and 3) to characterize the general airflow patterns for the system. The respective methods used for the objectives of the study were as follows: smoke, put into the push blower inlet, with visual observation; smoke tube traces and velocity measurements with a hot wire anemometer; and smoke tube traces. All three objectives of the study were accomplished and are presented in the report along with a discussion of the results. Some recommendations are also made for future research.**

### Introduction

Since 1981, the National Institute for Occupational Safety and Health (NIOSH) has been studying push-pull ventilation for open surface tanks such as plating tanks. These studies have focused on two types of push-pull ventilation: side and center. In side push-pull ventilation, a jet of air from a nozzle along one side of the tank is blown (or pushed) across the tank and collected (or pulled) by an exhaust hood along the other parallel side of the tank. In center push-pull ventilation, a jet of air from a nozzle in the center of the tank is blown toward exhaust hoods on two parallel sides of the tank. The major part of the NIOSH work has been on side push-pull ventilation. This report summarizes the results of a one-year study on center push-pull ventilation, which was part of the overall NIOSH study on push-pull ventilation. Full details of the study can be found in a report submitted to NTIS.[1]

The study was performed on a center push-pull system that was installed on a simulated 2.44m (8-foot) wide open surface tank. The push part of the system was made employing methods and materials commonly used by design personnel in industry. The objectives of the study are listed below:

1. To find the match points for the push and pull parts of the system; these points are described later.
2. To develop the velocity profiles at one match point for the push only, the pull only, and the combination of the two.
3. To characterize the general airflow patterns of the system.

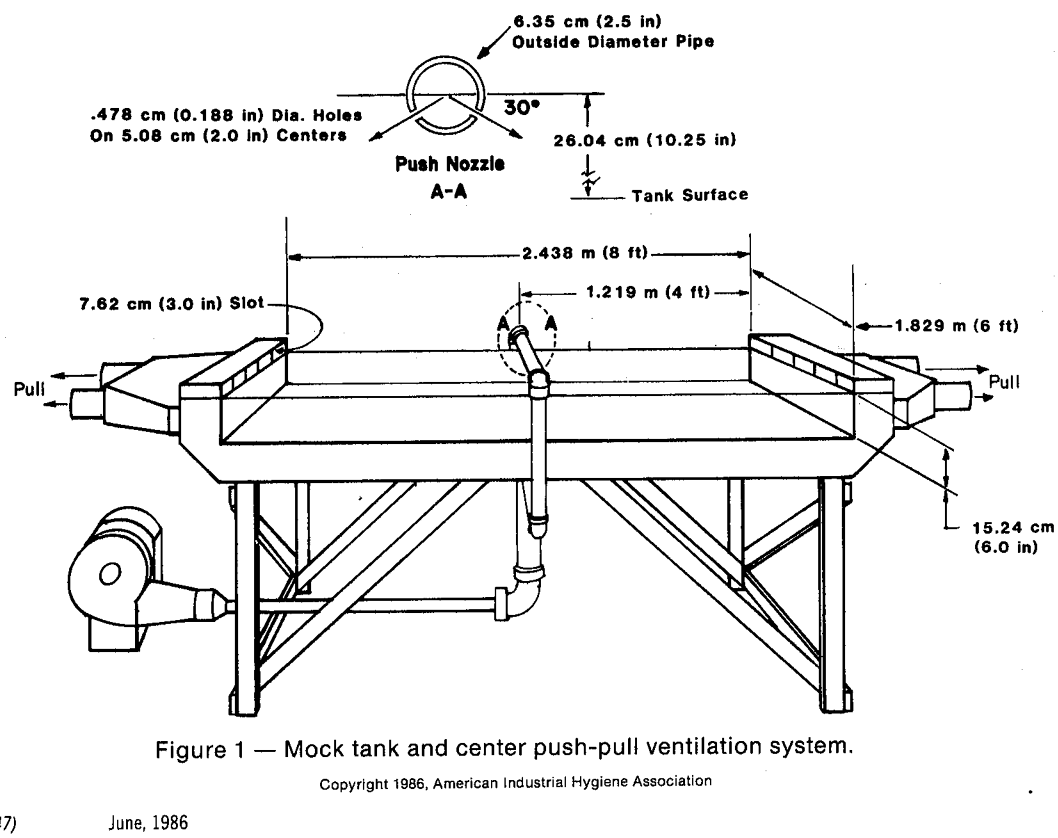


Figure 1 — Mock tank and center push-pull ventilation system.

The selection of the match points for the center push-pull system was the main objective of the study. Match points, as used in this report, are defined as the minimum pull flow needed to effectively control a given push flow. Using test methods similar to those in this study, Huebener and Hughes[2] discovered the existence of match points in their initial research for NIOSH on side push-pull ventilation. They also discovered that a family of match points could be found for a push-pull system; moreover, these points, when graphed, defined a curve that could be used to describe the minimum pull flow for a given push flow. The purpose of the match point part of this study was to find a similar family of match points for a center push-pull system. The purpose of the other two objectives of the study was to learn how the push-pull system worked.

**Method of Study**

Initially, a mock tank and center push-pull ventilation system were designed and constructed. The tank and ventilation are shown in Figure 1. The tank and system had adjustable push and pull flows, and the nozzle was a pipe with holes in it. Although other types of push nozzles — such as a slot and plenum — could have been used, a pipe with holes was selected because of its common use in industry. The end holes for the nozzle were located so that the jet expansion, based on Hemeon,[3] would be totally within the sides of the tank. The other holes for the nozzle were spaced on 5.08 cm (2 in) centers. As an additional part of the test setup, a baffle curtain was placed around the test area perimeter to reduce cross-drafts and assure an even air distribution into the test-setup area.

Second, test methods for the three parts of the study were selected. Because of its anticipated ease and simplicity, the selected method for the match point tests was smoke traces with observation. The smoke was generated by burning the smoke powder removed from smoke bombs. The smoke was put into the inlet of the push blower so that the smoke would cool as it went through the system and the blower would limit the volume of air entering the system. This eliminated the possible problems of convective forces and extra volume being generated from the powder combustion.

The methodology behind using the smoke was as follows: 1) to set the push flow, 2) to set the exhaust at maximum capacity, 3) to put smoke into the push blower inlet, and 4) to record observations on the smoke while incrementally reducing the exhaust flow. Enough preliminary runs with the smoke were made until a pattern in the system behavior was recognized. Then the judgment criteria to select the match points was chosen. For a fixed push flow, the criterion to select the corresponding match point exhaust flow was the point where 1) the smoke frequently spilled past the hood face a distance of 2.54 cm (1 in); or 2) when the smoke rose more than 60.96 cm (24 in) above the tank surface.

The method selected for the velocity profile part of the study was smoke traces in which commercial smoke tubes and readings from a hot-wire anemometer were used. A set of profiles was developed for the push only, the pull only, and the combination of the two. Velocity readings and smoke directions for the profiles were made along the table centerline at set distances from the nozzle centerline and at height increments of 2.54 cm (1 in) from the tank surface to the height where the velocity was about .25 M/s (50 fpm).

The method selected for the airflow pattern part of the study was smoke traces in which commercial smoke tubes were used with observation. Puffs of smoke from a smoke tube were blown around the tank, and the smoke patterns were recorded.

Third, two preliminary tests were performed to find the optimum hole size for the push nozzle and the best angle for the push nozzle. The best hole size for the push nozzle was found by trial and error, by the use of smoke traces and a vane anemometer (Figure 1). After verification of even flow distribution at several different flows, a .48 cm (3/16 inch) diameter hole was selected. This hole size follows the recommendation of Yung, Curran and Calvert[4] that the total nozzle outlet area be less than 37% of the cross-sectional area of the nozzle manifold.

The best angle for the push nozzle was found using smoke traces and observations at a set push flow at five pre-selected angles between 0 and 90 degrees. The best angle appeared to be 30 degrees from the horizontal. At greater angles, the air tended to be shot directly at the table surface, which caused a great deal of turbulence close to the nozzle. At a lesser angle, the air tended to overshoot the top of the exhaust hoods.

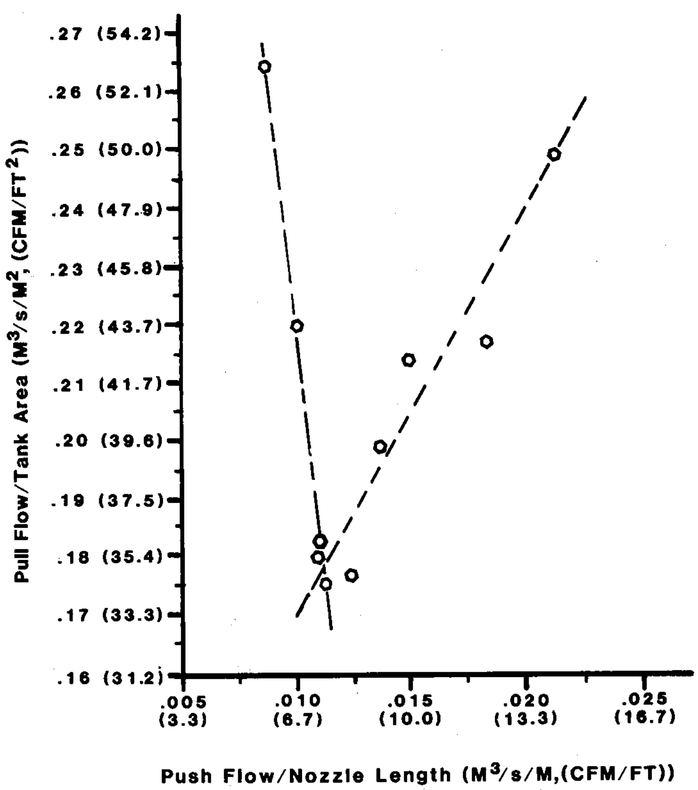


Figure 2 — Match points for the center push-pull ventilation system.

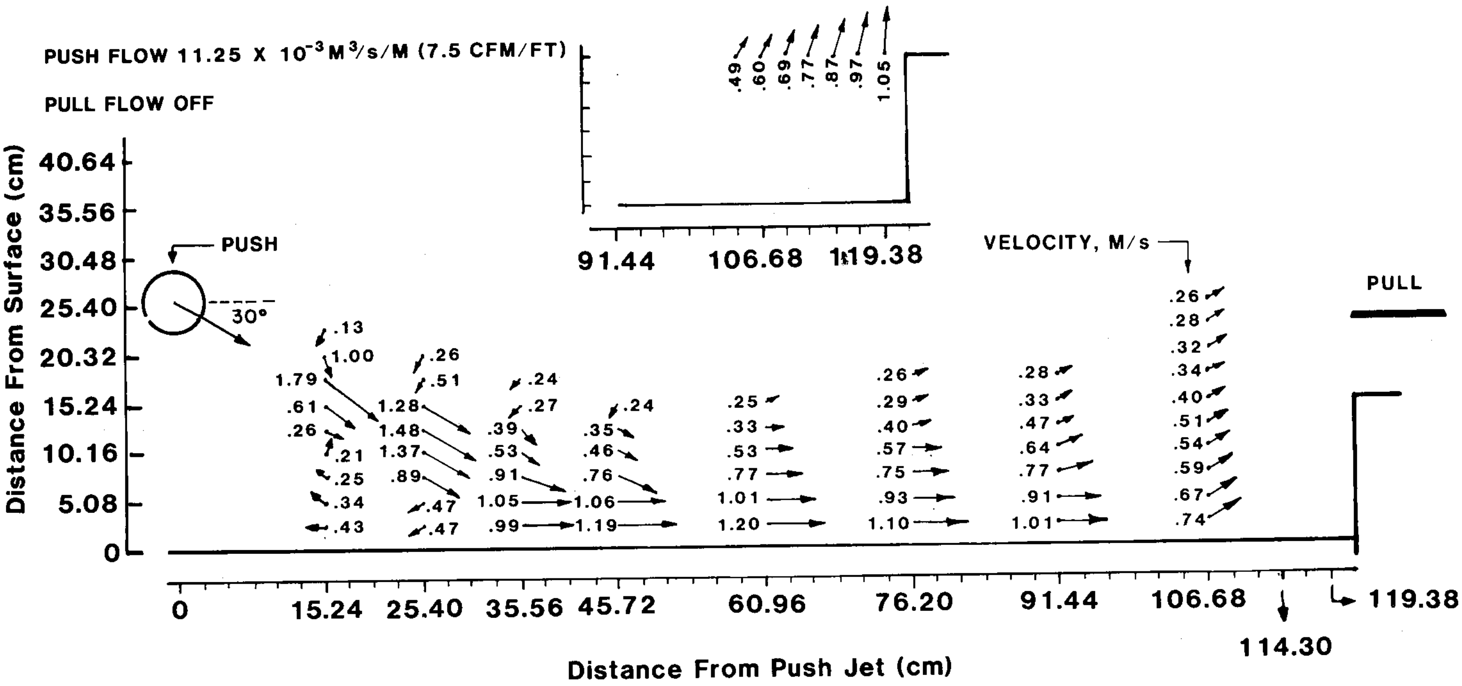


Figure 3 — Velocity vector profile (push only).

**Discussion**

The match points for the push-pull system are plotted in Figure 2. Immediately evident is the sudden break in the graph at the push flow per unit length of about .011 $M^3/s/M$ (7.5 cfm/ft). The sudden break in the graph definitely indicates that some type of optimum point had been found, which is consistent with the findings of Huebener and Hughes.[2] Additional evaluations of the push system to try to discover the reason for the sudden change showed that it was not due to poor distribution of the push air at the nozzle. Checks at push flows of .008 $M^3/s/M$ (5.00 cfm/ft) and .010 $M^3/s/M$ (6.67 cfm/ft) showed that the flow stayed fairly uniform across the tank. In addition, the jets at these push flows were still able to travel completely across the tank surface to the hood. There was also no related change in the nozzle manifold pressure over the interval of the push flows where the break occurred. In fact, the relationship between the manifold pressure and the push flow was linear. In the end, no conclusions could be reached to explain the break.

Another aspect of the break in the graph is that match points for push flows to the right of the optimum point were selected using the criteria for smoke spilling past the hood face. The points to the left were selected using the criteria for smoke rising too far above the tank surface.

The velocity profiles for the push-pull system with the push only, the pull only, and the combination of the two are shown in Figures 3, 4 and 5, respectively. Figure 3 shows the characteristics of the jet after it leaves the nozzle. This figure shows that the jet attaches quickly to the table surface after leaving the nozzle and stays attached to the surface. When the jet reaches the hood, it changes direction and shoots straight up the hood. Furthermore, the peak velocity of the jet over the entire distance occurs within 2.54 cm (1 in) of the tank surface even after it turns up the hood face. Examination of the figure also shows the jet widening and the velocities diminishing as it travels along the surface away from the nozzle.

The profile of the pull system only in Figure 4 shows that the velocities in front of the hood diminish rapidly with distance from the hood face. They reach a velocity of .25 M/s (50 fpm) within only 15.24 cm (6 in) of the hood face. This vividly demonstrates why control of a tank surface by an exhaust system alone is not really feasible; moreover, much of the air is drawn from above and behind the hood. This further demonstrates the inefficiency of using only an exhaust system since the area for which control is desired is in front of the hood.

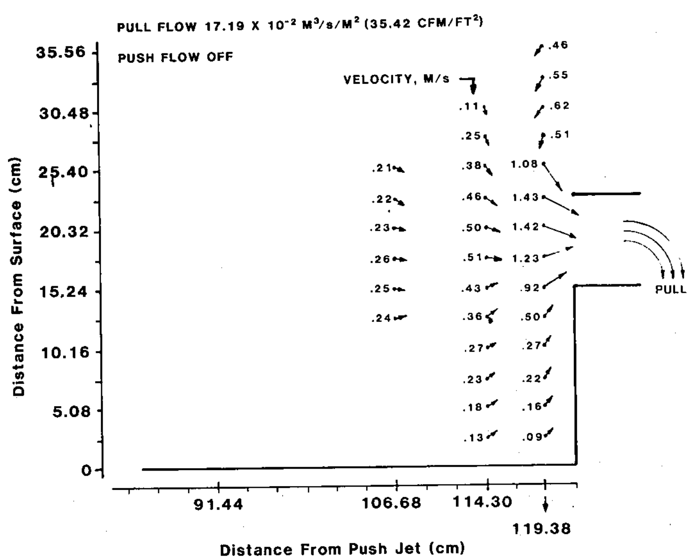


Figure 4 — Velocity vector profile (pull only).

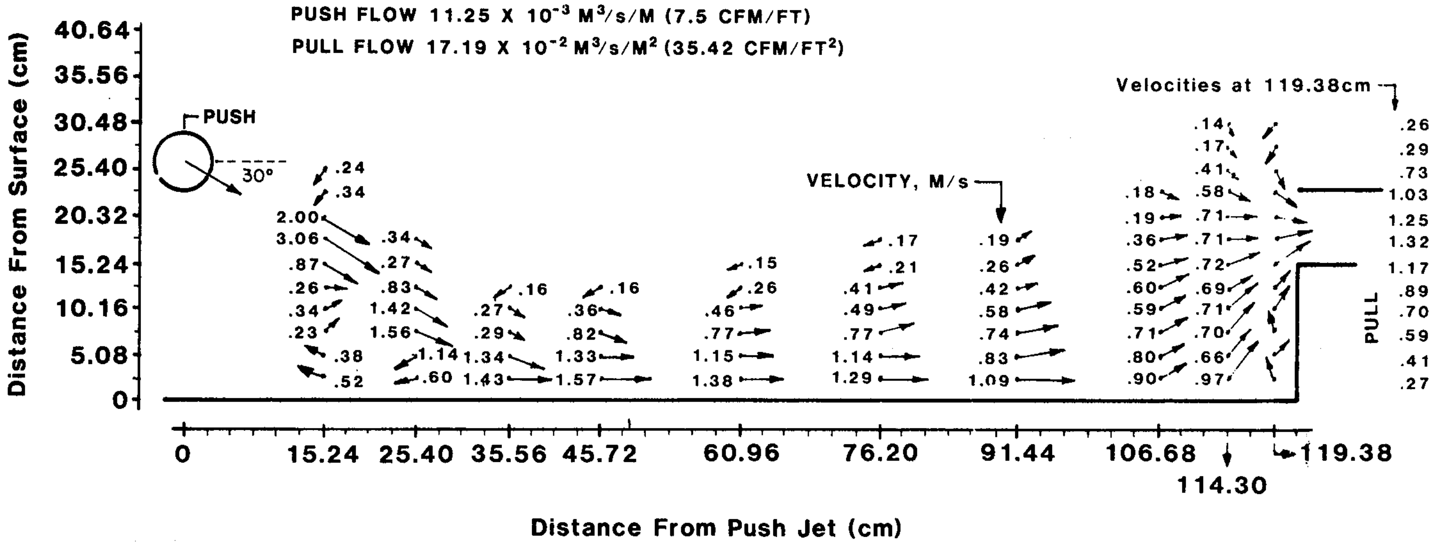


Figure 5 — Velocity vector profile (push-pull combination).

Merger of the push and pull as shown in Figure 5 discloses two interesting observations. First, the profile is about the same as for the push only for the airflows along the tank surface up to the hood. A great difference appears to occur next to the push nozzle, but this was believed to be due to positioning of the anemometer probe. At that close distance, it is very easy to move the probe a small distance and get a large change in velocity. Second, there is a great change in the velocities at the exhaust hood end. Here the airflow has shifted; less air now is drawn over the top of the hood and more from the front lower portion of the hood. More air is now drawn from the desired control area. Furthermore, when only the exhaust was used, the velocities in front of the hood fell off rapidly with distance from the hood face. With the addition of the push jet, the velocities in the same area in front of the hood are increased greatly to well above .51 M/s (100 fpm).

Based on the profiles, the push-pull system appears to work by two mechanisms. First, the exhaust captures the jet as it climbs the face of the hood. The hood does not appear actually to pull the jet off the tank surface into itself. Second, the control of contaminants (smoke in this case) was aided by the entraining of ambient air by the jet. The entrained air, which was pulled from all of the areas around the tank, further pulls escaped contaminant back to the tank. Whether this would occur in a drafty environment, however, is questionable.

The general airflow patterns developed from the smoke tube traces are shown in Figure 6. These patterns depict how the air moves into the perimeter of the tank. Figures 6a and b show that the jet at the nozzle entrains air from both the top and bottom. On the top of the jet, the air comes from above the tank surface. Under the jet, air is fed to the jet both by air split off from the original jet air when it hits the surface (Figure 6a) and by air pulled under the nozzle from the sides of the tank (Figure 6b). Air from the top of the jet was not observed to move from the top of the jet through the jet to the underside of the jet.

Figure 6c shows that, when the air traveling on the tank surface meets the sides of the tank, it climbs the sides of the tank and is rolled back over the tank surface. The air coming over the sides of the tank was observed to cause the rollback, effectively stopping any air from escaping over the sides of the tank. Without it, the jet would travel up the wall and continue in a straight parallel line away from the wall as was observed during the profile measurements at the hood face.

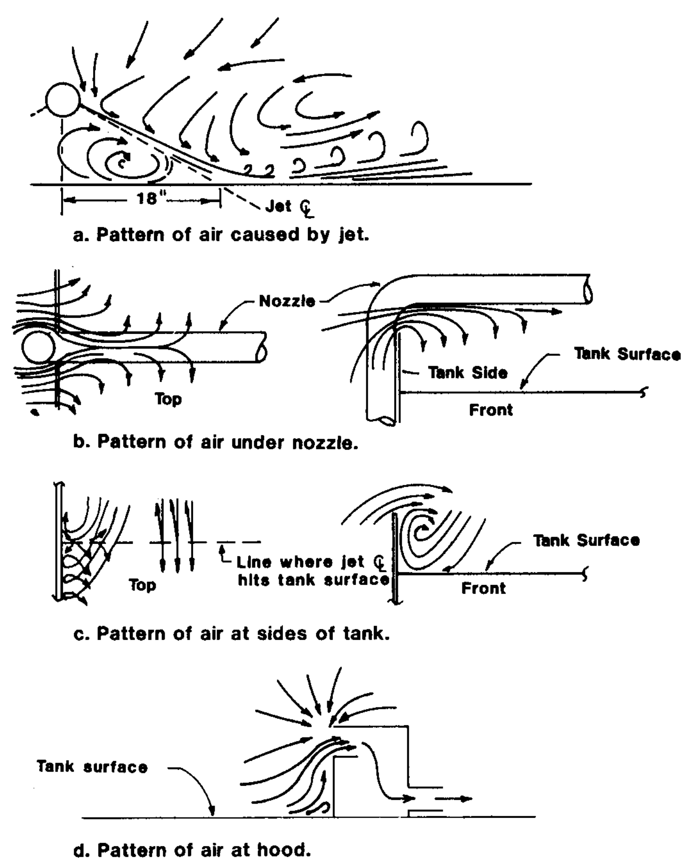


Figure 6 — General airflow patterns for the center push-pull ventilation system.

The air patterns at the hood are shown in Figure 6d. These patterns demonstrate that the jet air turns and climbs the hood face as verified in the velocity profiles. At the hood slot, the air turns and enters the hood. Virtually all of the air entering the lower two-thirds of the slot is jet and entrained air. The rest of the air entering the slot is mostly ambient air from above the hood.

## Conclusion

Although the information derived from this study contributes to the further understanding of push-pull ventilation, it can be considered to be only preliminary information as far as understanding center push-pull. A good deal of additional research is needed before a thorough and useful understanding of center push-pull is achieved. Some of the areas which need additional research to develop relationships to the center push-pull parameters are as follows: other system parameters (such as tank width, obstructions, and nozzle angle); environmental factors (such as drafts); and process conditions (such as bubbling and misting of the plating fluid).

For any future research, there are some recommendations that can be made based on this study. First, the smoke generation methodology caused some problems. Use of commercially available smoke generators which produce non-toxic, clean smoke is recommended. Second, the testing and data analysis, in which smoke with visual observation to select the match points was used, was difficult. The method required very good lighting and a good deal of training of the analyst. In addition, the selection of a point for a match point in each run was not always clear. Even though the obtained results are felt to be sound, a quantitative method of sampling in the duct may have been easier to use and possibly have yielded more usable results.

In conclusion, center push-pull can offer another option to designers for controlling emissions from plating tanks. This paper presents some understanding of center push-pull, but additional research is needed before a totally usable knowledge is available. Center push-pull as well as side push-pull are options worth considering for future research and design. They offer the potential for increased energy efficiency while increasing the protection of workers' health.

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