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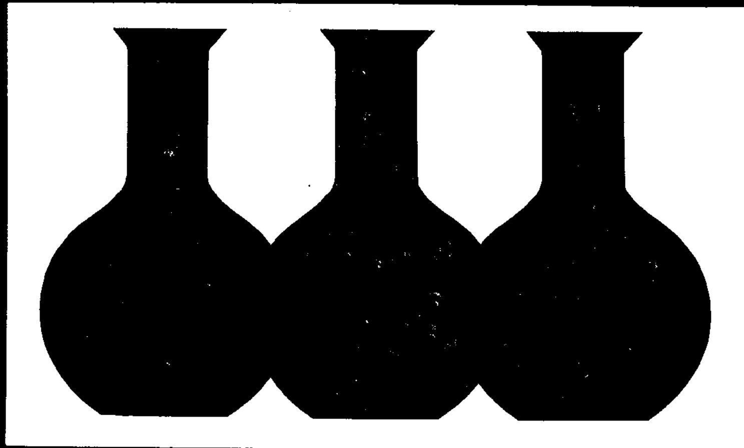

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16. Abstracts

A new design criteria for local exhaust systems for open surface tanks is developed taking into account higher gassing rates due to increased plating current densities, use of surface control agents such as plastic balls, push-pull ventilation methods for wide tanks and air agitated tanks. A hydrocarbon analyzer is used to monitor the amount of airborne contaminants emitted to the room and into the exhaust duct from a water-alcohol bath. Emission levels measured in the room for various operating conditions can be graphically related to the exhaust rate required to maintain specific threshold limit values for various baths as dictated by the toxicity and evaporation rate of the emitted material.

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DEVELOPMENT OF DESIGN CRITERIA FOR EXHAUST SYSTEMS FOR OPEN SURFACE TANKS

L. J. Flanigan, S. G. Talbert,
D. E. Semones, and B. C. Kim

Battelle
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

Contract No. HSM 099-71-61

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NIOSH Project Officers Note

The required exhaust flow rate for mist generation as specified on pages 60 and 61 are to be determined in the following manner.

1. Calculate K_{ae} as shown

2. Determine exhaust flow rate from Figure 37 as shown and label Q_1. This is the required flow rate of a 4 ft tank at 170°F. For other tank widths and temperature proceed to step 3.

3. Convert K_{ae} (from step 1) to an entry factor $(C_{ae})_e$ as follows:

$$(C_{ae})_e = \frac{K_{ae}}{1.9}$$

4. Determine exhaust flow rate (Q_2) from Figure 15 using entry factor $(C_{ae})_e$ as the room concentration of ethanol and the curve representing the actual tank width and/or temperature.

5. Using the same entry factor $(C_{ae})_e$ as in step 4 determine the exhaust flow rate (Q_3) from Figure 15, 4 ft, 170°F curve.

6. Correct exhaust flow rate Q_1 as follows

$$Q_1 \text{ corrected} = Q_1 \left(\frac{Q_2}{Q_3} \right)$$

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DEVELOPMENT OF DESIGN CRITERIA FOR EXHAUST SYSTEMS FOR OPEN SURFACE TANKS

Contract No. HSM 099-71-61

INTRODUCTION

The overall program had as its objective the development of design criteria for local exhaust systems which would assure the effective capture and removal of toxic contaminants emanating from open surface tanks. The project was divided into three phases having the following objectives:

Phase I. Identify and quantify those factors affecting emission and control of the toxic contaminants by conducting a survey of current industrial practice in the design, use, and operation of open surface tanks through a literature review and through discussions with users and equipment manufacturers.

Phase II. Plan an experimental program and design and construct an experimental open surface tank mock-up with a local exhaust hood and control monitoring apparatus capable of simulating representative tank temperatures, emission rates, surface control effects, evaporation of volatile liquids, and disturbances caused by room air motion.

Phase III. Develop design criteria for local exhaust systems based upon experimental measurements over the range of operating conditions identified in Phase I. These criteria are to include the effects of high gassing rates, surface control agents, evaporation rates, room air motion, and push-pull ventilation on tanks over 4 feet wide.

This final report summarizes the findings of the three phases of study, namely,

(1) Review of current tank ventilation practices

(2) Planning of the experimental program and design of equipment

(3) Development of design criteria based upon experimental studies.

In addition, a recommendation is given for additional work that is needed to more accurately classify the evaporation rate information given in the design manuals.

SUMMARY

The literature survey provided useful information on new processes, while the field visits were a better source of information with respect to current practices.

It was found that practically all of the exhaust hoods used by industry for open surface tanks are of the lateral, or semilateral, type. This is because, by exhausting from only one side or from opposite sides of a tank, ample space is available above the tank for baskets, conveyer mechanisms, etc. This type of hood also minimizes the potential exposure of personnel and equipment by capturing the toxic fumes near their source. Push-pull ventilation systems are gaining in usage, but not much design information is available.

Virtually all of the equipment manufacturers and users design their exhaust systems to the specifications contained in Industrial Ventilation, A Manual of Recommended Practice.[(1)*] The design criteria contained in the latest edition of this manual for exhaust systems for open surface tanks is essentially identical to that contained in the ANSI publication Z9.1-1971.[(2)] The existing design manuals were used as a basis for planning the laboratory experiments and designing the equipment.

In developing new design criteria for local exhaust systems for open surface tanks, the experimental studies took into account the trends toward

(1) Higher gassing rates due to increased plating current densities

(2) The use of surface control agents such as plastic balls

(3) Push-pull ventilation methods for wide tanks

(4) Air agitated tanks.

*Numbers in parentheses refer to References at end of report.

The experimental equipment, including a full-sized tank and hood, was designed to have sufficient flexibility to simulate the many operating conditions found in actual installations. The variables which were studied included the following:

(1) Hood design

(2) Tank width-to-length ratio

(3) Liquid and temperature level

(4) Exhaust flow rate

(5) Slot velocity

(6) Evaporation, air agitation, and gassing rates

(7) Cross drafts

(8) Makeup air introduction method.

A hydrocarbon analyzer was used to monitor the amount of airborne contaminants emitted to the room and into the exhaust duct from a water-alcohol bath.

From graphs presented in this report, the emission levels measured in the room for various operating conditions can now be related to the exhaust rate required to maintain specific TLV's (Threshold Limit Values) for various baths as dictated by the toxicity and evaporation rate of the emitted material.

REVIEW OF CURRENT PRACTICE

Literature Findings

The literature survey was conducted utilizing the BCL library, which provides excellent coverage of the pertinent fields of activity and also contains various indices of technical literature. In addition to surveying the literature, a survey letter was sent to 20 industrial tank and equipment manufacturers requesting information on examples of installations that (1) represented typical practice, (2) were significant with respect to size, and (3) were of advanced design. Contacts were also made with the health departments of a number of midwestern states requesting names of companies having advanced facilities.

Process Trends

Several new electrochemical processes with a potential need for emission controls were identified during the literature survey. These were

(1) Electrocoating, or Electropainting (EP)

(2) Electrochemical Machining (ECM)

(3) High-Speed Plating and Ultra-High Electrodeposition (UHE)

(4) Plating on Plastic Materials.

While electropainting or coating is a relatively new industrial process, the literature describes usage of compounds and materials that are generally listed in tables of hazardous chemicals of the ACGIH(1) and ANSI(2). For example, a commonly reported paint composition is the "amine-deficient" solution type. These paints are described as mainly polycarboxylic acid derivatives of alkyd, acrylic, epoxy, and polyester resins. Solubilization and dispersion may be achieved by adding a solubilizing amine such as diethylamine to the water solution of the carboxylic resin to produce a salt that is soluble in the water. The products of the electrolytic process usually are cathodic hydrogen gas and an anodically coated object. Alternate processes may occur at the cathode during anodic painting. For example, soluble ammonia may be formed instead of hydrogen. Also, the anodic formation of partially oxidized organics should be considered as an alternative anode reaction. The principal source of emissions requiring exhaust control appears to be mists formed by the evolving hydrogen while the solution is energized. Since operation is at or below normal room temperatures, evaporation is relatively minor, especially when no voltage gradient is imposed, as exists during electrolyzing of the solution.

The electrochemical machining processes cannot be classed as open-surface-tank operations because, characteristically, both the electrolysis zone and the electrolyte reservoir are totally enclosed. However, potentially hazardous emissions are generated. The container for the electrolysis zone serves two purposes: (1) hydrogen evolved at the cathode can readily be captured for exhausting and (2) splashing electrolyte is contained within the system for return to the circulation system. Anode and cathode current densities are equal and are in the range of 200 to 500 amps/in.^{2}. This current-density range is equal to 29×10^3 to 72×10^3 amps/ft^2, which is nearly three orders of magnitude greater than conventional plating current densities. Nevertheless, as explained earlier, the increased current densities do not generally result in emission-control problems because of the design of the ECM equipment and its auxiliary apparatus.

The high-speed plating and ultra-high electrodeposition (UHE) techniques involve higher current densities than conventional plating. In conventional plating the general range is from 5 to 300 amps/ft^2, while high-speed plating ranges from 100 to 500 amps/ft^2 and UHE reaches 1400 to 2900 amps/ft^2. The current densities for high-speed plating are not very much greater than the maximum current density for conventional plating. However, the much higher current densities of UHE are expected to produce higher gassing rates and, therefore, greater mist generation. At the present these processes are in the research stage, but in the future they undoubtedly will be adopted by industry.

The industrial procedures reported for plating on plastics offer no new hazardous chemicals or conditions for emission control. The processing of plastics is a rather recent development in large-scale industry such as in automotive applications. In practice, the processes are better described as adaptations of existing practices than as new practices.

A review of the recent literature on "Technical Developments in Metallic Finishes and Processes"[3] identified ongoing research on processes in the field. While these developments are now only in the R&D stage, they are developments which indicate future trends or practices in industry. Accordingly, the listing below gives laboratory developments that involve a component important to emission and control of contaminants. These developments include the uses of

(1) Organic compounds such as dioxane and formamide in aluminum anodizing

(2) Antimony and selenium in chemical coloring processes

(3) Chromic-sulfuric acids for anodizing titanium

(4) Additives such as chlorides, fluorides, chlorinated hydrocarbons, and arsenates to chromic-nitric-fluosilicic, or hydrofluoric acid baths for producing chromate conversion coatings

(5) Fluorinated surfactants in pickling aluminum

(6) Additives such as stannous chloride, sulfides, thiosulfates, and ethanolamine to solutions for pickling iron and steel

(7) Use of sulfides in solutions for pickling titanium

(8) Acid-dipping solutions of fluosilicic-hydrofluoric-nitric acid for titanium and titanium alloys

(9) Additions such as selenium stabilizers and sulfides to electroless copper plating baths based on fluoboric acid-hydrofluoric acid compositions (also, organics such as triamines)

(10) Reagents such as hydrazine and sulfamates in electroless nickel plating, as well as ammonia and stannous chloride

(11) Selenium-containing brighteners for copper electrodeposition.

Ventilation Criteria

In the literature survey a number of papers and articles were found which generally discussed ventilation, and some were found relating to specific applications and problems. However, essentially no data were found which could be used to establish new design criteria.

The primary reference manual used by industry to design exhaust systems, including hoods for open surface tanks, is Industrial Ventilation, A Manual of Recommended Practice.(1) This manual was prepared by a Committee on Industrial Ventilation for the American Conference of Governmental Industrial Hygienists. The latest (12th) edition was published this year. This publication includes essentially all of the design information contained in the American National Standard booklet, ANSI Z9.1-1971, on "Practices for Ventilation and Operation of Open Surface Tanks".(2)

Based on the design data given in the Industrial Ventilation Manual(1) or in the ANSI Z9.1-1971 Standard(2), the exhaust flow rates specified for open surface tanks depend on three basic factors. These are

(1) The hazard potential of the vapors escaping from a tank, which are designated A, B, C, or D depending on the TLV (Threshold Limit Value) of the contaminant

(2) The rate of gas, vapor, or mist evolution from the bath – rated as 1, 2, 3, or 4

(3) The type of exhaust hood used. When lateral exhaust hoods are used rather than enclosing or canopy hoods, then the ratio of tank width to tank length must also be considered.

The laboratory experiments were planned to verify whether or not the design criteria given in References (1) and (2) provided an adequate margin of safety. However, two areas of uncertainty were identified as regards the present design criteria.

The first area of uncertainty is the magnitude of the factor of safety included in the design flow rates. For example, one designer stated that the concentration in the worker's breathing zone around a properly operating tank will be approximately 1/10 of the TLV initially. Then as parts or baskets are lowered and raised, the contaminant level may increase to 1/4 or 1/2 of the TLV.

The second area not clearly defined is the basis on which the gassing or vapor evolution rates were determined. An attempt will be made to put these rates on a more quantitative basis so that the laboratory experiments will be representative of field operations as well as reproducible.

The design of push-pull systems for tank ventilation is not adequately covered in the design manuals. Several technical papers have been published giving various design parameters for push-pull hoods which proved helpful in planning the experiments.

A field survey was made which included discussions with equipment designers, industrial and governmental hygienists, and visits to both small and large users of various types of open tanks.

Process Changes

The process changes of note that were encountered in the field visits were of two types: (1) modifications of existing processes and (2) processes which have developed since the presently used design criteria were developed.

Modifications of Conventional Processes

Two noteworthy modifications of conventional processes were encountered in the field visits:

(1) The increased use of air agitation in metal electrodeposition processes. Perhaps greater than 75 percent of the nickel plating tanks now employ air agitation, with the air being introduced through perforated pipes located near the bottom of the tank. Many of these are modifications of original installations which did not include local exhaust ventilation systems, so while more and more platers have converted to using air agitation, not all that have been modified have been vented. The installation of exhaust systems seemed to depend upon how extensive the tank modifications were. Agitation air volumes as large as 2 cubic feet/minute for each square foot of open tank surface were used in typical mixed sulfate-chloride semi-bright or bright nickel baths. Temperatures were rather low at 130 to 140 F, and no appreciable gassing occurred at either the anode or the cathode during plating operations. Thus, the only additional gas to be exhausted was the air provided for solution agitation. The principal hazard is airborne mists of compounds such as nickel sulfate and nickel chloride. Naturally, some thermal updraft existed above the warm solution which lifted water vapor and aerosols. In one instance, an operator reported that a chemical analyses showed the mists to contain only steam in the emissions captured above nickel-plating tanks. Nevertheless, in work on this program it was assumed that any mist can contain chemicals from the solutions involved.

The acceptance of plated plastic parts has been an incentive to the use of air agitation in the plating of copper from acid copper solutions. The use of air agitation in copper plating increases the probability of forming airborne mists containing the chemicals from the copper bath. Airborne mists are produced because the air is purposely bubbled through the plating tank, as described previously for nickel plating.

(2) The development of mist suppressants. The use of chemical mist suppressants is practiced in chromium plating. However, platers do not usually change the exhaust ventilation practices because design guidelines are not available. For example, some operators continued to exhaust air at about the same rates as was used when no chemical suppressants were employed. Other operators reported circumstances wherein no local exhaust ventilation was used when suppressants were in the bath. The suppressants are frequently used for processes that use bright chromium as the final deposit. The temperature of

operation may be only as high as 130 F. The chromium plating process is inefficient, resulting in hydrogen evolution from perhaps 70 to 80 percent of the current at the cathode. In this instance, the electrochemical process adds to the potential hazard by production of fumes from the fine hydrogen bubbles escaping at the surface. This leads to the formation of airborne mists containing the chromic acid. Mist suppressants tend to overcome this problem by causing formation of a foam blanket at the solution surface. Local exhaust is frequently used for these open-surface tanks, even though a blanket of foam exists on top of the solution.

The chemical suppressants are not used in the so-called "hard-chromium" baths. Instead, plastic floats or hollow balls are used to cover the entire surface of the solution to lessen the mist formation described above. Venting is used in combination with the surface floats. Some platers prefer not to use floats, particularly when float size or shape is not compatible with the part or plating-rack geometry or position in the tank.

New Processes

Some of the new electrochemical processes that were observed during field visits include the following:

(1) Plating on plastics. Basically, the plastic-finishing industry has adopted previously accepted finishing practices to accomplish the highly specialized coating of plastics with metals. Since no new emissions are involved, the plastics processors encounter no special exhaust ventilation problems. Frequently, both plastic and metal parts are plated in the same plant. In fact, once metallized, the plastic parts can be plated in the same bath as the metal parts for final finishes such as bright nickel and bright chromium.

Sensitizing and activation baths contain stannic chloride and palladium chloride, respectively. Both baths contain hydrochloric acid. Mists that contain these chemicals represent a hazard, but the threshold-limit values of the chemicals are already identified in documents such as the ANSI standards. When electroless nickel is used, the same may be said for chemicals used to reduce nickel ions to yield the nickel coating. Except for the innovation of air agitation, as discussed earlier, no special exhaust needs are encountered in the acid copper baths used in the plating of plastic parts.

(2) Electrodeposition of paint (EP). The electrophoresis of dispersions of paint polymers in aqueous solutions (EP) is a new technology that has recently become a large-scale industrial process in the United States. In practice, some paint lines include a "tunnel" enclosure which covers the tank on all sides except for the openings at the entry and exit. Production parts are moved on the conveyer line through the enclosure. This type of hood enclosure aids in the local capture of exhaust emissions, whether due to evaporation or gas evolution. When an enclosure is used, the process is not strictly an open surface tank, but an exhaust

nevertheless is necessary because combustible gases are always a consideration, even though the electropainting is done in the aqueous solution. The automotive industry uses large tanks of this type for coating entire car bodies. Tank capacity may be as large as 50,000 gallons for car bodies or as small as 200 gallons for small parts. Normal ventilation procedures are reported to be adequate.

Exhaust Systems

The most common type of exhaust hood used by industry is the lateral exhaust hood, of which there are four basic variations:

(1) Single-slot, updraft or downdraft

(2) Multiple-slot, usually two

(3) Semilateral, extending over the edge of the tank

(4) Push-pull, employing an air curtain.

Virtually all of the exhaust hoods seen on open surface tanks were of the lateral or semilateral design. These hoods consisted of either one or two face slots, or an entirely open face of the semilateral type which partially extended over the edge of the tank. Push-pull systems were used on the wider tanks, and the largest tanks viewed were 10 ft wide by 10 ft long.

Table 1 lists the various sizes of tanks with lateral exhaust hoods observed in the field. Quite often, lateral hoods were located only on one side of tanks which were wider than 3 ft, and some were seen on tanks wider than 4 ft. These configurations generally resulted in incomplete capture of vapors rising from the opposite edge of the bath surface.

It was also observed that push-pull systems were not usually used until tank widths reached or exceeded 4 feet. There was sometimes blow-by of fumes past the ends of the hood due to the influence of the push air.

Other deficiencies observed during the field visits included interference of hood draft by cross drafts, severe boiling and rising vapors at surfaces of steam-heated panels, escape of vapors from parts or baskets lifted out of tanks, corrosion of metal hoods, broken plastic hoods, deposit buildup inside hood slots, insufficient exhaust flow, poorly maintained systems, and infrequent use (or nonexistence) of safety monitoring equipment.

TABLE 1. LATERAL EXHAUST HOODS SEEN ON FIELD VISITS

	Single Width		Double Width		Push-Pull	
	W x L, in.	W/L	W x L, in.	W/L	W x L, in.	W/L
	36 x ~60	0.6	36 x ~48	0.75	32 x 72	0.44
	48 x 48	1.0	48 x 120	0.40	54 x 120	0.45
	54 x 108	0.5	42 x 126	0.33	60 x 60	1.00
	38 x 72	0.53	28 x 480	0.06	48 x 96	0.50
	42 x 30	1.4	78 x ~144	0.54	120 x 120	1.0
	48 x 84	0.57	48 x 360	0.13		
	24 x 36	0.67	30 x 120	0.25		
	50 x 65	0.77				
	~36 x ~60	0.60				
	36 x 240	0.15				
	36 x ~48	0.75				
	48 x 96	0.50				
	28 x ~48	0.58				
Min.	24" W	0.15	28" W	0.06	32" W	0.44
Max.	54" W	1.4	78" W	0.75	120" W	1.0
Avg.	40" W	0.66	44" W	0.35	63" W	0.68

EXPERIMENTAL PLANNING

Development of Experimental Program

The experimental program was developed using the criteria contained in the Industrial Ventilation Manual(1) and in the American National Standards Institute Standard Z9.1-1971(2) as a guide, together with the information on trends gathered from the literature and field visits.

To provide a concise summarization of the tabular data contained in the Industrial Ventilation Manual, the tabulated data were plotted in graphic form.

Figure 1 is a graphic presentation of the present recommended minimum exhaust flow rates for tanks with lateral hoods. The curves were plotted from the data given in Tables 5-5-3 and 5-5-4 of Reference (1). The class designations such as A-2 are a combination of the hazard potential, A, and the gassing or

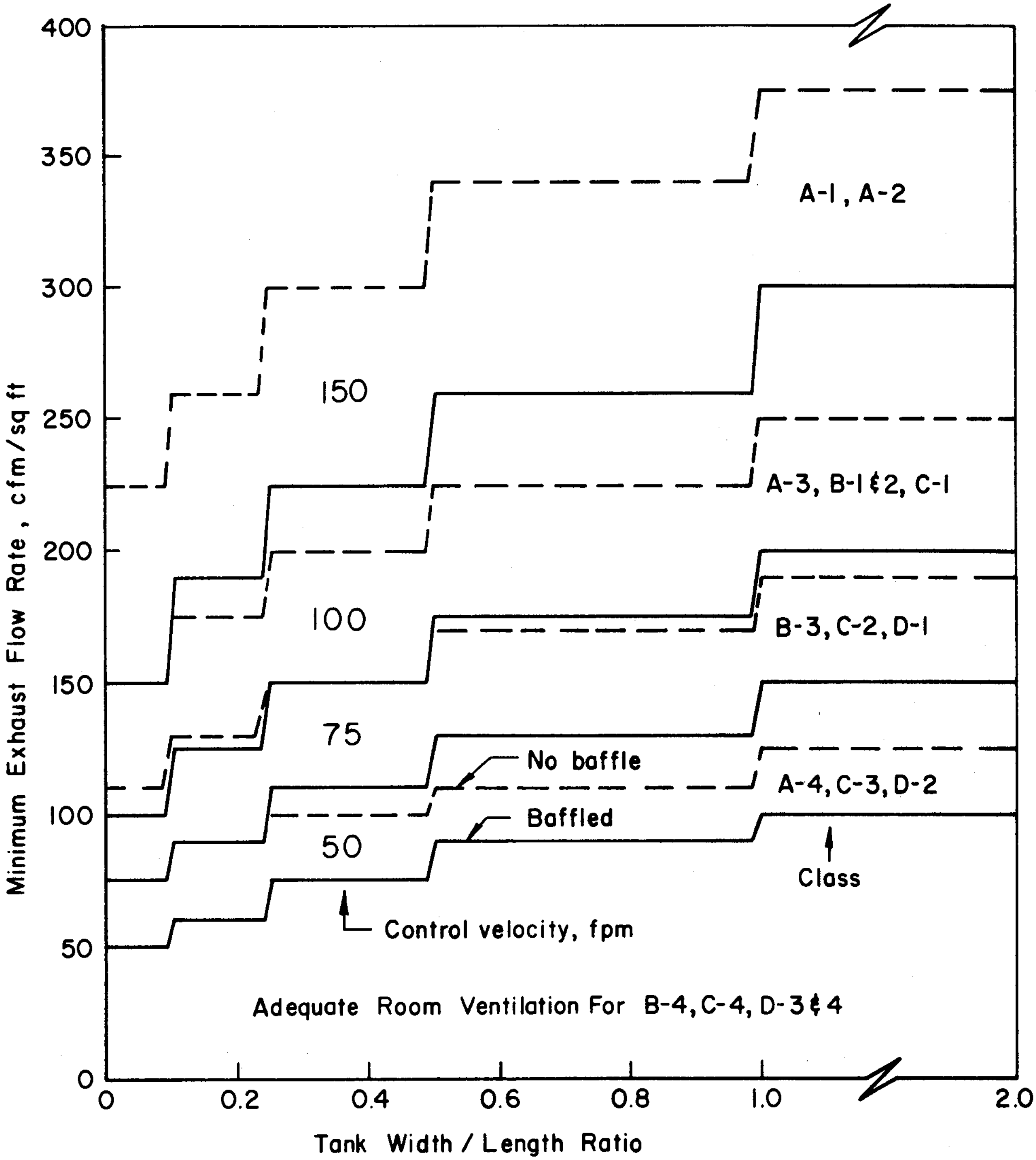


FIGURE 1. MINIMUM EXHAUST RATES FOR TANKS WITH LATERAL HOODS

evaporation rate, 2, of the airborne contaminants. The control velocity refers to the air velocity measured above the edge of the tank on the side opposite the exhaust hood. A "baffled" tank is one which is located next to a wall or uses an upward plenum [Ref. (1), Drawing VS-503A], and a "no baffle" configuration is represented by a free-standing tank with a downward plenum (Drawing VS-503B).

Figure 2 shows an alternate way of plotting the data for baffled tanks with width-to-length ratios between 0.5 and 0.99 contained in Figure 1. This form of presentation was more convenient for analyzing and comparing data generated during the experimental studies than was the stepped form. The concentration values used in preparing the curves are the Threshold Limit Values (TLV's) specified for the various classes of hazard potentials. The present design criteria when expressed in the form shown in Figure 2 together with the trends established in the earlier program effort defined the parameters for which experiment data were needed to update the design criteria. The parameters selected and the anticipated range over which they were to be varied are as follows:

Parameter	Range
Ratio, width/length	0.1 to 2.0
Bath temperature	85 F (Rate 4), 122 F (Rate 3) 170 F (Rate 2), 200 F (Rate 1)
Slot velocity	0 to 4000 fpm
Exhaust flow	0 to 375 cfm/sq ft
Makeup air	Perforated ceiling, cross drafts
Hood type	Latteral (updraft or downdraft, and multiple slots), semilateral, and push-pull
Baffles	Hood baffle to simulate upward plenum, Tank baffle to simulate slots along both sides
Air agitation	0 to 2 cfm/sq ft
Mist suppressant	Plastic balls, 2-in. diameter
Material handling equipment	Drum, hangers

Exhaust system performance was to be judged in two ways: (1) with a visual flow tracer and (2) by quantitative measurement of emitted contaminants. A smoke tracer was to be used to define the flow patterns around the tank, hood, and material handling equipment and to determine the flow rates at which the exhaust system ceased to be 100 percent effective in removing emitted vapors. For operation at less than 100 percent effectiveness, the contamination levels in the breathing zone around the tank were to be determined by measuring the amount of emitted vapor in the air.

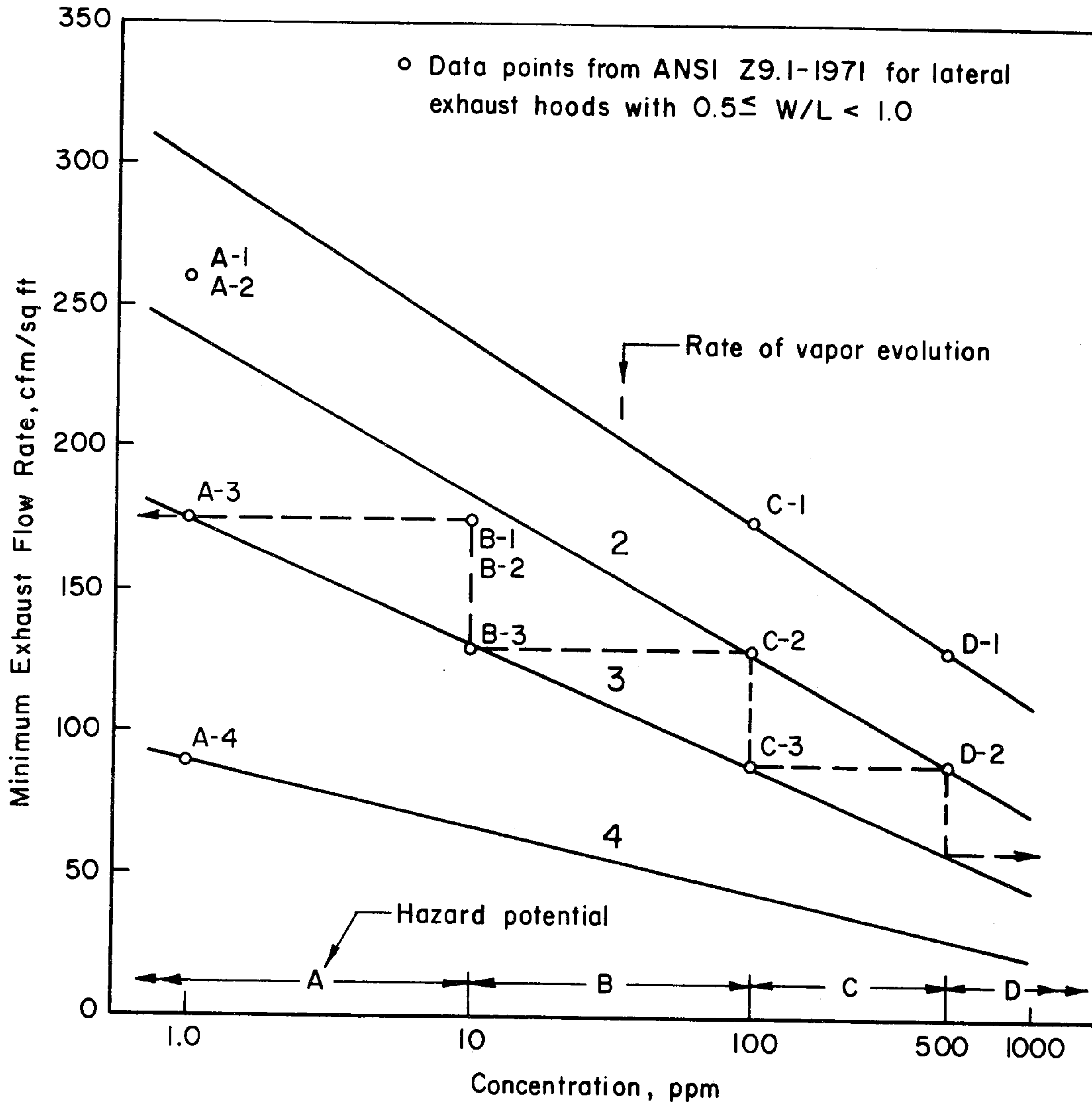


FIGURE 2. MINIMUM EXHAUST FLOW RATES FOR BAFFLED TANKS

Design of Experimental Facility

The required operating capabilities of the experimental apparatus were defined by the experimental planning study. Therefore, design of the equipment involved determination of how best to implement the experimental plan in the laboratory. One of the parameters to be studied was makeup air, so researchers decided to use an existing laboratory room which would provide a draft-free environment as well as a closed space for making quantitative emission measurements. Consideration of a number of alternatives culminated in the formation of the following plan:

(1) Use a full-sized tank and exhaust hood which would allow ample variations to be made to duplicate or simulate many representative conditions

(2) Use ethanol-water mixtures to simulate emission of volatile vapors and aerosols from tank solutions

(3) Monitor the emissions of gases and aerosols (mists) by measuring the ethanol concentrations in the room air at appropriate locations around or above the tank; (this was accomplished using a Beckman Hydrocarbon Analyzer, Model 109)

(4) Simulate the four different rates of vapor evolution from the tank by varying either the bath temperature and/or the bath liquid or composition

(5) Provide air agitation with a perforated tube located near the bottom of the bath

(6) Produce realistic gassing conditions by bubbling air through a porous tube placed in the bath at typical anode and cathode locations

(7) Provide cross flow with a large circulation fan and baffles.

Figure 3 is a schematic drawing of the laboratory setup. The room in which the equipment was located was 18 ft wide by 22 ft long, with a 10-ft-high suspended ceiling. The ceiling panels were slotted to provide a uniform and gentle supply of makeup air to the room. The lateral exhaust hood could be adjusted to provide a variable slot height, and a vertical baffle was added to represent the effect of an upward plenum takeoff.

The tank dimensions were 4 ft by 8 ft and 30 in. deep. The hood slot was located across the 4-ft dimension, and the entire hood assembly was designed to move relative to the tank so that various width-to-length ratios of exposed bath surface could be obtained.

Four heater blankets, each rated at 15 kw, were installed directly beneath the stainless steel tank. One of these heaters was thermostatically controlled to

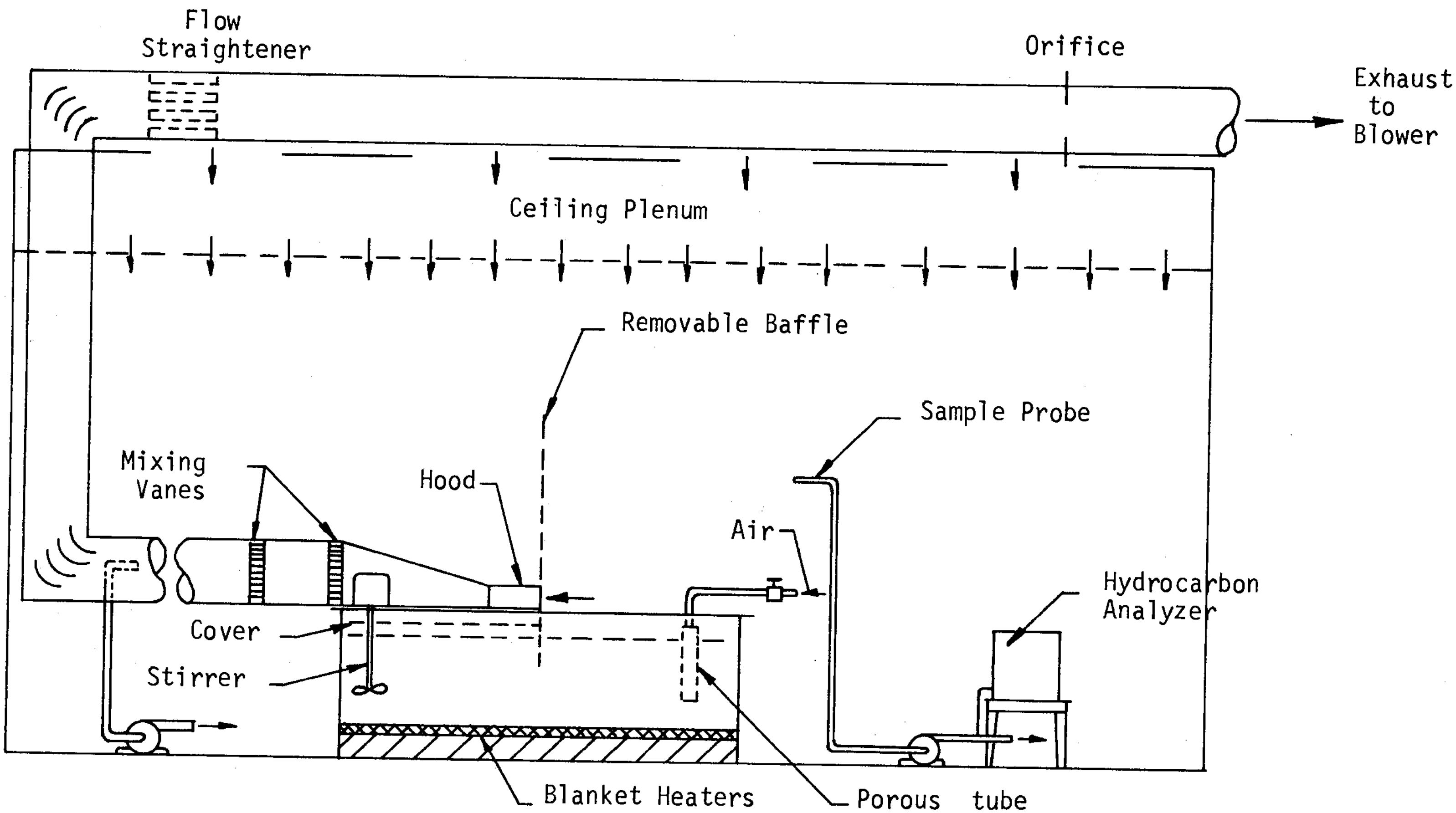


FIGURE 3. SCHEMATIC OF LABORATORY SETUP FOR OPEN SURFACE TANK STUDIES

maintain a given temperature, while the others could be manually switched on or off as needed. However, these gradually deteriorated, so two steam-heated coils were installed to complete the study.

Figure 4 shows one of the two mixing devices which were installed in the exhaust duct upstream of the duct sample probe to thoroughly mix the air and vapors entering the hood, thus providing an accurate measure of the amount of vapors drawn off the tank.

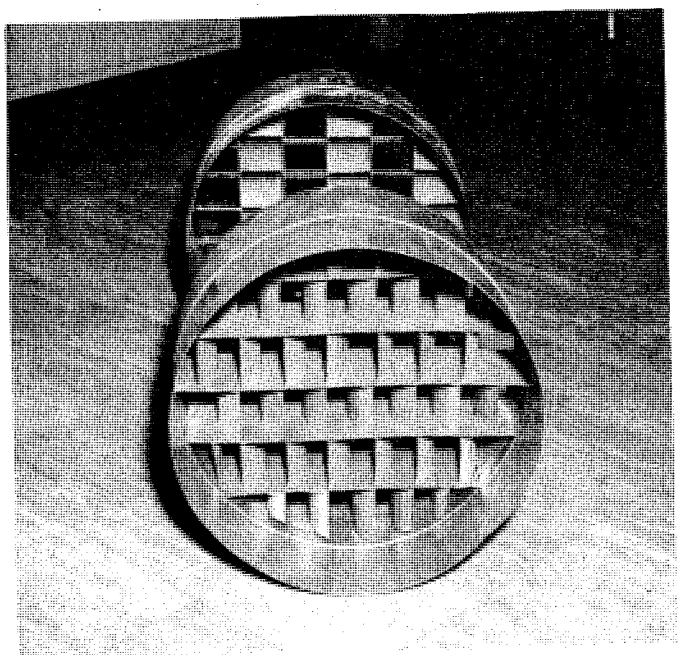


FIGURE 4. MIXING DEVICE USED IN EXHAUST DUCT

Figures 5 and 6 are photographs showing a typical laboratory setup both with and without the hood baffle in place. The arrangement shown has a tank width-to-length ratio of 0.5 (2 ft by 4 ft) and a liquid level 6 in. below the edge of the tank. The probe height was 64 in. above the floor, and its inlet was 12 in. in front of the tank.

Figures 7 and 8 are photographs showing a simulated parts barrel in its normal raised and lowered positions, respectively. The barrel was continuously rotated while it was being cycled up and down so as to maintain a wetted, heated surface. In the raised position, the barrel rotated through bath liquid which was circulated to a water tray located under the barrel.

Figures 9 and 10 show the semilateral and multiple-slot hood arrangements, respectively. The face opening of the semilateral hood (Figure 9) was 22 inches by 48 inches, with a 2-inch flange along the top edge. The overall size of the multiple-slot hood face (Figure 10) was also 24 by 48 inches. The center portion of this hood face could be adjusted up or down to change the ratio of slot sizes. The slot sizes shown in the photograph were 2-1/4 inches along the bottom and 3/4 inch at the top.

FIGURE 5. PHOTOGRAPH OF LABORATORY SETUP

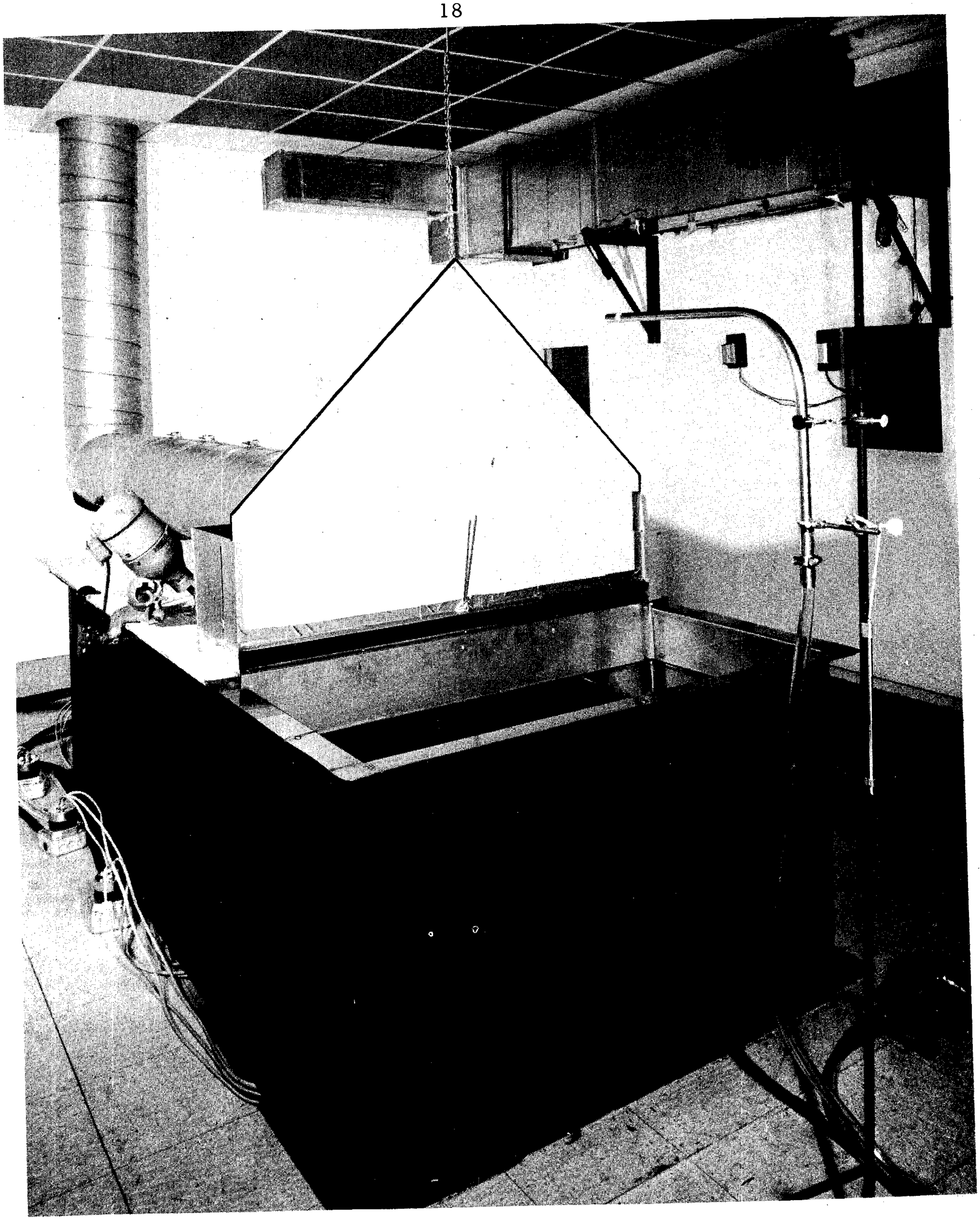


FIGURE 6. LABORATORY SETUP WITH HOOD BAFFLE INSTALLED

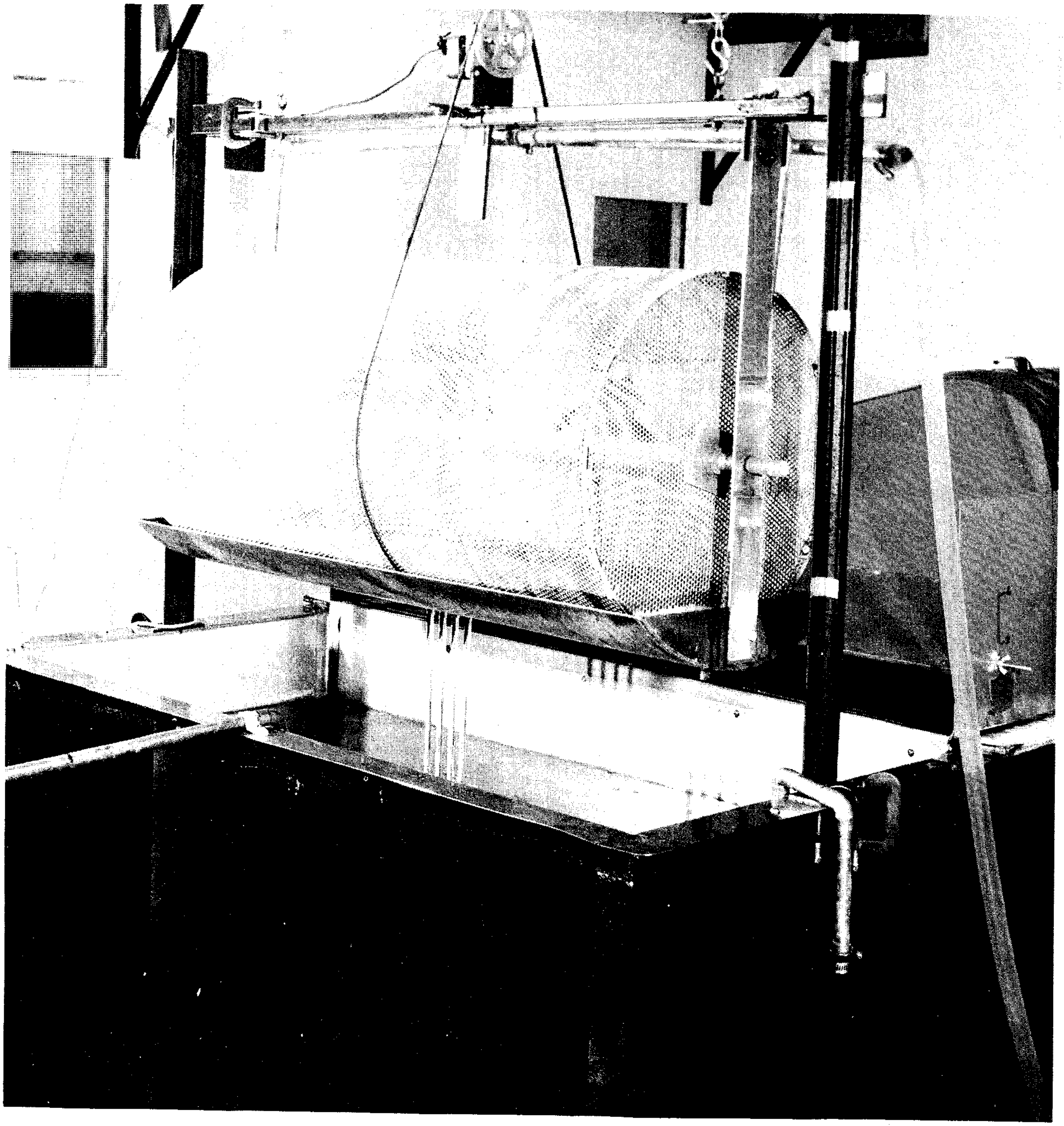


FIGURE 7. SIMULATED PARTS BARREL IN RAISED POSITION

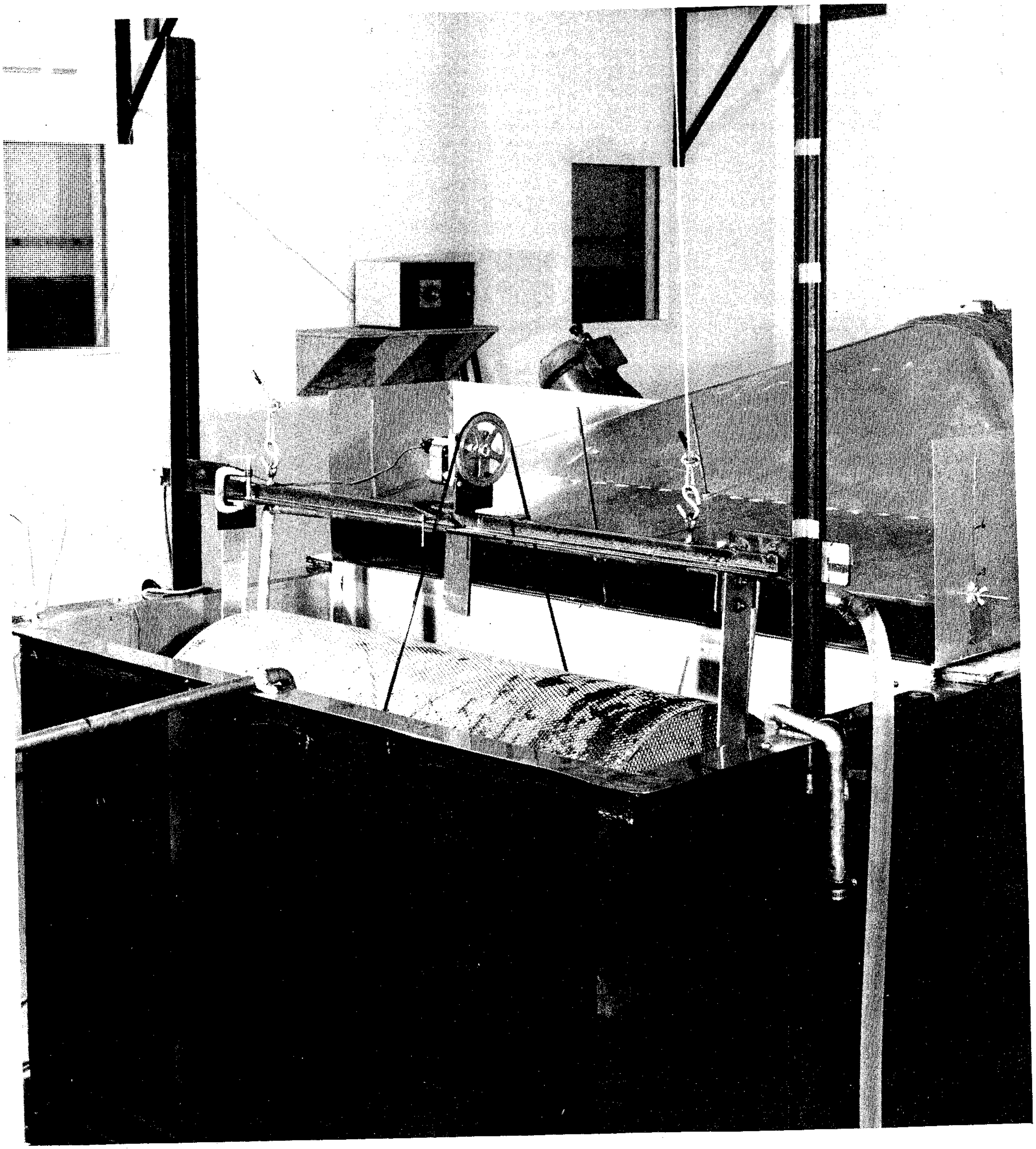


FIGURE 8. SIMULATED PARTS BARREL IN LOWERED POSITION

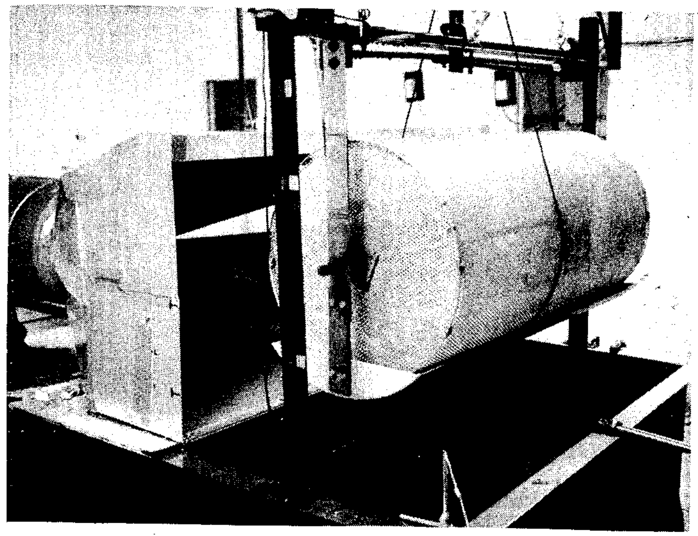


FIGURE 9. SEMILATERAL HOOD

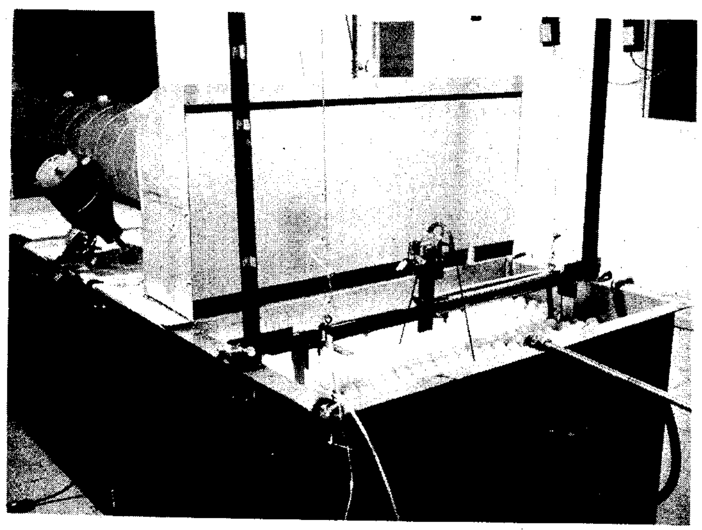


FIGURE 10. MULTIPLE-SLOT HOOD

Figures 11 and 12 show the push-air header and nozzle arrangement which was used for most of the push-pull ventilation studies. The nozzles were located on 6-inch centers placed 3 inches from the edges of the tank. The nozzles could be individually swivelled to produce the most satisfactory air flow pattern. These nozzles were developed for this purpose by Spraying Systems, Inc. for General Motors Corporation.(4) They are termed "Swivel Blow-Off Nozzle Assembly, Model Number 10877", and have a rating of 10 cfm at 4 inches of water pressure.

To obtain an accurate and continuous measure of the alcohol concentration in the bath, a sample was continuously circulated through a chilled-water reservoir. This cooled the sample to 60 F so that a standard alcohol hydrometer could be used.

Air agitation was provided with a perforated 47-inch-long copper tube located near the bottom of the tank. The 1/8-inch-diameter holes were spaced at 2-inch intervals, and a rotameter was used to measure the air flow rate.

The gassing which occurs at the anode and cathode in electroplating operations was simulated by bubbling air through a porous tube. This tube was a sintered stainless steel filter 2 inches in diameter and 36 inches long with a mean pore size of 20 microns which produced very fine bubbles and mist.

Plastic balls were used to study the effects of surfactants on reducing emissions of vapors and mists. These were 45-mm(2-inch)-diameter spheres made of polypropylene.

EXPERIMENTAL STUDIES

Experimental studies were first conducted with the basic open surface tank using a single-slot lateral hood to determine flow patterns, capturé velocities, and room concentrations of contaminant. These then were followed with studies aimed at determining the effects of changes such as parts cycling, use of other hood geometries, gassing, surfactants, air agitation, and room air motion. As was discussed previously, all studies were conducted in an enclosed space in which uncontrolled air motion was kept to a minimum by introducing makeup air through a perforated ceiling. Thus, the results obtained represent those which would be achieved under near ideal conditions.

Basic Open Surface Tank

Behavior of the room air motion as it passed over a tank and into an exhaust hood and the effect of tank temperature were determined qualitatively and quantitatively. Qualitative determinations were made using a visual smoke tracer released

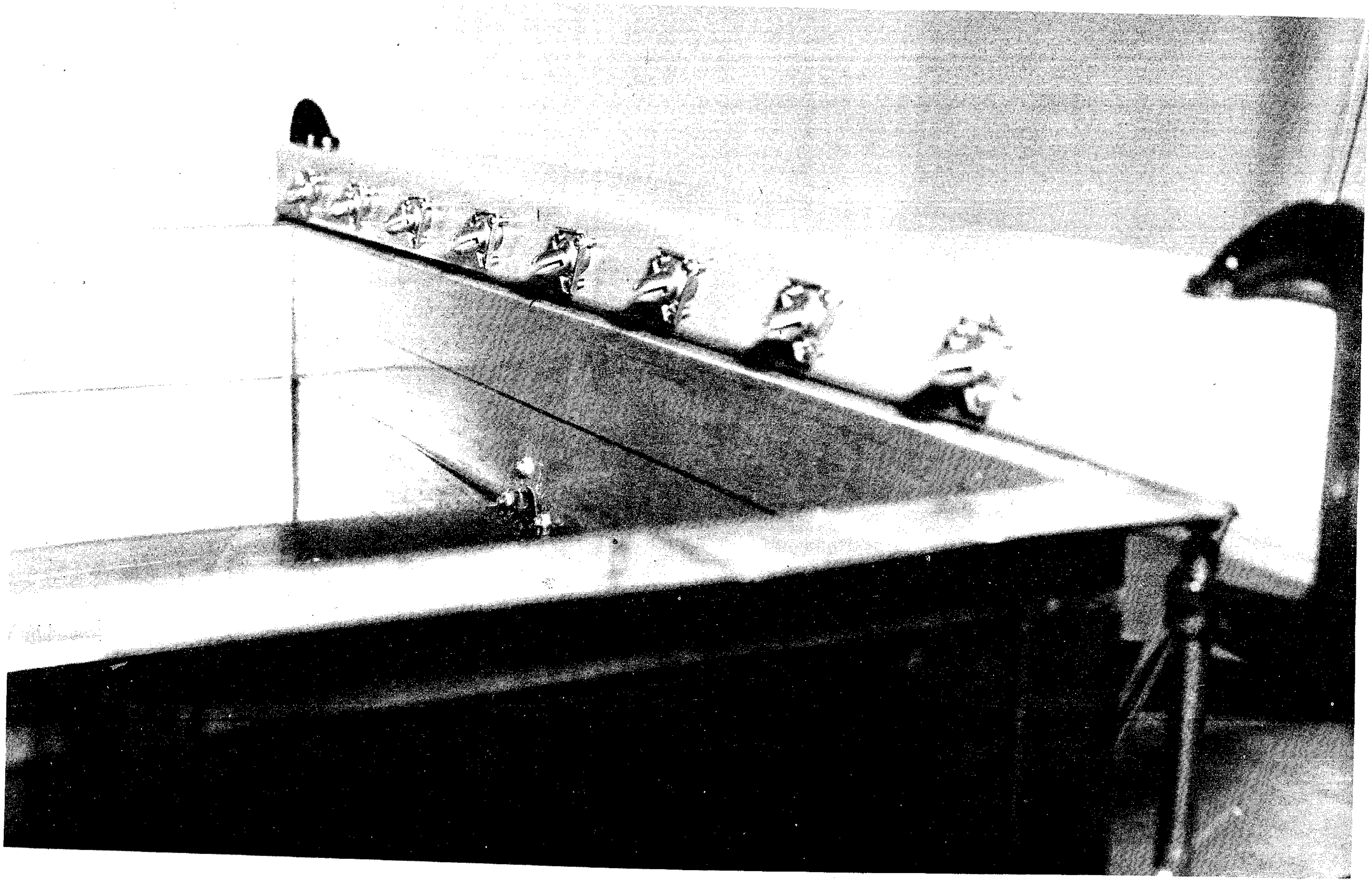


FIGURE 11. PUSH-AIR HEADER WITH SWIVEL NOZZLES

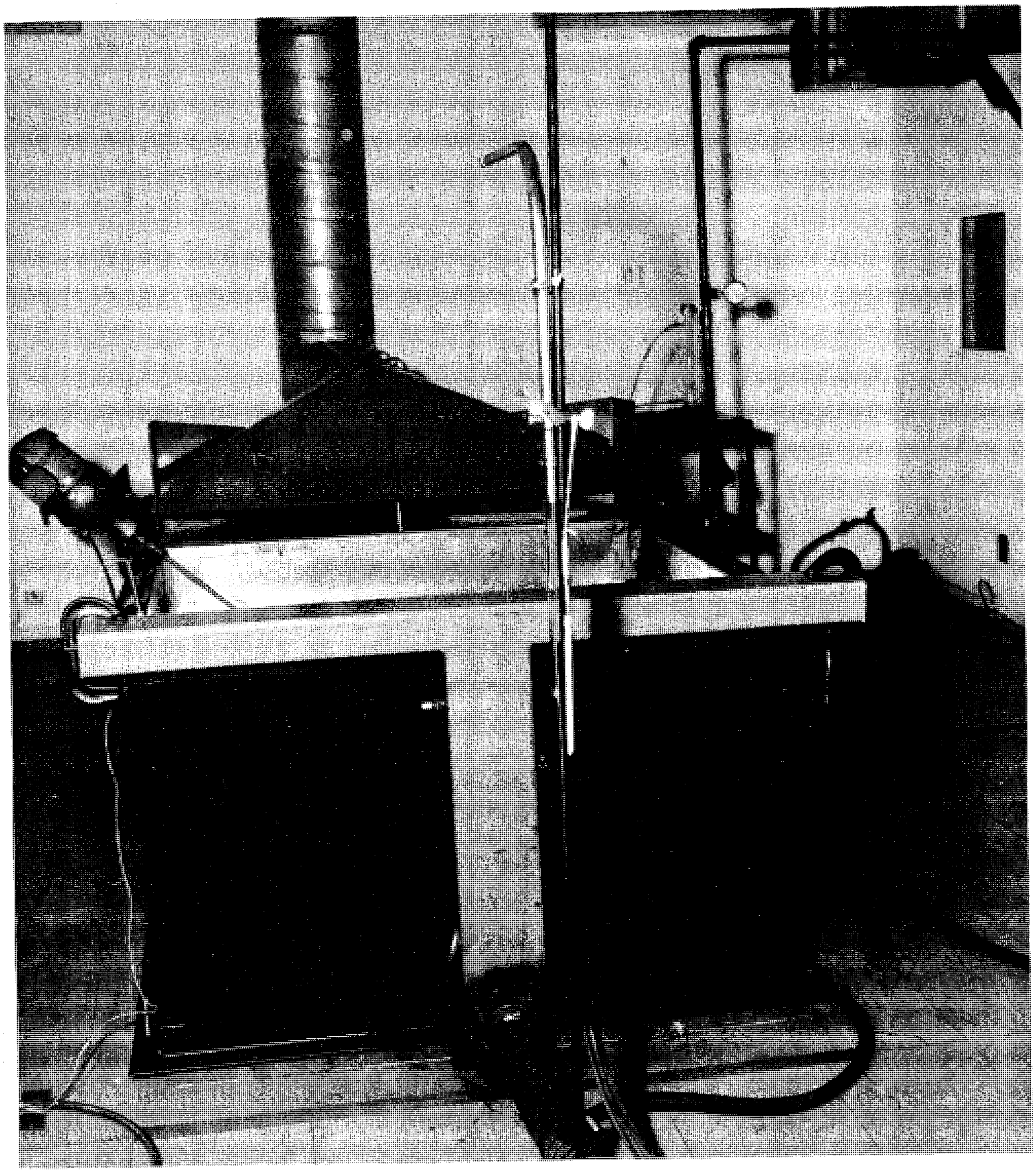


FIGURE 12. TANK ARRANGEMENT FOR PUSH-PULL VENTILATION

through a small-diameter hand-held probe. Flow velocities were measured with a thermal anemometer. Quantitative measurements were made with a continuous-sampling hydrocarbon analyzer.

Single-Slot Lateral Hood

Figure 13 shows the general flow patterns obtained with a basic open surface tank with a single-slot lateral hood. The slot affected air movement in all directions around it, resulting in air being drawn from the sides and from over the top of the hood as well as from over the tank. This suggests that a more efficient hood would result if these side and top flows were blocked with baffles or by an upward-hood plenum. There was less horizontal air movement at the liquid surface 6 inches below the top of the tank than in the plane formed by the top of the tank.

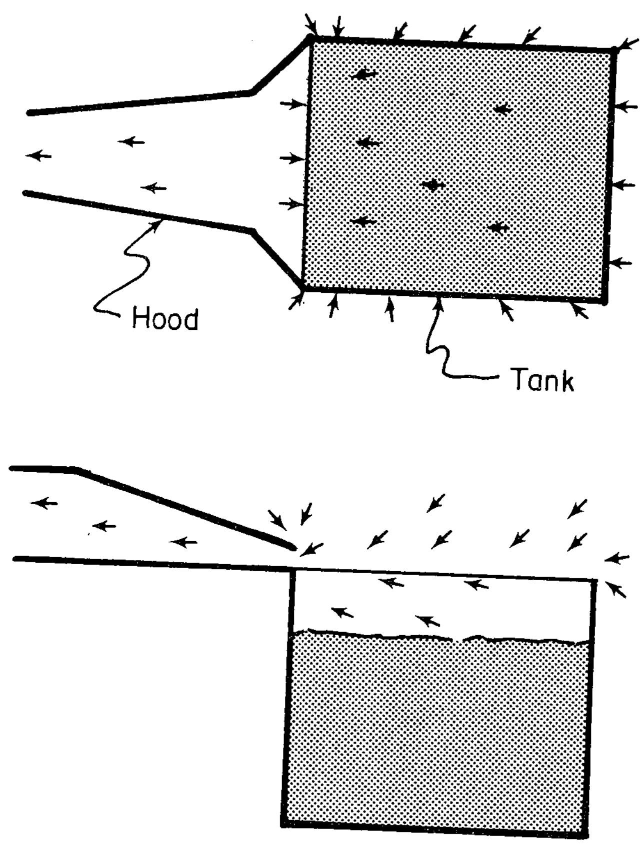


FIGURE 13. FLOW PATTERNS AROUND OPEN SURFACE TANK WITH SINGLE-SLOT LATERAL HOOD

Figure 14 is a plot of the exhaust flow rate needed to obtain complete capture of a visual flow tracer as a function of tank temperature. These curves illustrate the effect of eliminating the flow from over the top of the hood. Subsequent measurement of emissions to the room showed that, although the smoke tracer was captured at these flow rates, there was some escape of the alcohol tracer, particularly at the

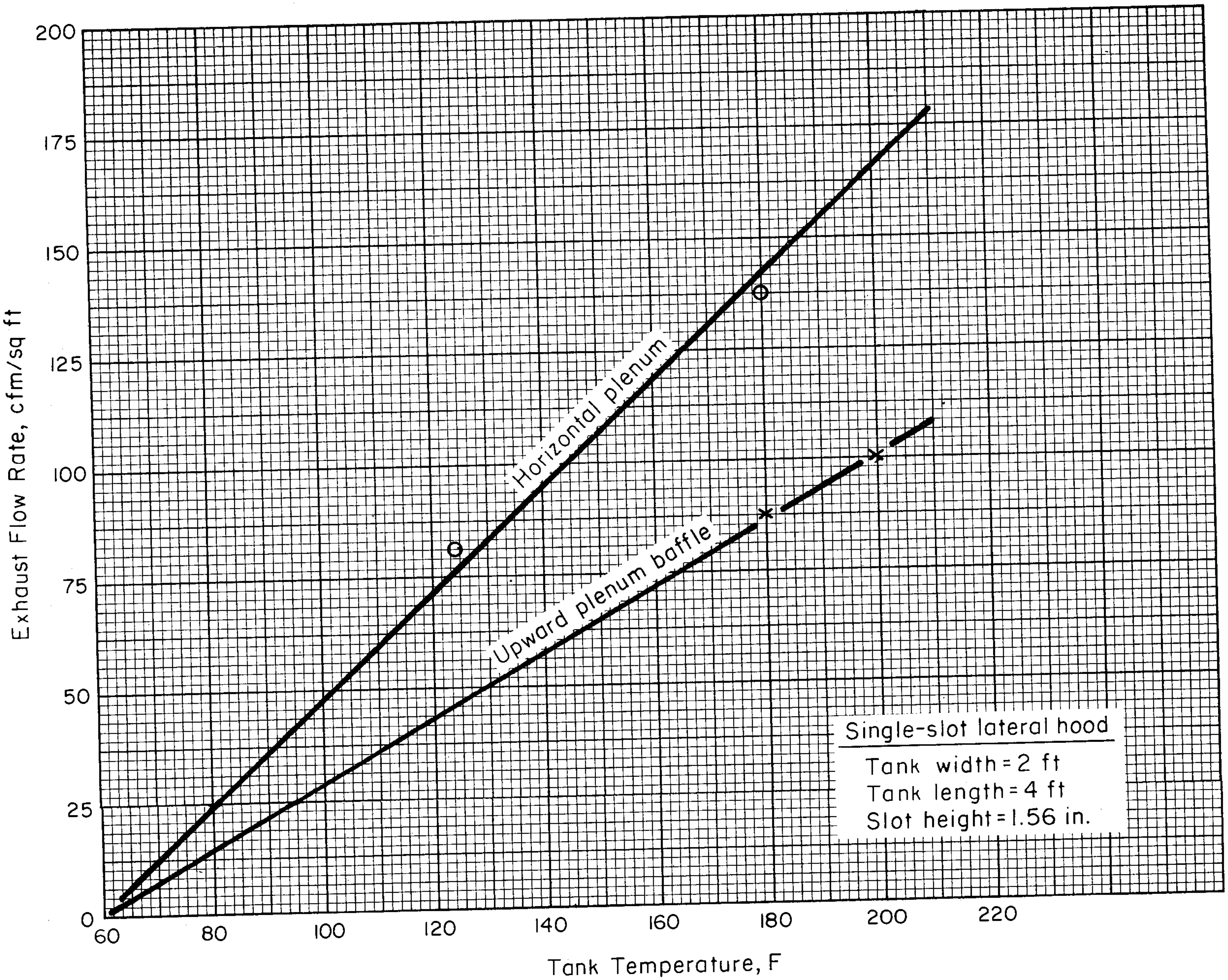


FIGURE 14. EXHAUST FLOW REQUIRED FOR COMPLETE CAPTURE OF VISUAL FLOW TRACER

higher temperatures. Thus, these data do not define the exhaust flow rates needed for 100 percent capture of vaporized bath constituents.

Room emissions were determined for the basic open surface tank using the techniques described previously. The results of these studies are shown in Figure 15. The curves show room concentration as a function of exhaust flow rate for three tank fluid temperatures and three tank sizes. The data show that increasing tank temperature and tank width both increases the emissions. Increasing the temperature has a dual effect in that the higher temperature raises the vapor pressure and, therefore, the evaporation rate of the fluid, as well as the buoyant forces which must be overcome by the lateral air movement generated by the hood.

The visual flow studies showed that a significant fraction of the exhaust air entering the hood did not pass over the bath surface and thus did not contribute to direct removal of emissions. Therefore, studies were made to determine the magnitude of the effects of these flows. This was done by installing a vertical baffle above the slot in the lateral hood (representing an upward plenum) and by placing vertical panels along the sides of the tank.

The vertical baffle was shaped to conform to the geometry of an upflow plenum; that is, it was full tank length for a height of 12 inches and then tapered at a 45 degree angle as would a hood having a single exhaust duct (see Figure 6). The side panels were mounted on the top edge of the tank and extended 3 feet upward.

The capture velocities obtained with various configurations of baffles and side panels are shown in Figure 16. The capture velocity is the air velocity measured on the tank centerline 3 inches above the edge of the tank on the side opposite the exhaust hood. The data shown were obtained with a room-temperature tank. In other studies it was found that as tank temperature was increased the capture velocity also increased with the low exhaust flow rates due to the effects of thermally induced buoyancy. At higher exhaust flow rates, however, the effect of buoyancy was less pronounced; at the highest rates the capture velocities approached those obtained with a cold tank. The higher tank temperatures also created fluctuating flow patterns which resulted in variations in the velocities.

The curves show that with a baffle added the same capture velocity can be obtained with about 80 percent of the flow required without it. With side panels and no baffle only 33 percent as much air is needed, and with both the baffle and side panels only 25 percent is required. Capture velocity is a measure of the magnitude of the horizontal flow over the front edge of the tank which captures emissions. These reductions in exhaust flow rate apply to the room emission data shown in Figure 15.

Flow rates measured with the basic open surface tank include flow from the sides and back as well as from over the tank surface itself. Consequently, the magnitude of the flow rates expressed on a unit area basis are dependent on tank size, because as tank length is increased the surface area increases while the end

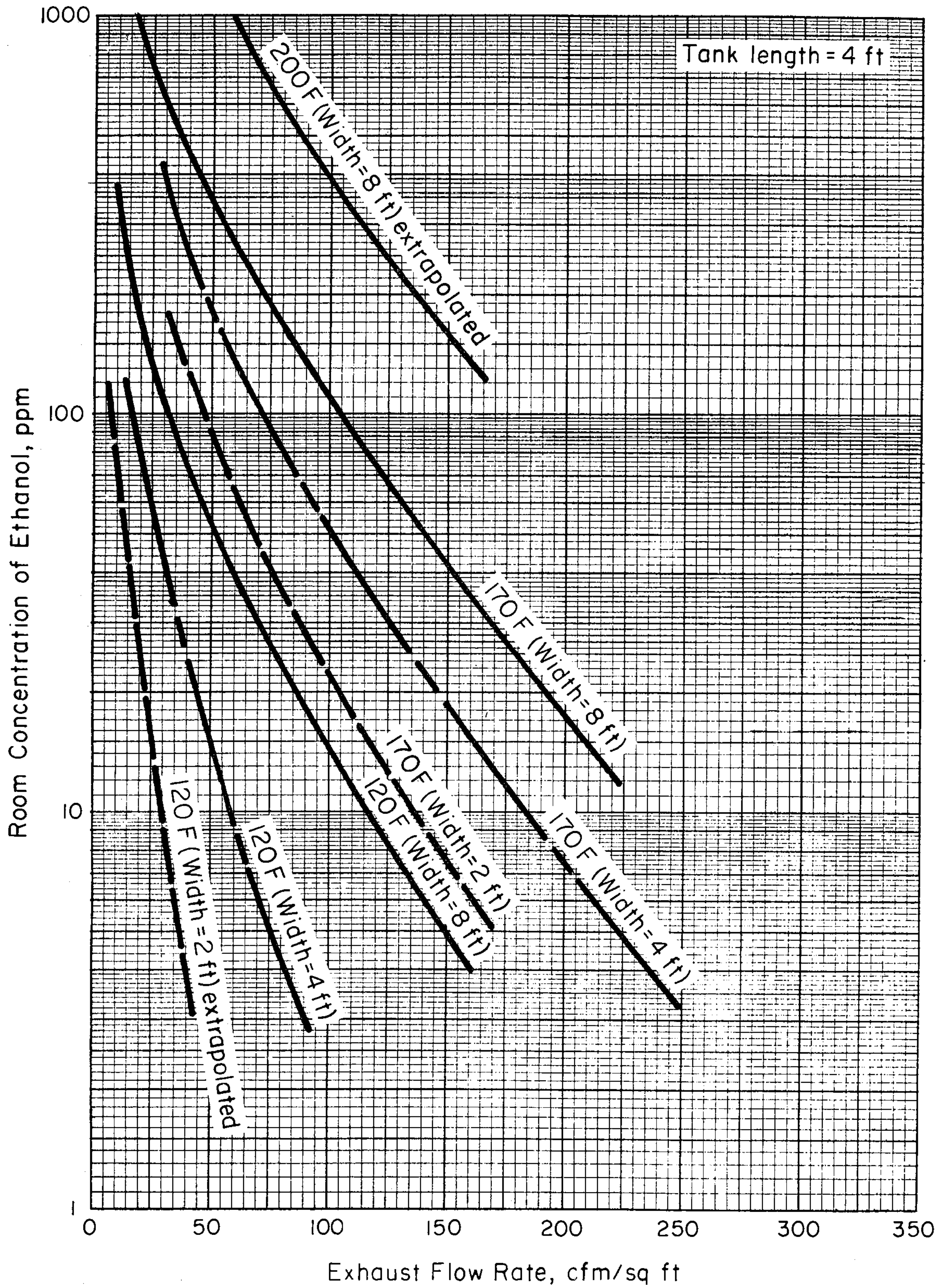


FIGURE 15. ROOM EMISSIONS FOR BASIC OPEN SURFACE TANK WITH SINGLE SLOT LATERAL HOOD

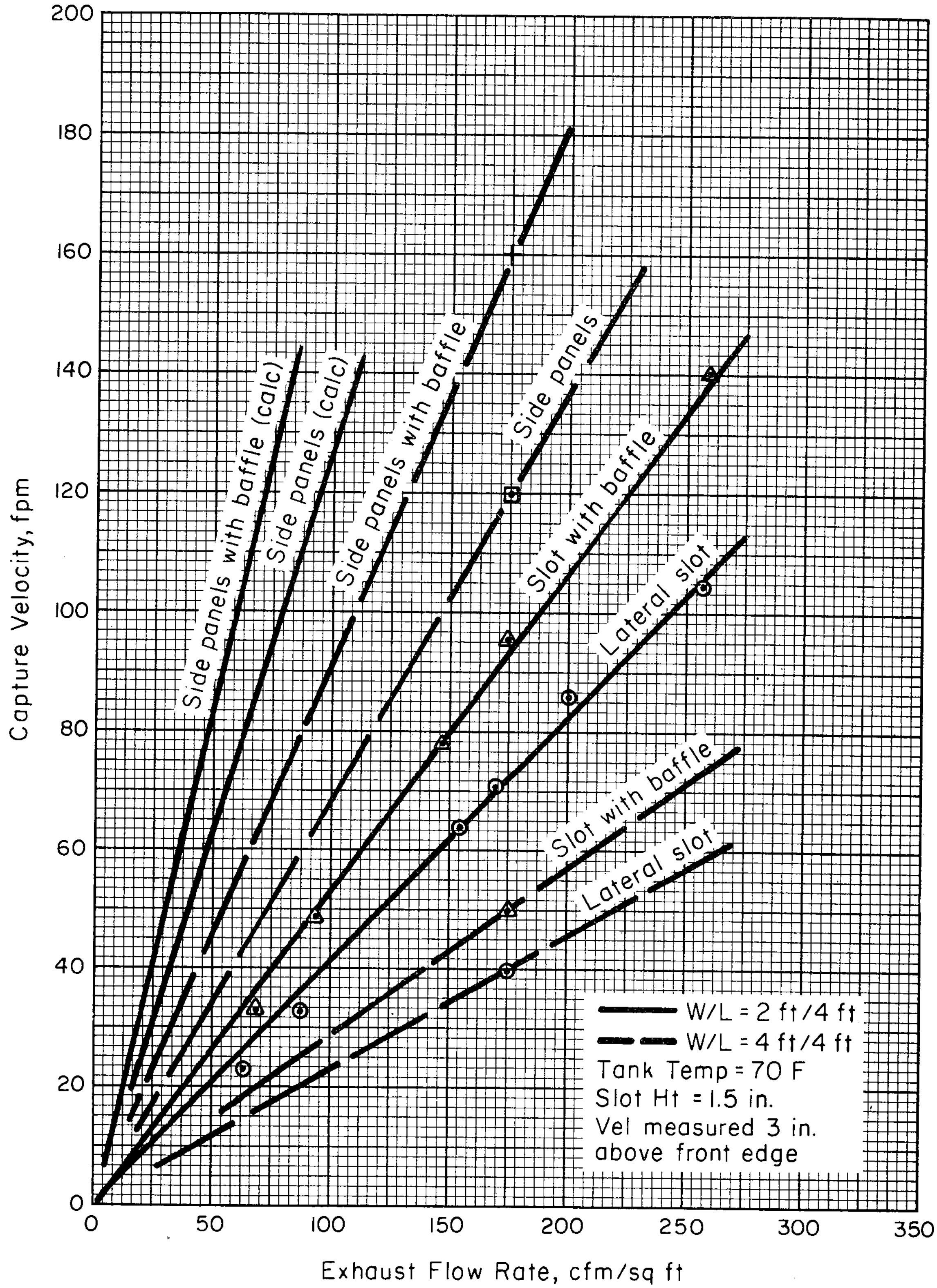


FIGURE 16. CAPTURE VELOCITIES FOR AN OPEN SURFACE TANK WITH SINGLE-SLOT LATERAL HOOD

effects remain fixed. Thus, as tank length is increased, the ratio of air from the ends to air from over the tank decreases. The side panels were installed such that no air entered from the sides, so the flow rates needed to obtain any selected capture velocity were those that would occur away from the ends of a long tank. Converting the unit area flow rate to a total tank flow rate by multiplying by the experimental tank area both with and without side panels and subtracting the two values, the magnitude of the end flow can be determined. Having this value, the flow rate needed for a tank of any length can be determined as the sum of the end flow plus the flow over the center of the tank.

Effects of Hood Geometry

Exhaust hood slot velocity and slot location were studied to determine their effects on capture velocity and room emissions for the basic open surface tank.

Slot velocity was varied by varying the height of the slot while maintaining a constant flow rate. The resulting slot velocities ranged from 700 to 6000 fpm. Over this range of slot velocities there were no measured differences in capture velocity over the front edge of the 2 by 4-ft tank. In all cases the slot velocity was uniform along the entire 4-ft length of the hood.

Raising the bottom of the slot above the top edge of the tank decreased the collection efficiency because increasing amounts of air entering the hood were drawn from the room.

Overall, the results showed that as long as the slot velocity was uniform over the face of the opening, the actual slot velocity was not critical. In practice, space limitations often preclude the use of a hood which will provide a uniform velocity profile at low absolute velocities; therefore, as a general practice a face velocity of 2000 fpm should be used.

Cycling of Parts Barrel

A large number of open surface tanks are used to process small parts that are carried in perforated parts barrels. These barrels when raised for transport constitute a significant source of contaminants, since they are well above the exhaust opening in a single-slot lateral hood, which is the type most commonly used. Therefore, a simulated parts barrel was constructed and installed on the laboratory tank. The barrel was constructed of perforated aluminum sheet having 0.19-inch-diameter holes and 50 percent open area. A pan was placed under the barrel through which tank fluid was circulated so that, by rotating the barrel, its surface could be kept wet and at operating temperature. The barrel was 1.5 ft in diameter and 3 ft long. The system as it was installed on the tank was shown previously in Figures 7 and 8.

When the barrel was in the raised position (Figure 7) the exposed wetted surface area was 15.4 sq ft, and in the lowered position (Figure 8) the exposed wetted area was 6.5 sq ft. When raised, the bottom of the barrel was 6 inches above the top edge of the tank and 12 inches above the liquid surface. In use, the barrel was raised and lowered to simulate the motions occurring in typical industrial operations. One complete cycle consisted of a 10-second lift, a 10-second hold, a 10-second lowering, and (for a 50 percent cycle) a 30-second hold in the lowered position. For a 25 percent cycle the holding time in the tank was 120 seconds. Thus, a decreasing cycle time indicates an increasing length of time during which the barrel is immersed in the tank.

Figure 17 shows the room emissions obtained with the barrel operated on a 50 percent cycle in the 2 by 4-ft tank having a single-slot lateral hood located along one of the 4-ft sides.

Figure 18 shows the room emissions at two operating temperatures for the basic open surface tank and for a 50 percent cycle with a barrel to illustrate the effect that a barrel has on room emissions. Of course, as barrel cycle time (that is, the percentage of the total cycle time that the barrel is out of the tank) decreases, its effect on room emissions decreases; this is shown in Figure 19. The curves show that a linear relationship exists between room emissions and lift times. Data are not included for lift times greater than 70 percent because this would represent unrealistically short immersion times or conversely, long lift times. In actual practice, long lift times would result in relatively lower emissions due to the rapid cooling and drying of the barrel which takes place. In field observations of operating systems it appeared that the major source of emissions from lifted barrels initially came from the barrel surface rather than from the internal load. As the barrel dried and cooled the emission rate appeared to drop significantly.

Figure 20 is a plot of room emissions as a function of tank temperature for a number of exhaust flow rates and is a cross plot of the data shown in Figure 17. By cross plotting it can be seen that above about 120 F buoyancy and vapor pressure effects result in a constant relationship between room emissions and tank temperature for any particular flow rate.

At low exhaust flow rates, velocities around the tank and a barrel in the raised position are very low; therefore, it might be expected that for the experimental apparatus where the barrel was continuously rotated the direction of rotation would have an effect on room emissions. This was found to be the case as shown in Figure 21. In field use, the barrels are not usually rotated when they are lifted, and they are constructed of thick plastic which cools slowly, so one would expect that the emission levels would be about midway between the two curves of each pair shown in Figure 21. As the 350 cfm/ft^2 curve shows, at higher exhaust flow rates where induced velocities were higher there was no effect of direction of rotation. In all barrel-cycling studies except these the direction of barrel rotation was with the top moving toward the hood.

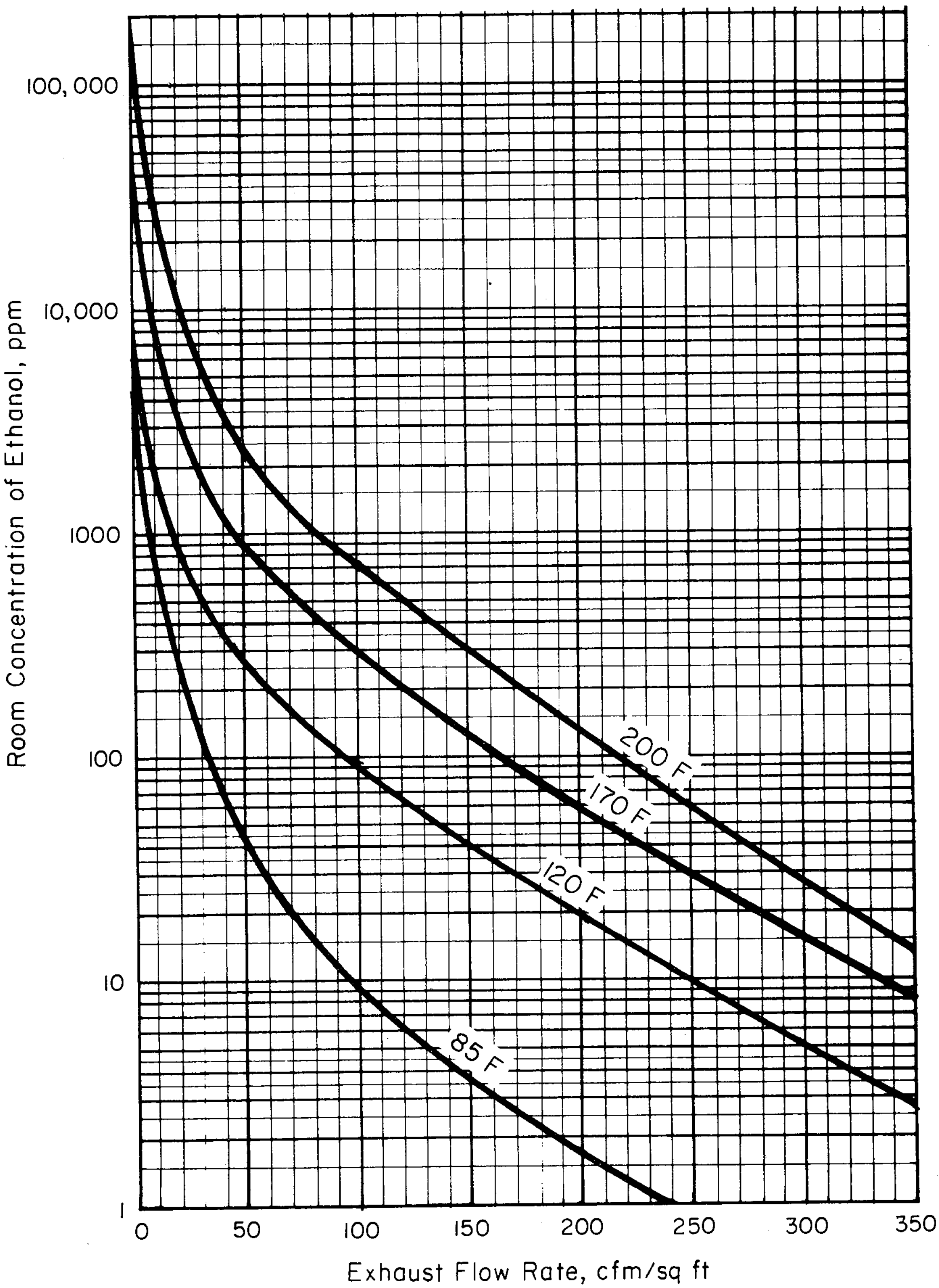


FIGURE 17. ROOM EMISSIONS WITH BARREL CYCLING IN A 2-FT BY 4-FT TANK WITH 50 PERCENT CYCLE

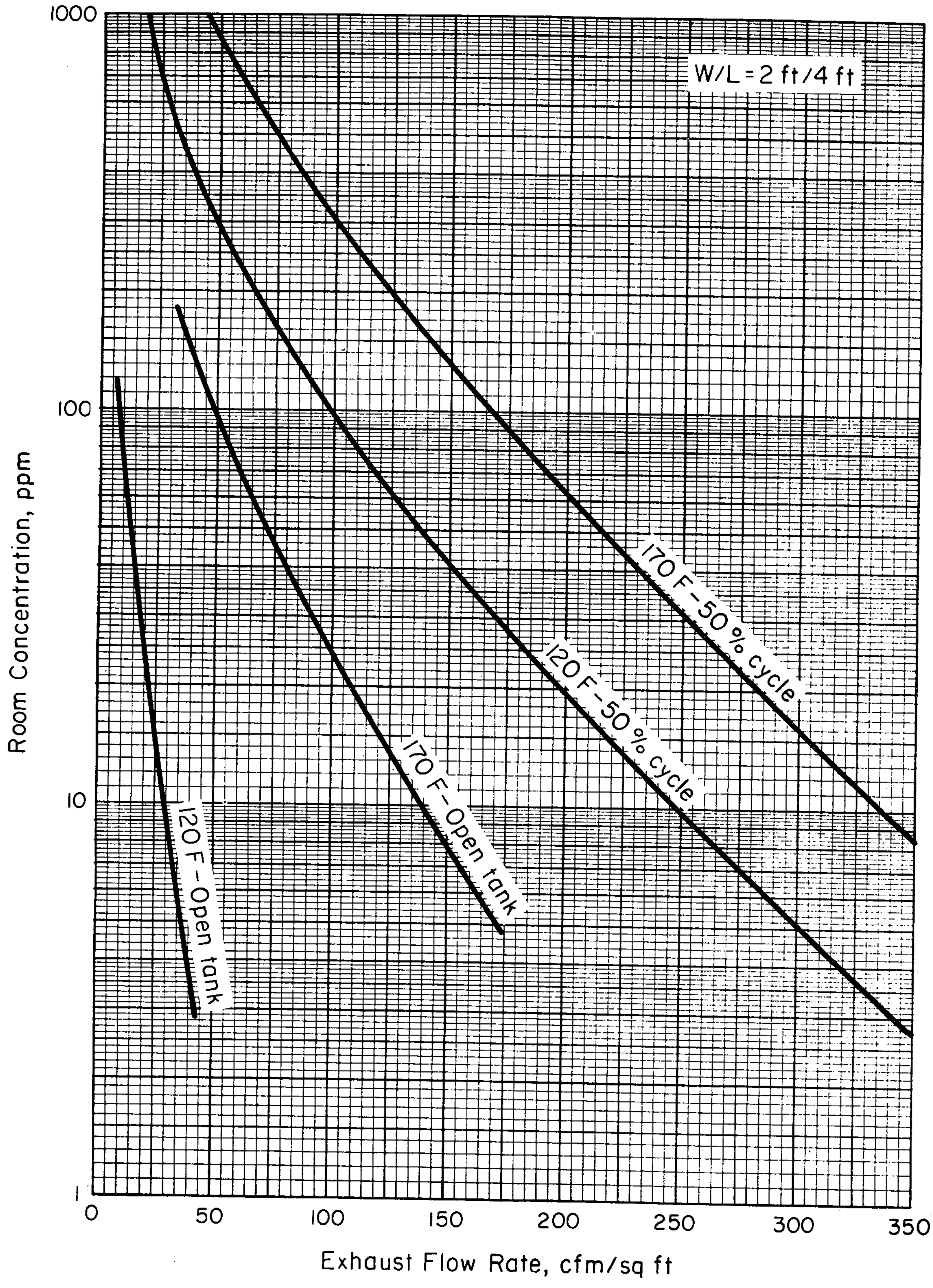


FIGURE 18. COMPARISON OF ROOM EMISSIONS WITH AND WITHOUT PARTS BARREL

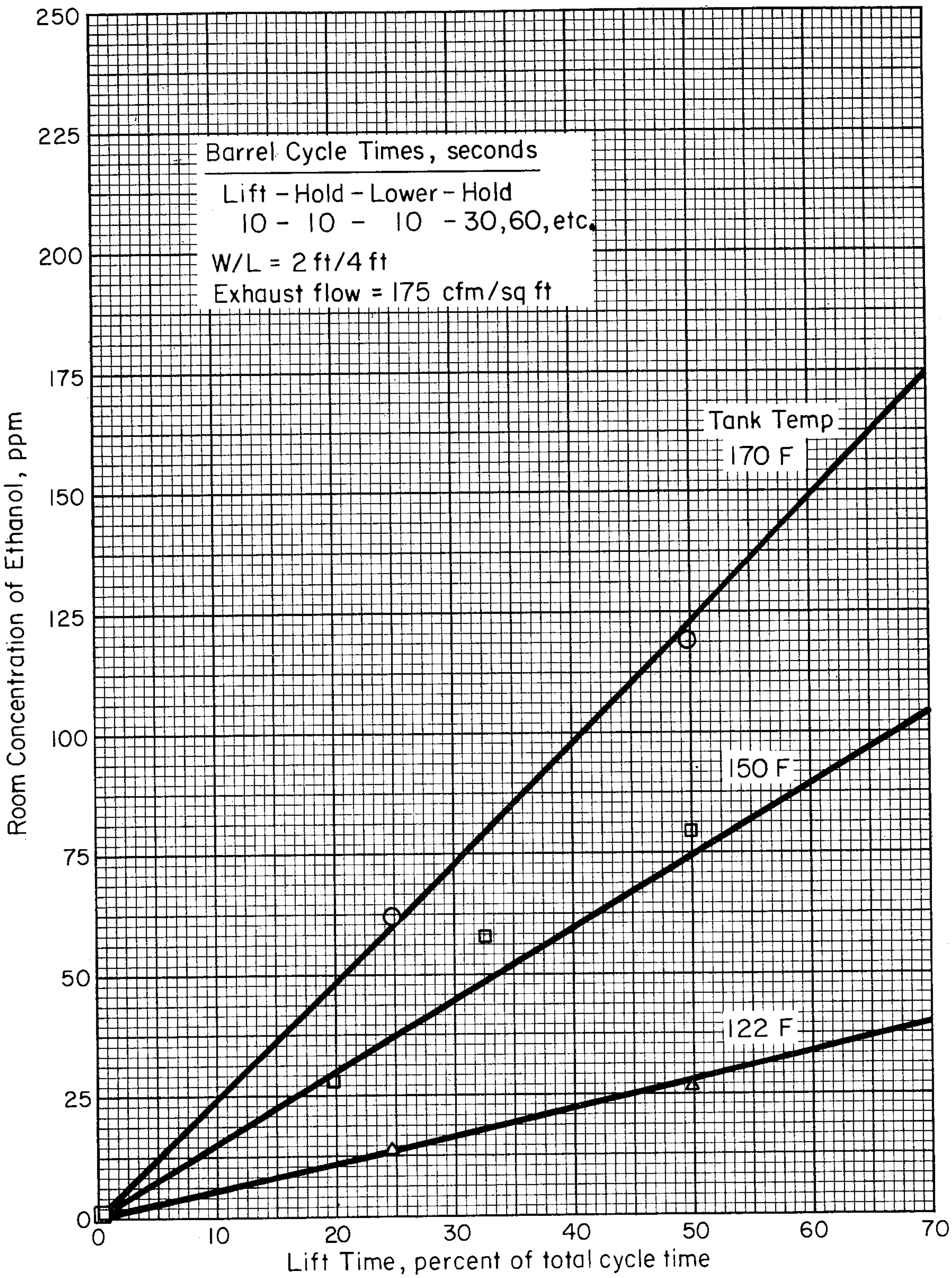


FIGURE 19. EFFECT OF BARREL CYCLE TIMES ON ROOM EMISSIONS

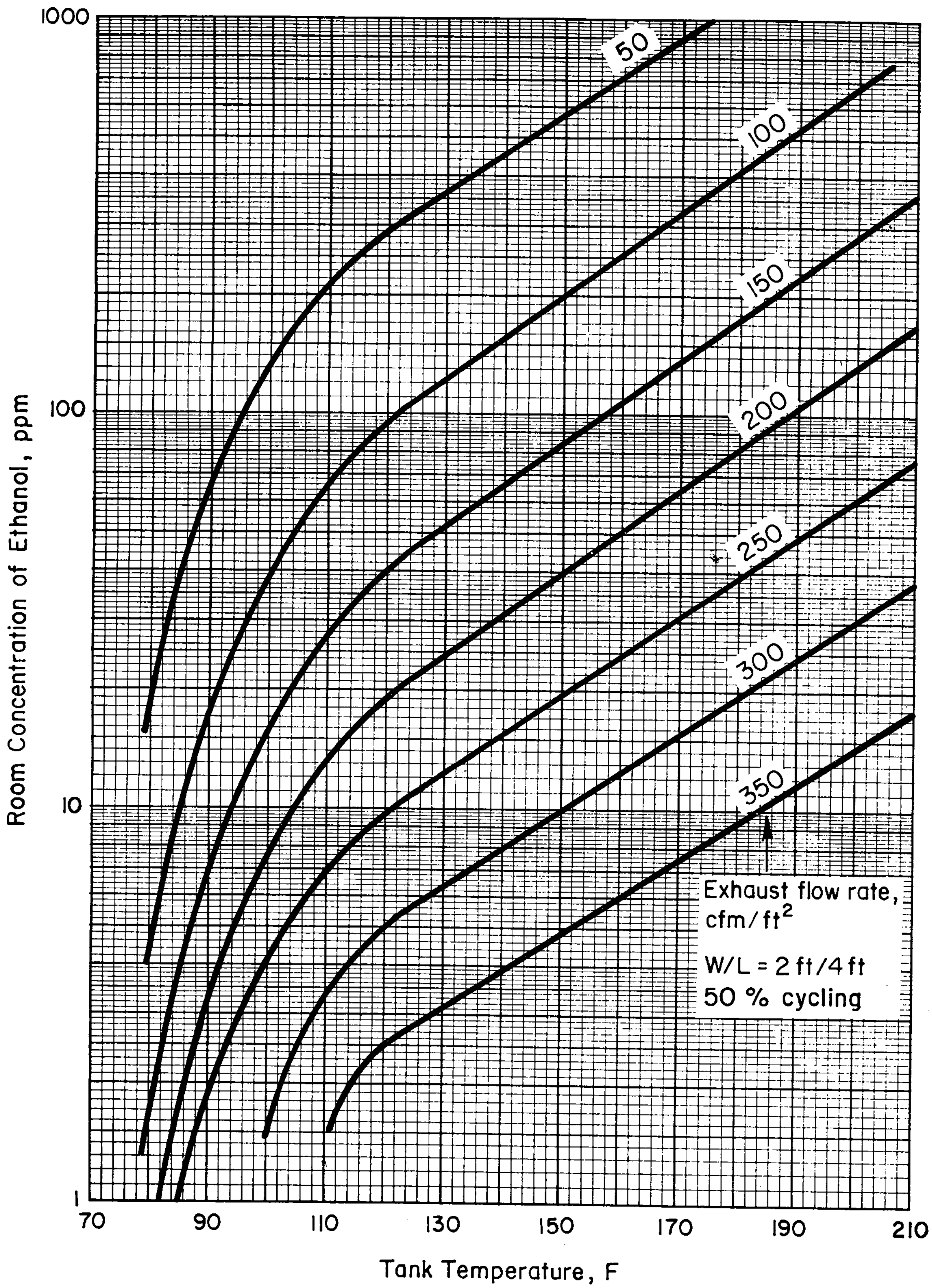


FIGURE 20. EFFECT OF TANK TEMPERATURE ON ROOM EMISSIONS

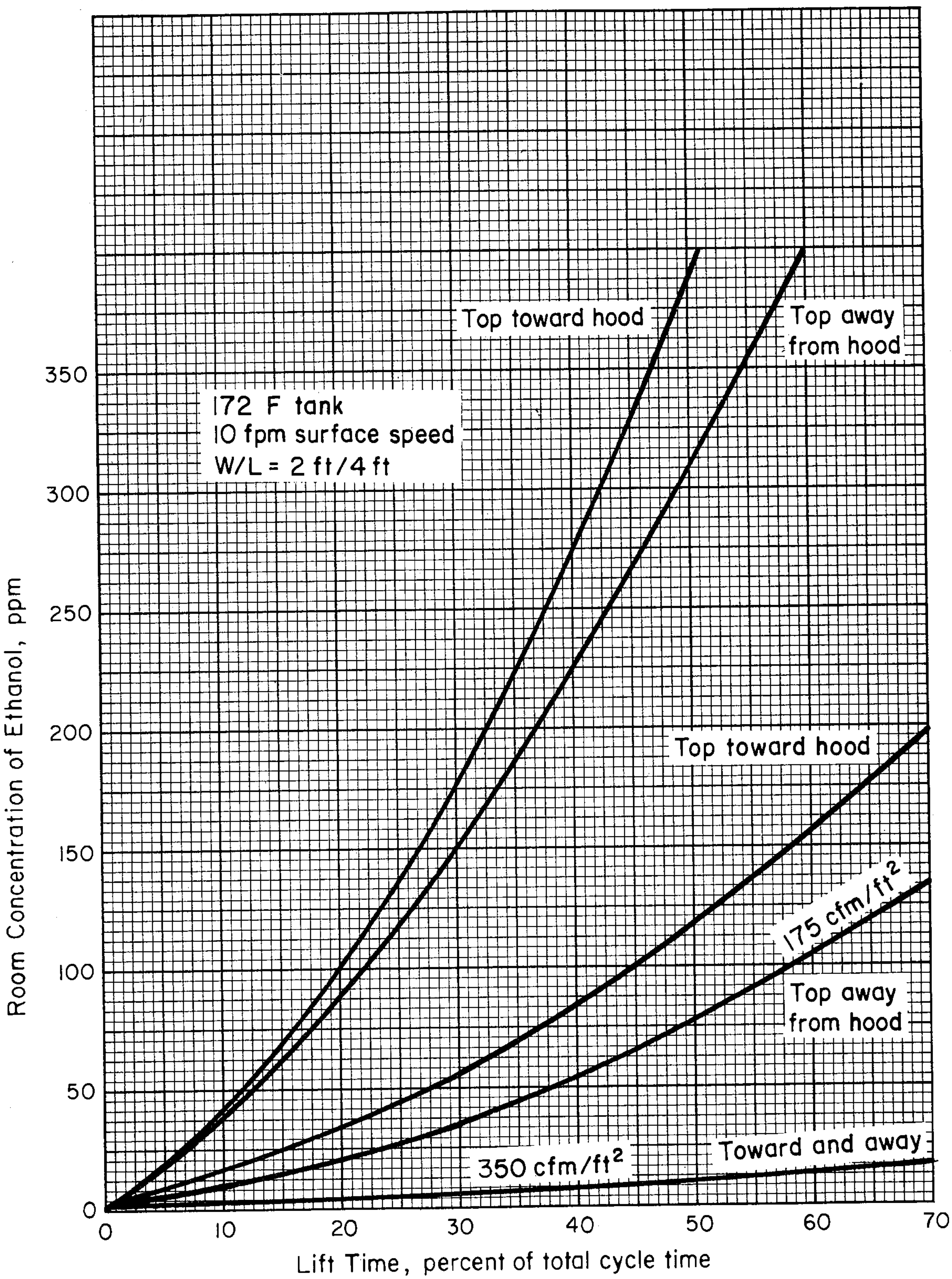


FIGURE 21. EFFECT OF DIRECTION OF BARREL ROTATION ON ROOM EMISSIONS

Studies of room emissions with the same barrel in a 4 by 4-ft tank were conducted with the barrel located in three places in the tank: (1) with its axis perpendicular to the exhaust hood slot and in the right half of the tank, (2) with its axis parallel with the slot and in the half adjacent to the hood, and (3) with its axis parallel with the slot and in the half of the tank farthest from the hood slot.

Figure 22 shows the room emissions obtained with the barrel in a 4 by 4-ft tank and, for comparison, the emissions obtained with a basic open surface tank. Locating the barrel in the front half of the tank away from the exhaust hood in particular resulted in significantly greater emissions than obtained with a basic open-surface tank. It is interesting to note that at the higher exhaust flow rates with the barrel perpendicular and with it adjacent to the hood, the flow rates required approach those required for an open surface tank. This was the result of the increase in local air velocities around the barrel caused by the presence of the barrel close to the hood which blocked part of the flow area.

A single-slot lateral hood, as has been shown, is not particularly effective in capturing emissions from a raised parts barrel. A number of modified hood designs which were deemed to be compatible with barrel-handling equipment were studied. These included baffles, multiple slots, and semilateral-type hoods. These designs were described previously.

Figure 23 shows the room emissions obtained with the several different hood designs used on a 2 by 4-ft tank with a 50 percent lift cycle. All of the modified designs showed a marked improvement in performance, with the open-face semilateral design being the best as it required only 55 percent as much exhaust air. For similar studies on a 4 by 4-ft tank, the exhaust flow required was reduced to 80 percent with the modified hoods, there being no appreciable difference between types.

Push-Pull Exhaust Systems

The high exhaust flow rates required for tanks over about 4 ft wide becomes economically unattractive because of the distance over which air has to be pulled to achieve good capture. Collection efficiency can be greatly enhanced by the addition of air jets along the far side of the tank to push air and vapors across the liquid surface toward the exhaust hood opening.

The push-air assembly for the experimental studies consisted of a 3 by 6-inch rectangular supply header 4 ft long equipped with nozzles located on 6-inch centers. Photographs of the system are shown in Figures 11 and 12. Most of the studies were conducted with the adjustable flat jet nozzles shown in Figure 11. However, the eight 3/4-inch-diameter holes located in the header behind the nozzles were also used by themselves to produce round air jets.

Figure 24 shows the relationship between flow and pressure for the flow nozzles and the round holes. The nozzles require a considerably higher pressure

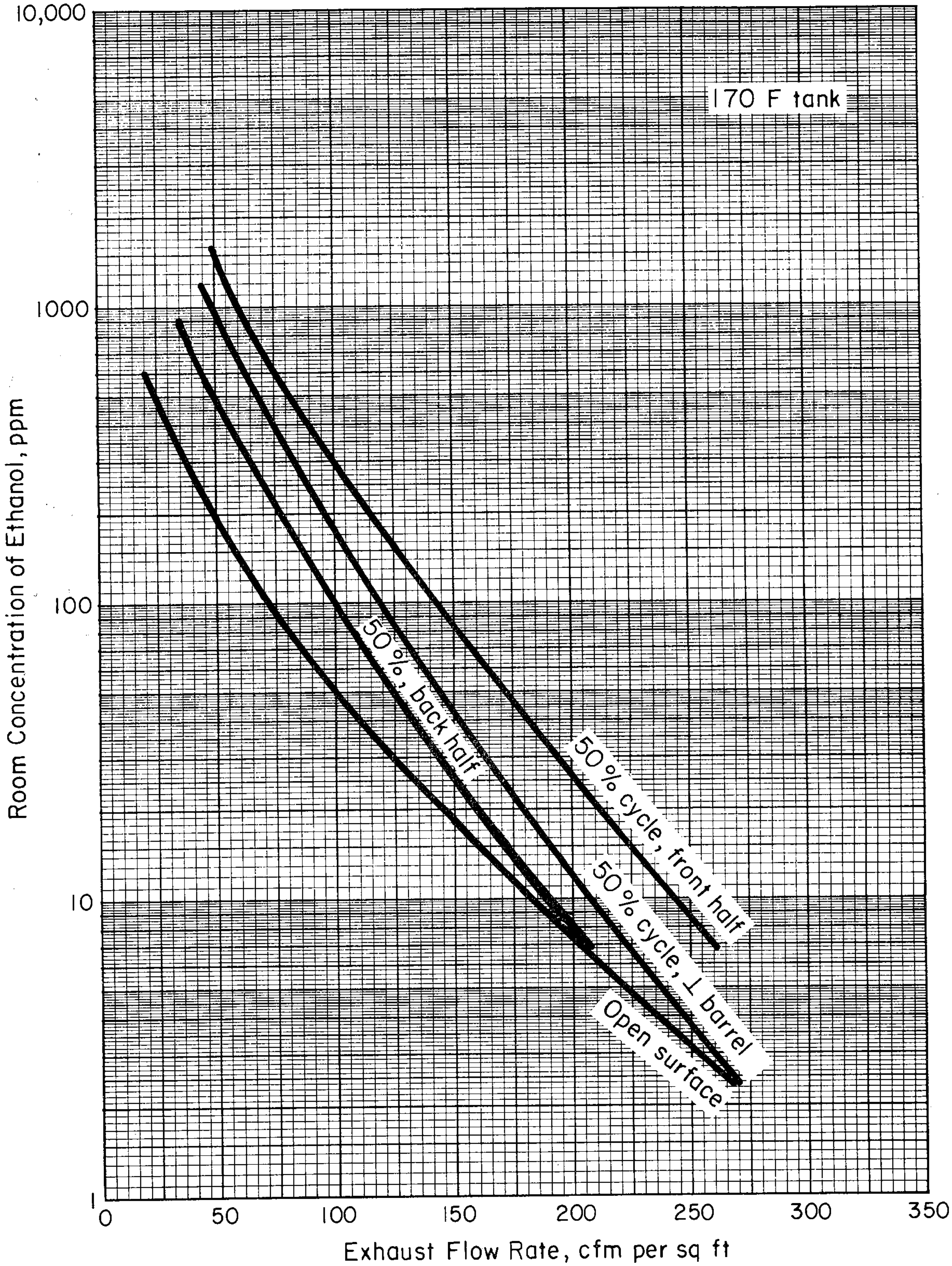


FIGURE 22. ROOM EMISSION OBTAINED WITH BARREL CYCLING IN 4-FT BY 4-FT TANK

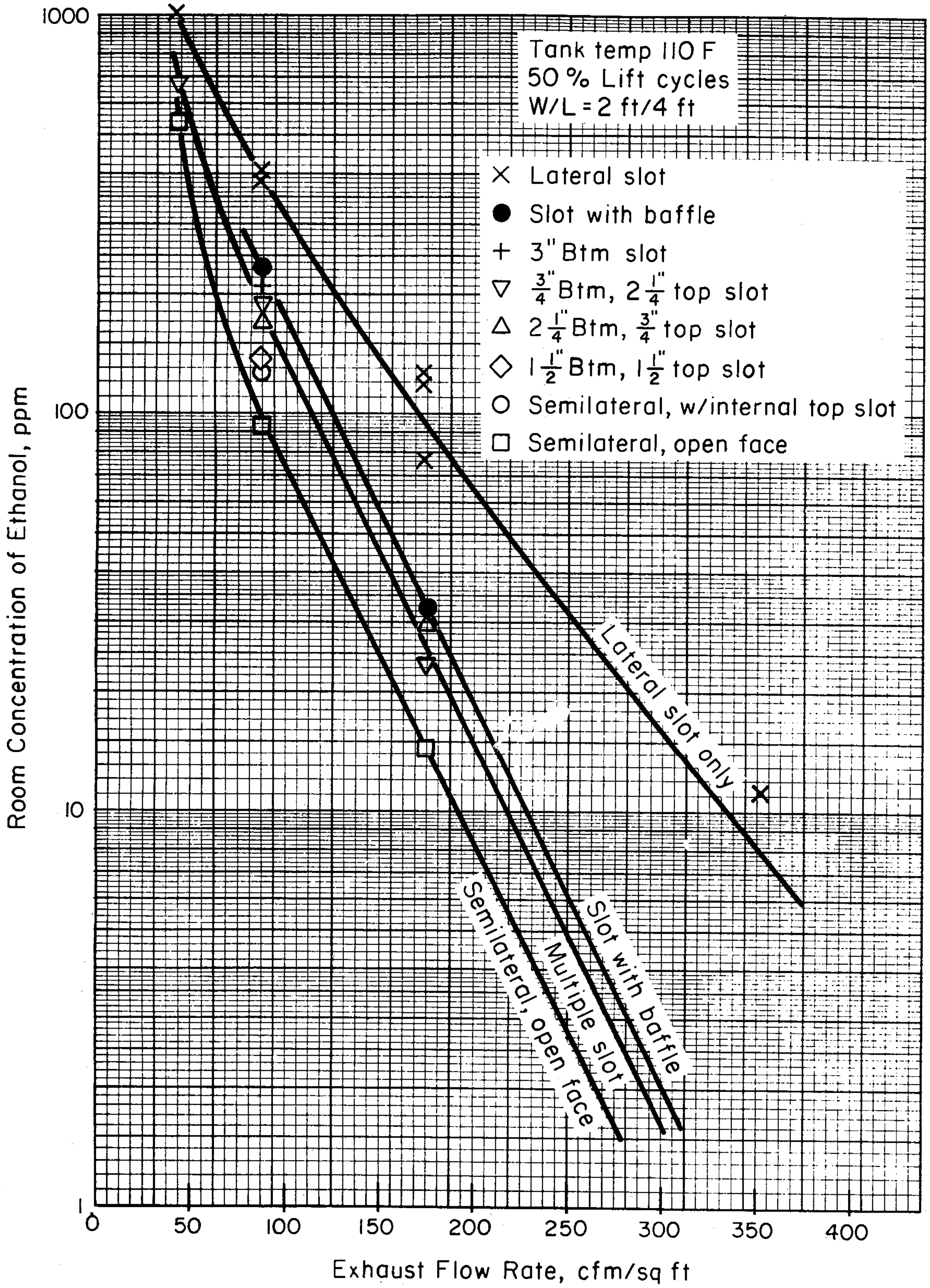


FIGURE 23. ROOM EMISSIONS WITH LATERAL, SEMILATERAL AND MULTI-SLOT HOODS

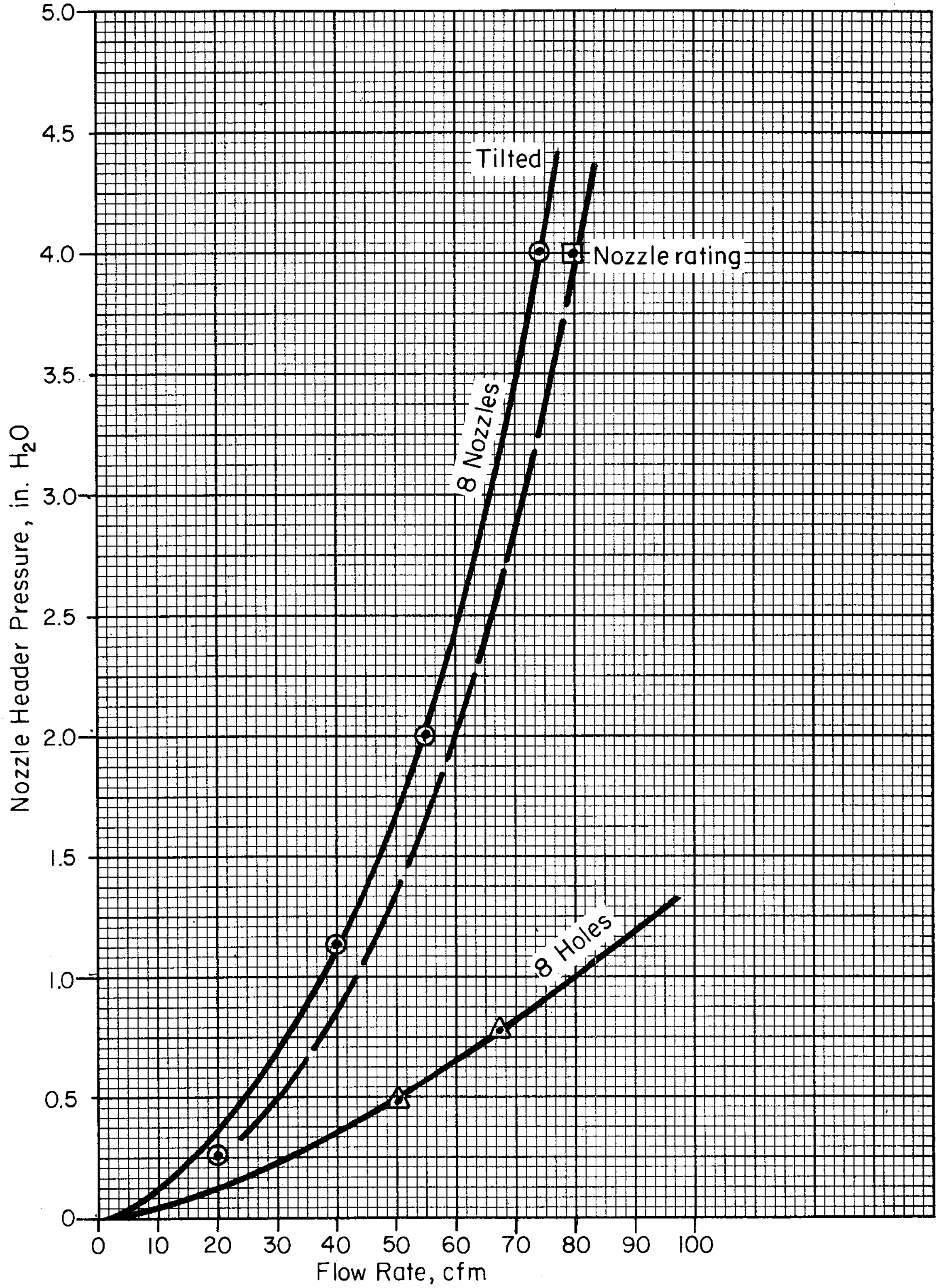


FIGURE 24. FLOW CHARACTERISTICS OF STRAIGHT AND TILTED NOZZLES AND ROUND HOLES

for the same flow; however, the actual pressure required in either case is such that it can be supplied by a simple low-cost blower.

Push-air systems, while being more efficient in capturing emissions, do increase air flow velocities over the liquid surface which, in turn, increases evaporation and heat loss. The flow velocities obtained at a couple of operating conditions with both nozzles and holes are shown in Figure 25. In Figure 26 the effect of varying push-air quantity on the velocity profiles existing above the liquid surface is shown. Figures 25 and 26 show data taken with a 12-inch slot height in the lateral exhaust hood. A 6-inch slot height was later found to be about optimum at these flow rates, as somewhat lower room emissions were obtained. Emissions increased significantly when the slot size was reduced to 3 inches. Therefore, a lateral hood designed with a slot velocity of 500-1000 fpm appears well suited for a push-pull system. It must be remembered that these lower velocities can lead to wide variations in face velocities across the slot opening unless the hood is well designed to achieve uniform flow distribution or unless a distributed resistance such as a perforated plate is installed in the hood.

Room emission studies in which push-air flow rate was varied while exhaust flow rate was held constant showed that there is an optimum push-air flow rate for each pull rate with respect to minimizing room emissions.

Figures 27 and 28 show the effect of push-air flow rates on room emissions for two tank temperatures and several exhaust flow rates for a 4 by 4-ft and an 8 by 4-ft tank. From the curves it can be seen that for each exhaust rate there is a push-air rate that results in minimum room emissions.

Room emissions were measured both with and without push air for the 4-ft-wide and 8-ft-wide tanks. The results of these studies are shown in Figures 29 and 30. The curves in Figure 29 for exhaust flow only are from Figure 15 and are presented to show the magnitude of the effect of push air on reducing room emissions. For the 8-ft-wide tank, emission measurements were also made with only exhaust flow to determine if emissions from a tank of that width could be controlled with exhaust flow only. They can, but the quantity of air needed is very high.

A comparison of the two temperature curves for operation with both push and pull air flow for the 4-ft-wide tank (Figure 29) with the same two curves for the 8-ft-wide tank (Figure 30) shows that the room emissions as a function of exhaust flow per sq ft of tank surface are essentially the same; that is, with optimum push-air flow the exhaust flow rate needed per sq ft of surface area is not affected by tank width. This is not true for exhaust-only control systems.

The push-air flow rates used to obtain the data shown in Figures 29 and 30 were those found to produce minimum room concentrations (Figures 27 and 28). These optimum push-air flow rates as a function of exhaust flow rates are shown in Figure 31 and are to be used in conjunction with Figures 29 and 30. It was found that the optimum push-air flow rates for a 4-ft-wide tank and an 8-ft-wide tank could be represented by a single curve.

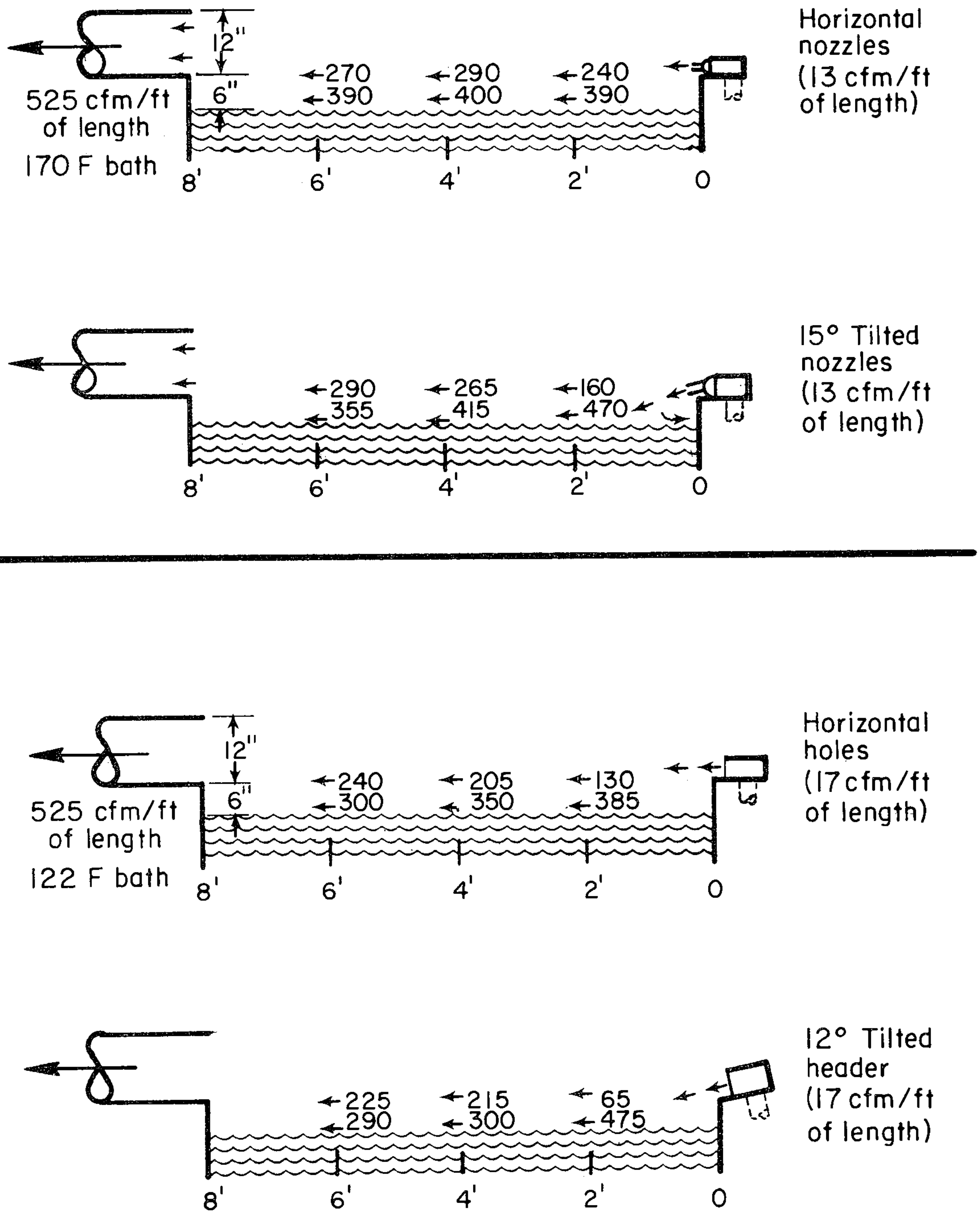
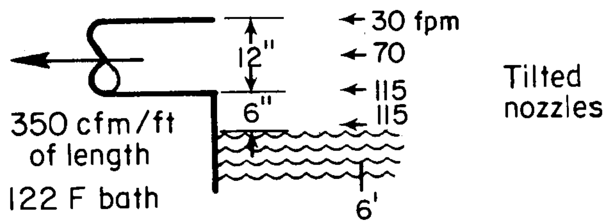
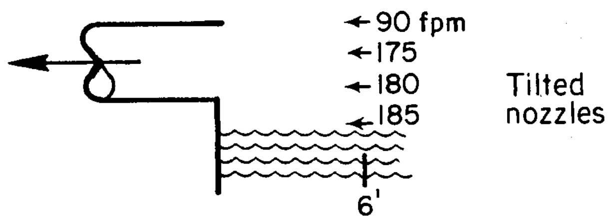


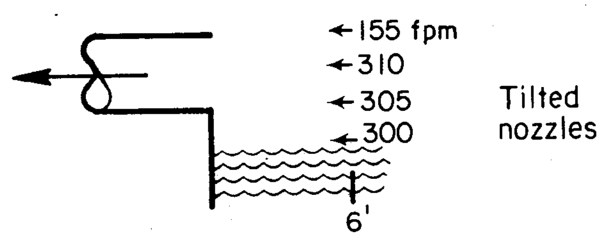
FIGURE 25. SURFACE AIR VELOCITIES OBTAINED WITH PUSH AIR NOZZLES AND HOLES IN AN 8-FT-WIDE TANK



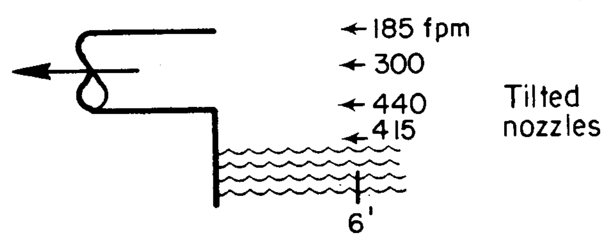
a. 0.25" H_2O, 5 cfm/ft of length



b. 1.0" H_2O, 9.5 cfm/ft of length



c. 2.0" H_2O, 13.25 cfm/ft of length



d. 4.0" H_2O, 18.25 cfm/ft of length

FIGURE 26. EFFECT OF PUSH-AIR RATES ON THE AIR VELOCITY PROFILES OVER THE LIQUID SURFACE OF AN 8-BY-4FT TANK

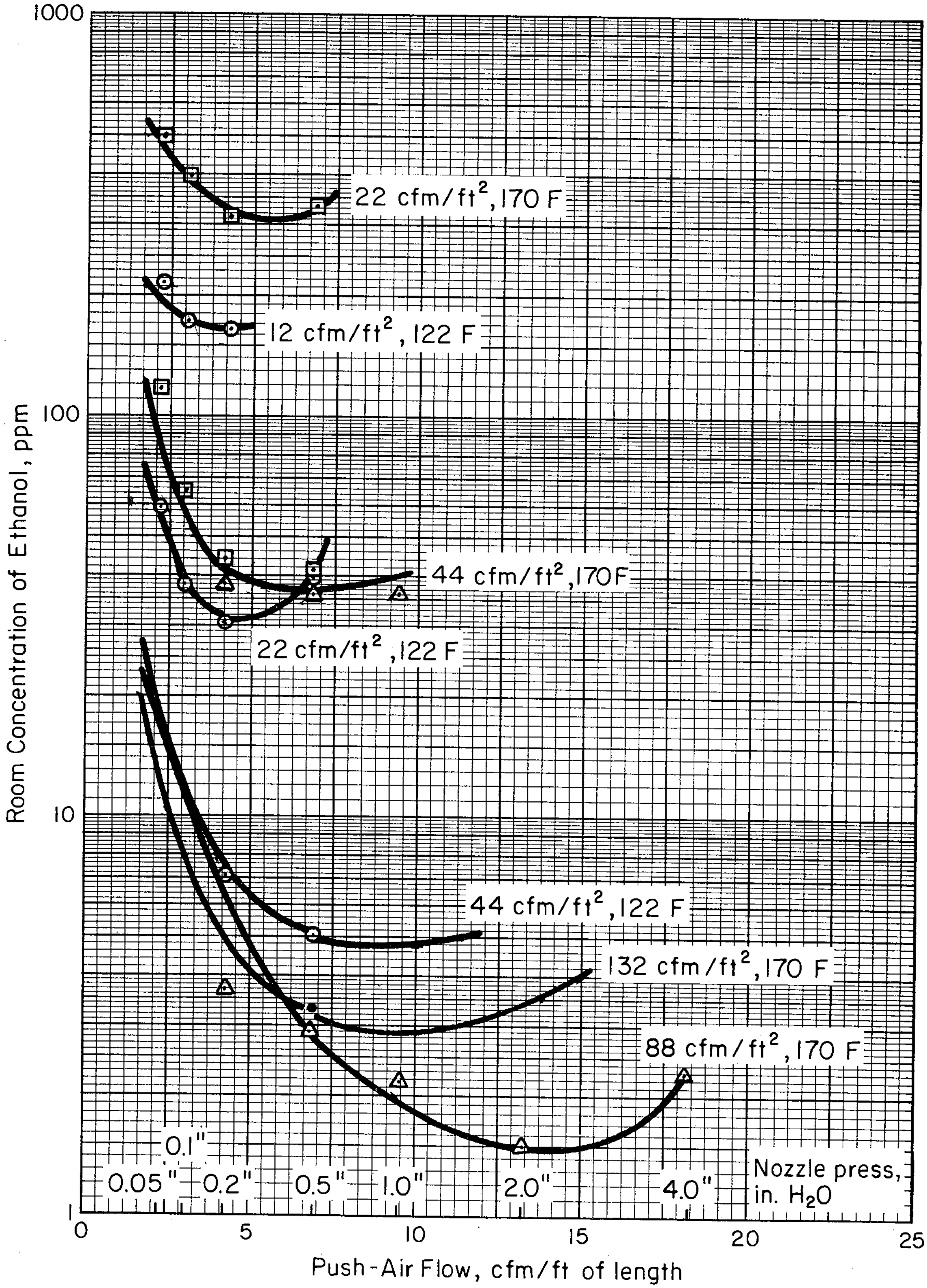


FIGURE 27. EFFECT OF PUSH-AIR RATE ON ROOM EMISSIONS FROM A 4-FT-WIDE TANK

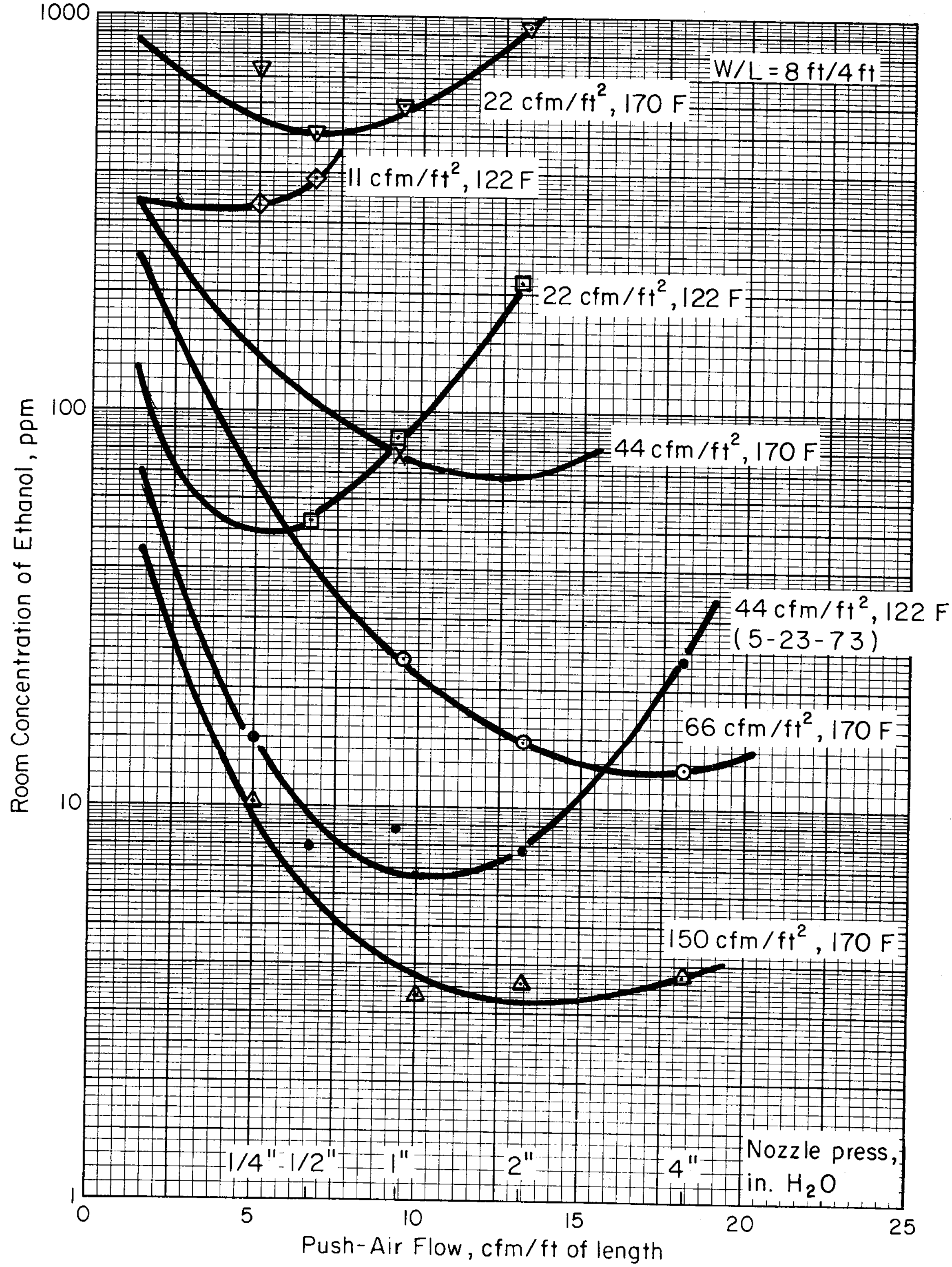


FIGURE 28. EFFECT OF PUSH-AIR RATE ON ROOM EMISSIONS FROM AN 8-FT-WIDE TANK

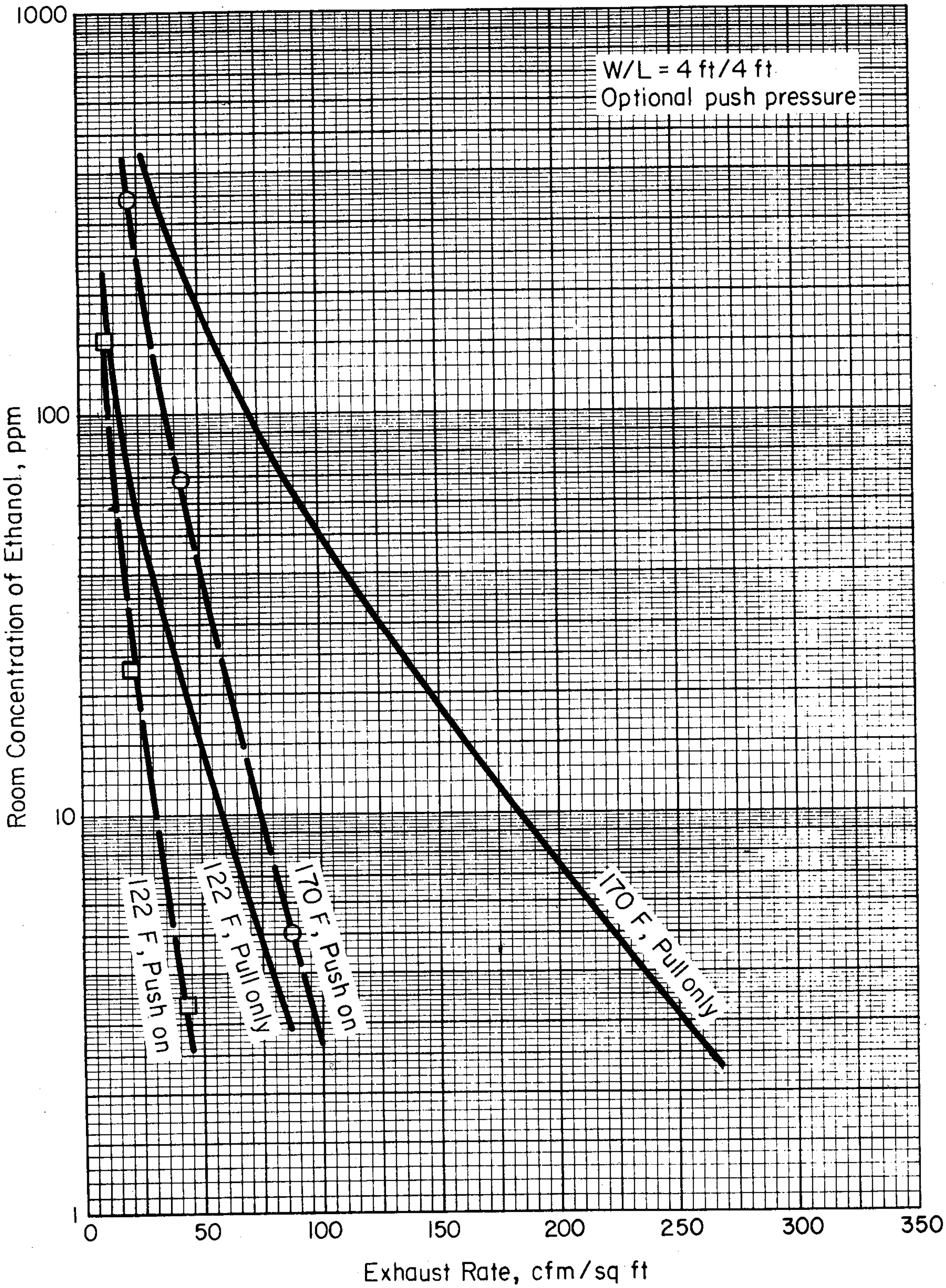


FIGURE 29. ROOM EMISSIONS FOR PUSH-PULL EXHAUST SYSTEM ON A 4-FT-WIDE TANK

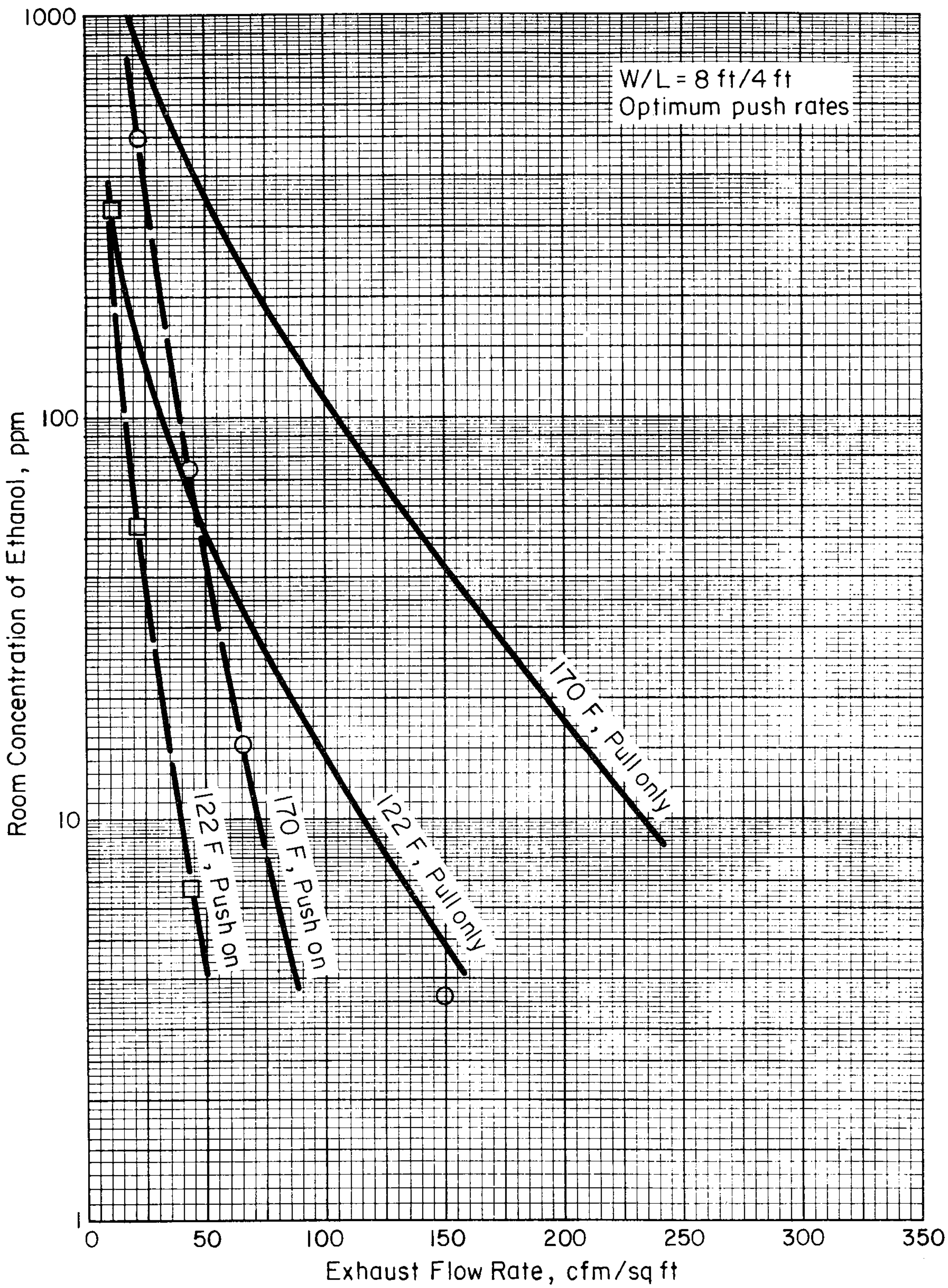


FIGURE 30. ROOM EMISSIONS FOR PUSH-PULL EXHAUST SYSTEM ON AN 8-FT-WIDE TANK

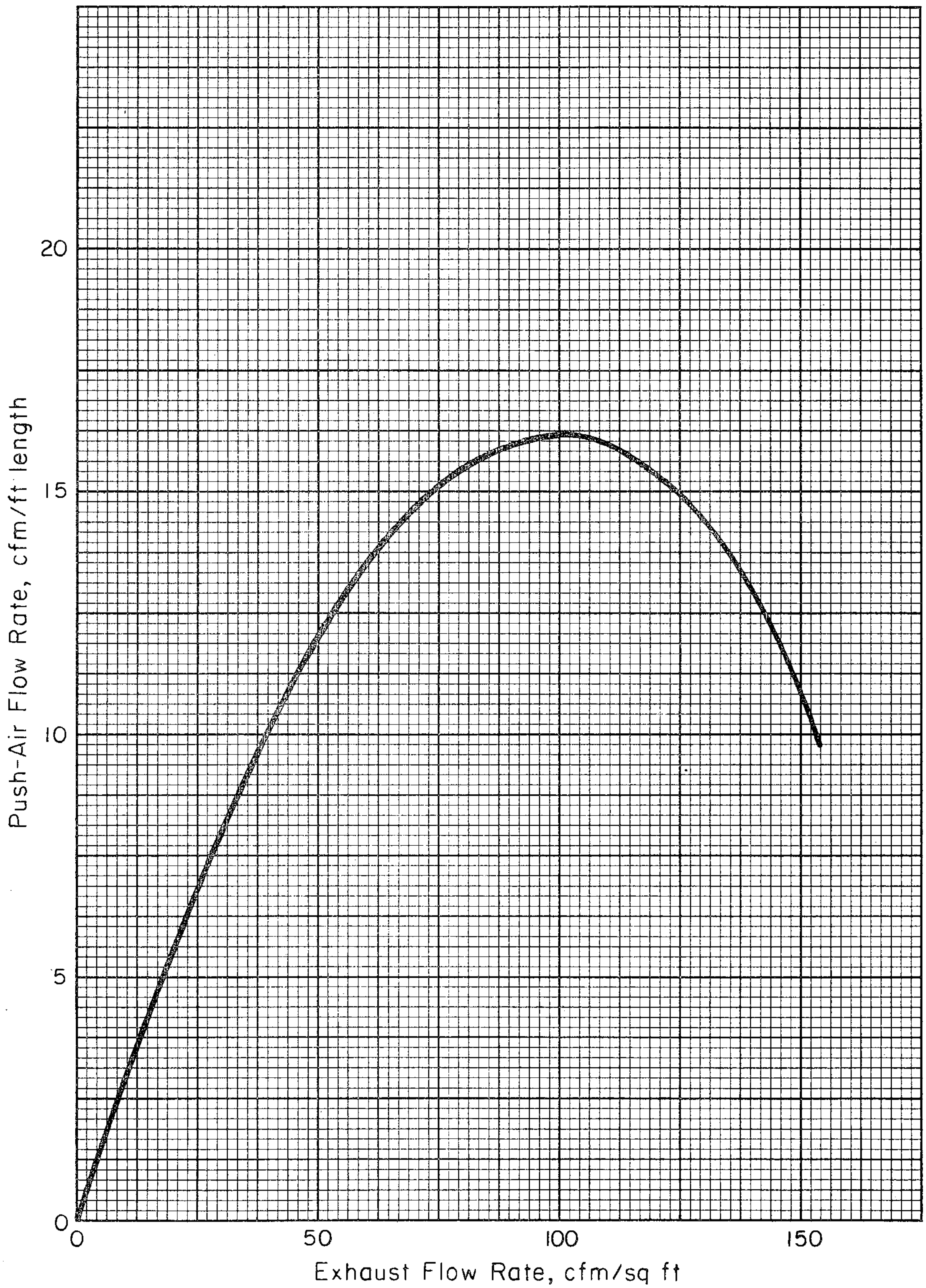


FIGURE 31. PUSH-AIR FLOW RATE REQUIRED FOR MINIMUM ROOM EMISSIONS

The triangular baffle installed above the exhaust hood opening on the 4-ft-wide tank when operating with push air reduced the exhaust flow required to obtain any given room concentration to 80 percent of that required without the baffle. For the 8-ft-wide tank the effect of the baffle was negligible.

Evaporation Rates and Surface Control Agents

For a given condition of room air movement over a tank surface, the rate of evaporation is proportional to the difference in vapor pressures between the evaporating liquid and the vapor of that liquid in the air in the immediate vicinity. With other conditions constant, the rate of evaporation increases in nearly direct proportion to the air velocity.

The vapor pressure of the ethyl alcohol in the 4 percent by weight alcohol-water solution used in the experimental studies is shown in Figure 32.

Evaporation rate data were taken in conjunction with other measurements for many of the operating conditions and configurations studied in the laboratory. An analysis of these data showed that, relative to the basic 4 by 4-ft open surface tank,

- Air agitation at 0.23 cfm per sq ft increased evaporation rate by a factor of 3.3
- Barrel cycling (50 percent cycle) increased evaporation rate by a factor of 3.1
- Push-pull systems increased evaporation rate by a factor of 1.7.

The evaporation rate for the basic 4 by 4-ft open surface tank when operating at a temperature of 170 F with an exhaust flow rate of 88 cfm per sq ft was 0.15 lb per hr per sq ft.

Specific comparisons of predicted and measured evaporation rates showed that the effects of operating variables on evaporation rates can be predicted. For example, the measured evaporation rate when operating at 122 F was 0.28 times that when operating at 170 F with other conditions equal. The value anticipated from a ratio of the vapor pressures was 0.27. When the tank surface area was doubled – 16 sq. ft to 32 sq. ft – the measured increase in evaporation rate was 2.1.

The effect of surface control techniques on reduction of evaporation rate was determined experimentally. The water-alcohol solution used in the laboratory limited the experimental studies; i.e., liquid surfactants used in various industrial baths were not appropriate for use with the alcohol-water bath. Therefore, the studies were conducted using 1.75-in.-diameter hollow plastic spheres. With the spheres arranged such that the open-surface area was minimized, the evaporation

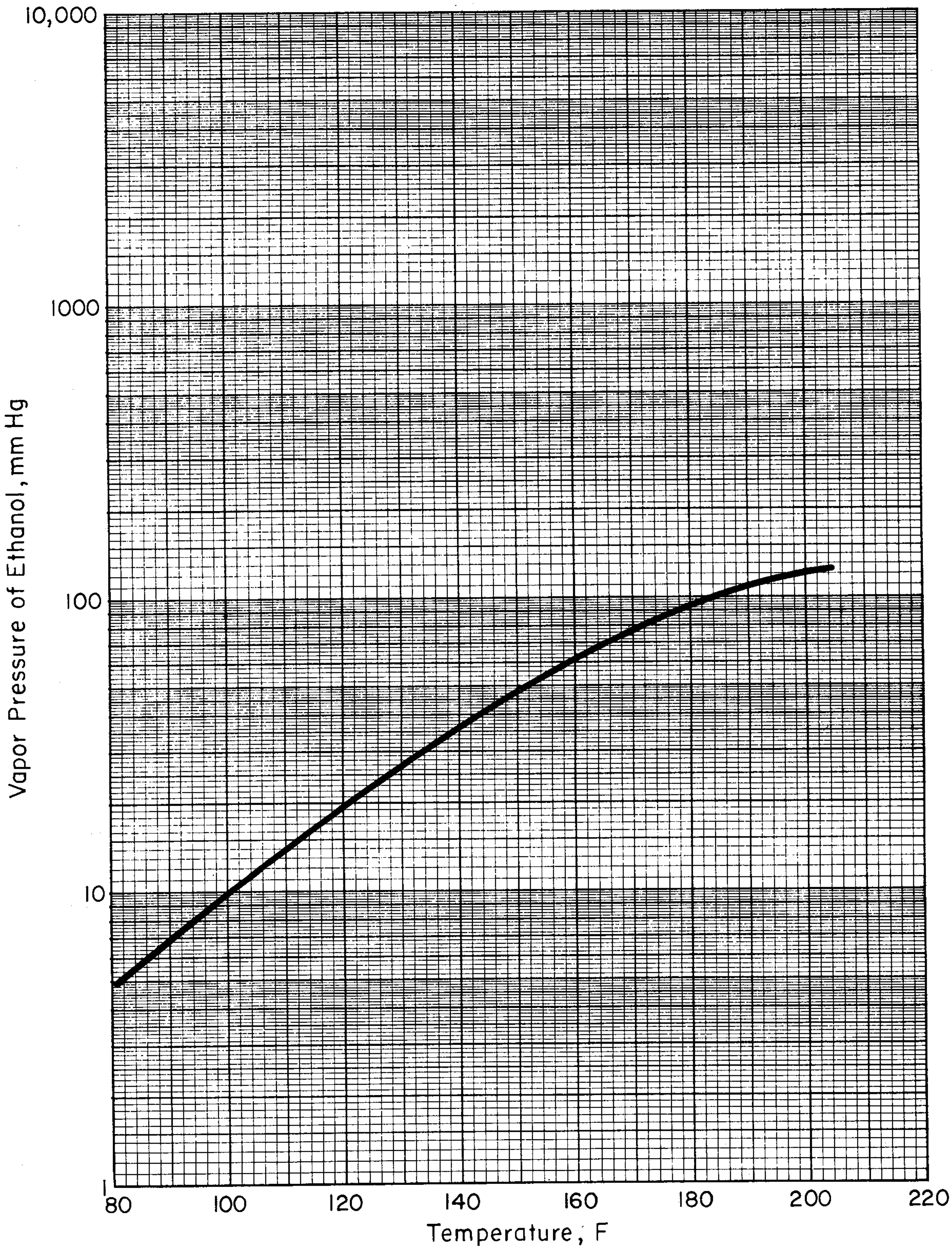


FIGURE 32. VAPOR PRESSURE OF ALCOHOL IN A 4 PERCENT BY WEIGHT ALCOHOL-WATER SOLUTION

rate was reduced to 20 percent of that obtained with an open surface. Measurements of room emissions with the spheres showed a corresponding reduction factor of five relative to those obtained with a basic open-surface tank. The spheres also reduced emissions with simulated gassing by the same amount.

Air Agitation

Air agitation is a technique used to continually stir the contents of a tank by bubbling air from a multi-hole tube located near the bottom of a tank. This air disturbs the surface of the liquid; this increases the evaporating surface area and carries off an increased amount of contaminant from the bath.

The equipment used to provide air agitation in the laboratory tank consisted of a pipe 47 inches long containing 1/8-in.-diameter holes spaced on 2-in. centers. There are no standards for air flow rate, so the flow was adjusted to produce surface conditions that appeared to be similar to those observed in the field. The resulting air flow rate for "normal" agitation was 0.92 cfm per foot of pipe length. To obtain a "high" level of agitation, a flow rate of 2.2 cfm per foot was used.

Figure 33 shows the increase in the room concentration of alcohol resulting from air agitation as a function of the flow rate of the agitating air.

Gassing

In some electroplating processes, gases are generated at the cathodes and anodes. Qualitatively, gassing has the same effect on exhaust hood performance as air agitation; however, the bubbles are much smaller and "foam" is produced on the surface.

Gassing was simulated in the laboratory tank by passing air through a 2-in.-diameter by 36-in.-long metal tube located near the side of the tank opposite the exhaust hood. The tube had a mean pore size of 20 microns, which produced very fine bubbles and mist. A flow rate of 0.13 cfm per foot of length was selected to represent the maximum gassing rate expected from an electrode area of 10 sq. ft with an electric current of 150 amps per sq. ft.

Studies of the effect of gassing on room emissions were made with both push-pull and pull-only exhaust systems. It was found that with push-pull exhaust systems the push air controlled the additional emissions produced by the gassing so that there was essentially no increase in room emissions as a result of having gassing. With pull-only systems there was an increase in room emissions, the magnitude of which is a function of the exhaust flow rate. This is as expected, since the major parameter is the ratio of the momentum of the upward flow to the lateral flow produced by the exhaust hood. Figure 34 shows the increase in room concentration as a function of the exhaust flow rate for pull-only exhaust systems.

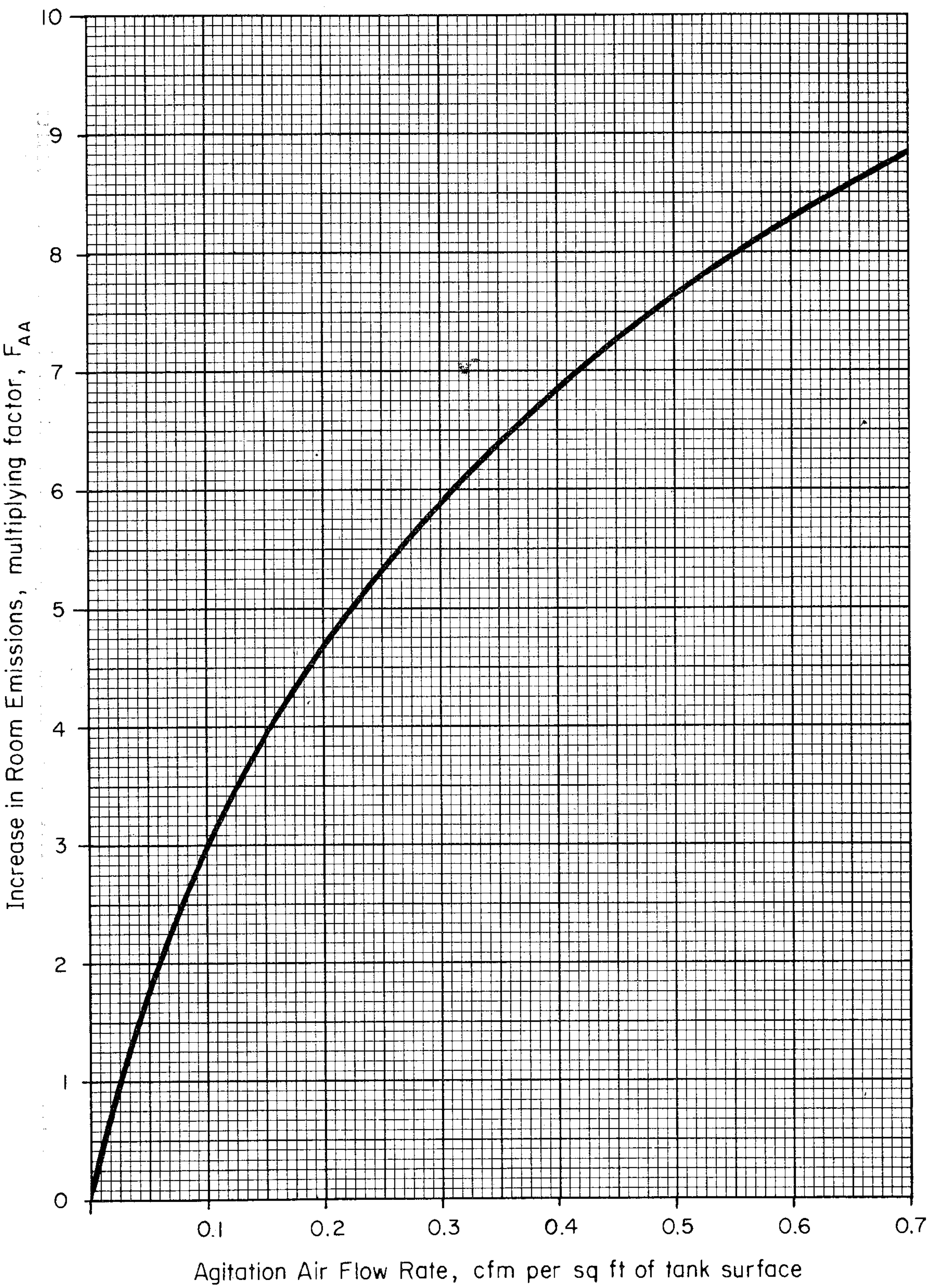


FIGURE 33. EFFECT OF AIR AGITATION ON ROOM EMISSIONS

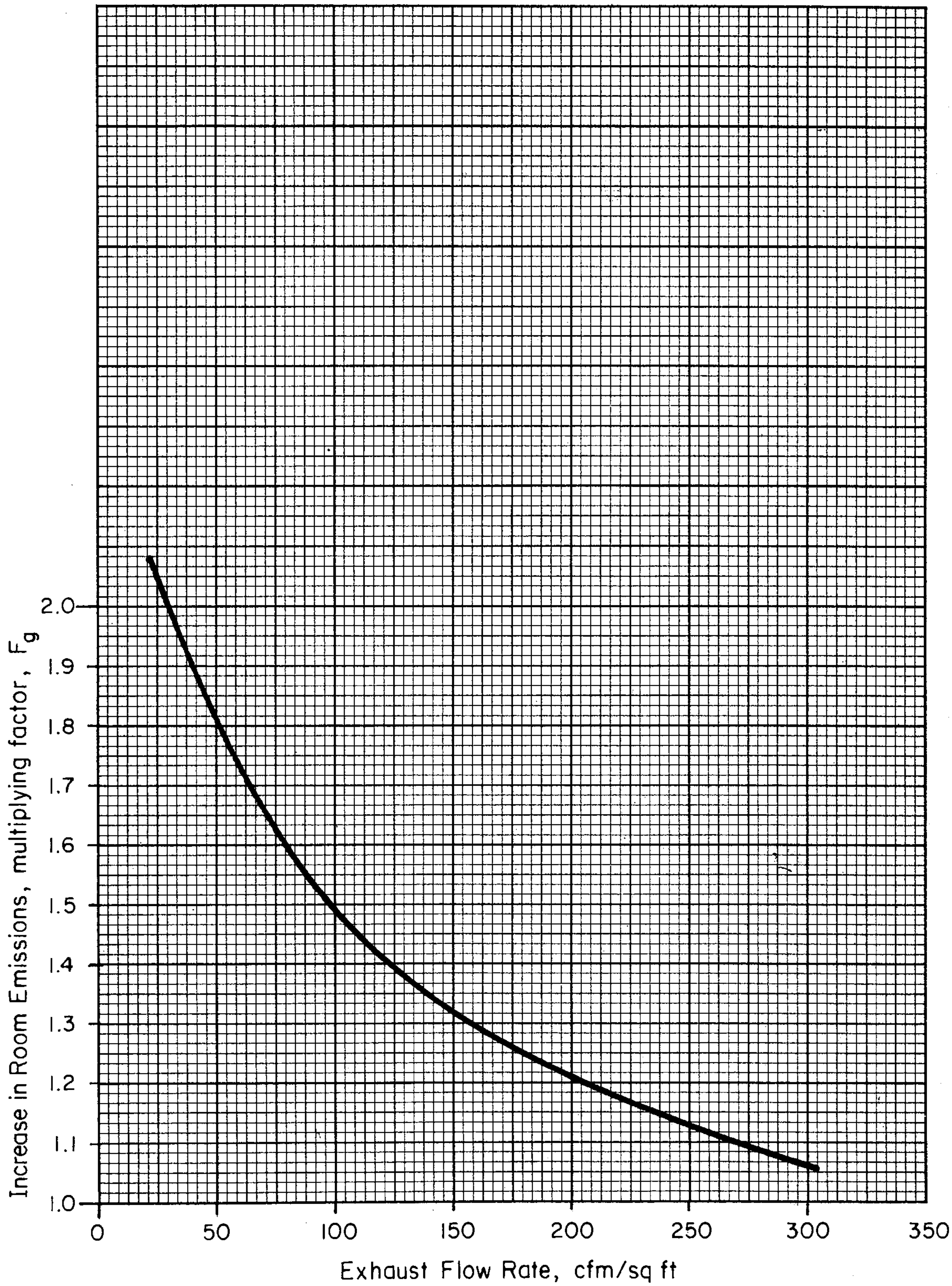


FIGURE 34. EFFECT OF GASSING ON ROOM EMISSIONS WITH PULL-TYPE EXHAUST SYSTEM

Cross Drafts

Cross drafts divert the normal flow of air over the tank created by the exhaust hood. The degree to which the flow is diverted is a function of the ratio of the momentum of the cross draft to the momentum of the exhaust flow. For air flow the momentum is proportional to the square of the velocity. Because cross drafts divert the air flow over the tank, their effect on room emissions and the resultant exposure of workers vary greatly with the location around the tank at which measurements are made (relative to the direction of the cross draft and the direction of the exhaust flow).

The arrangement of equipment used for the cross-draft studies is shown in Figure 35. Measurements of the velocity profile immediately upstream of the tank showed that a uniform velocity was achieved. The increase in room emissions due to the cross draft was determined by operating until a constant room concentration was obtained. The equilibrium value was then used to define the increase in room emissions. Conduct of the studies in this way resulted in values higher than those that would have been obtained if there had been general room ventilation in addition to the makeup air.

Figure 36 shows the increase in room concentration of contaminant as a function of the crossflow velocity.

Mist Generation

Air agitation and gassing both involve the upward movement of gas bubbles through the bath to the liquid surface. These bubbles agitate the liquid surface, causing the formation of liquid droplets or mists. Larger droplets rise above the surface and then fall back, but the smaller ones are caught in the moving air above the tank. With volatile fluids these small droplets evaporate, but with fluids having little or no vapor pressure they are transported as liquid droplets.

The room concentrations – resulting from the transport of mist droplets when operating with the gassing rate of 0.4 cfm expected from an electrode area of 10 sq ft with an electric current of 150 amps per sq ft in a 4 by 4-ft tank – are shown in Figure 37 for a tank equipped with a single-slot lateral hood and with a push-pull exhaust system.

DISCUSSION AND APPLICATION OF DATA

The emissions from a given tank configuration are a function of the vapor pressure and diffusivity of the bath constituents and the bath temperature, with the temperature defining the magnitude of the buoyancy effects. The alcohol used in

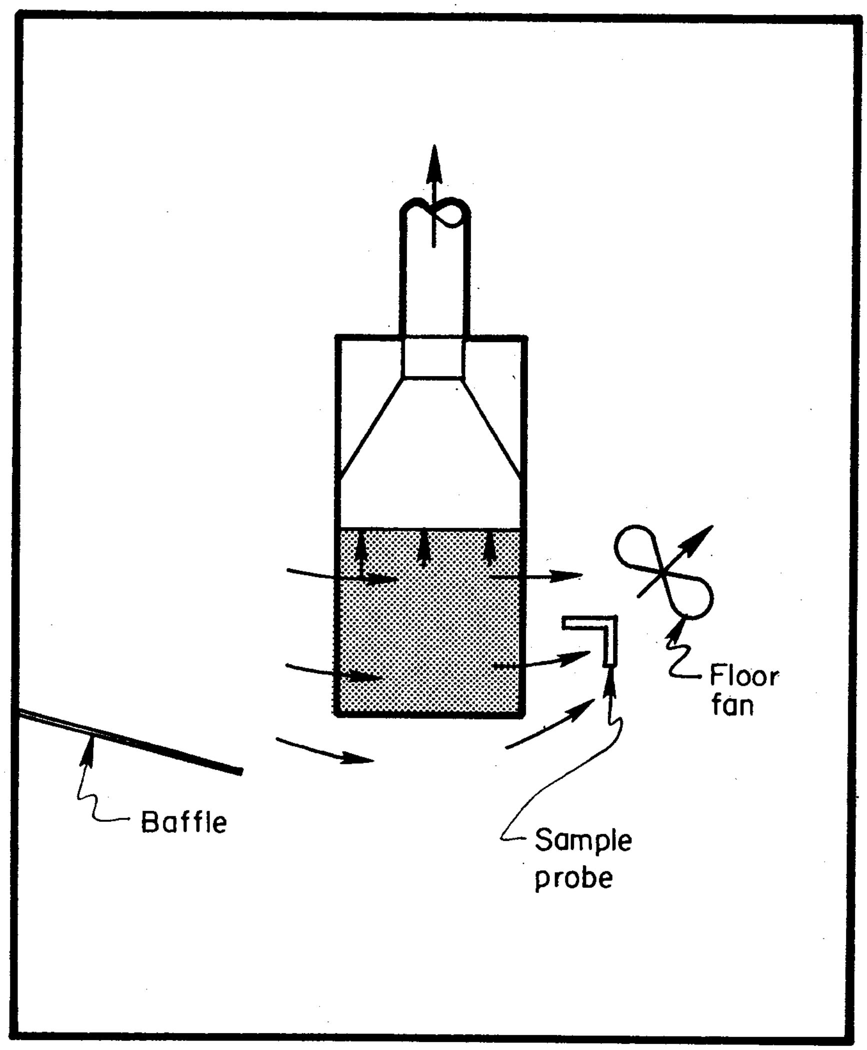


FIGURE 35. ARRANGEMENT FOR CROSS-DRAFT STUDIES

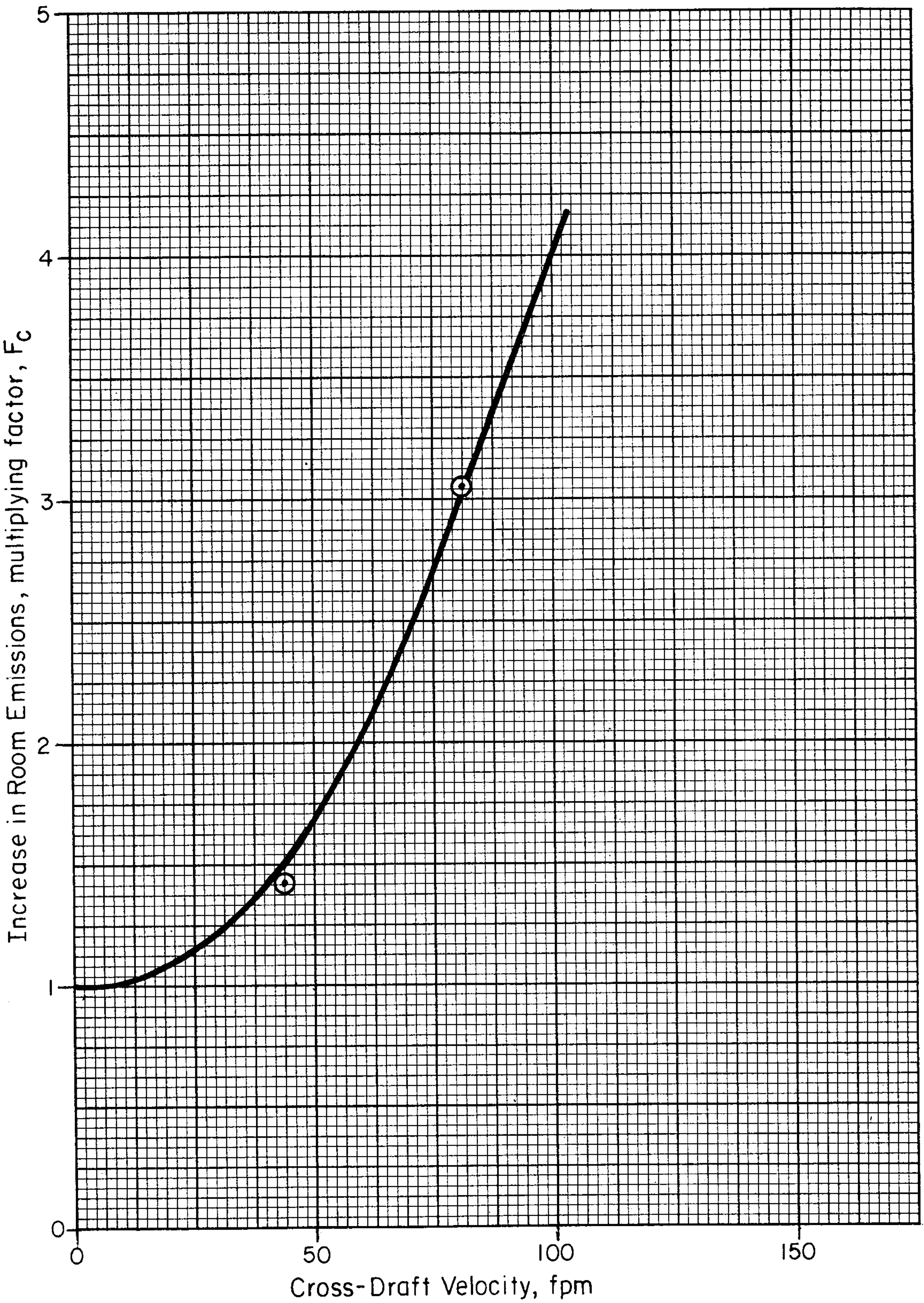


FIGURE 36. EFFECT OF 90-DEGREE CROSS DRAFT ON ROOM EMISSIONS

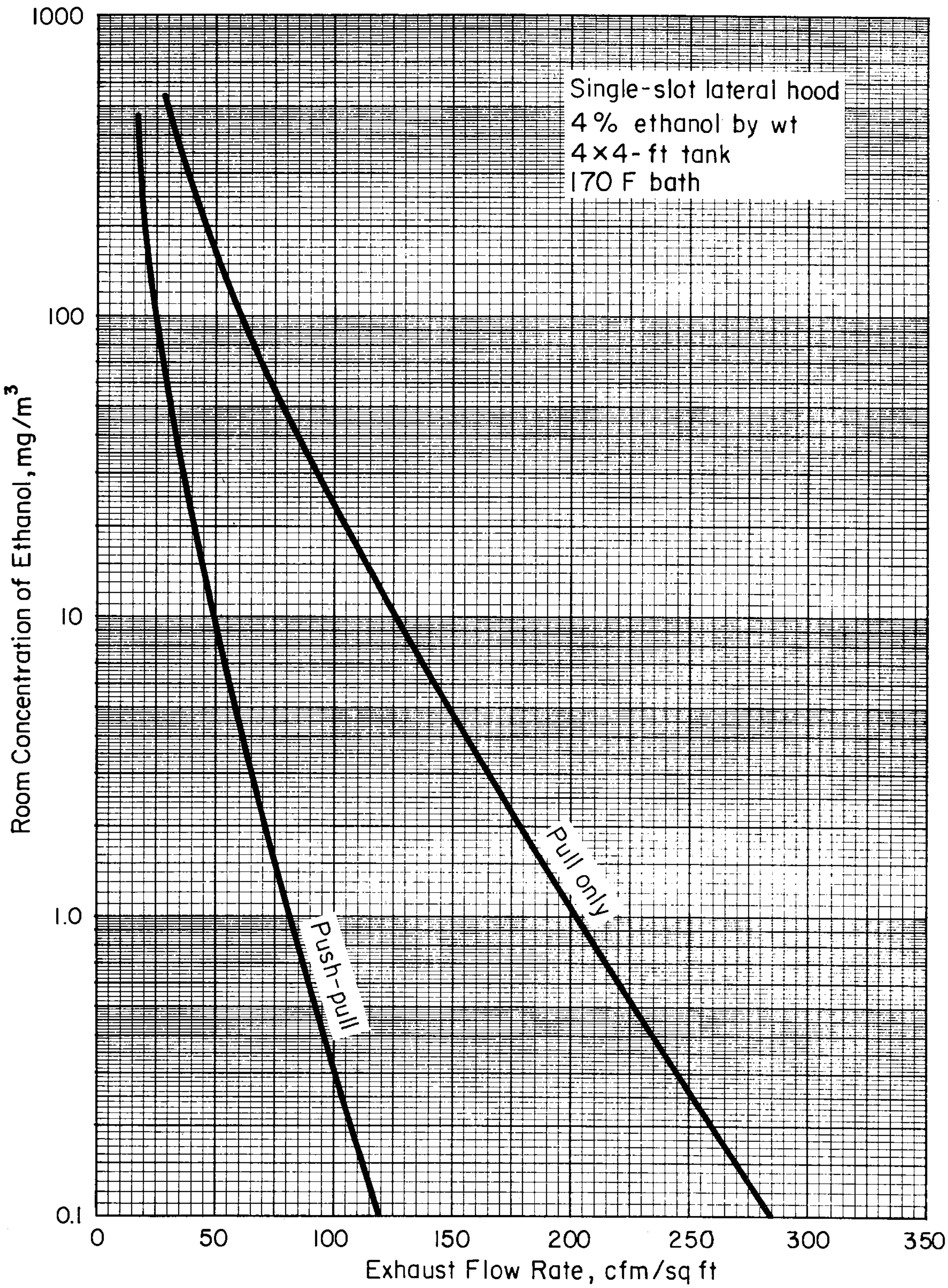


FIGURE 37. ROOM EMISSIONS FROM BASIC OPEN SURFACE TANK DUE TO MISTING

the experimental studies can be thought of as an evaporating fluid having a known vapor pressure and diffusivity. Thus, any other fluid having a different vapor pressure and diffusivity can be represented in terms of an "equivalent concentration" of alcohol. Since the key parameter in the design of an exhaust system is the desired concentration of a contaminant to which a worker should be exposed, it is most convenient to express the "equivalent concentration" as a room concentration of alcohol. This can be done using the following equation:

$$C_{ae} = C_x \left(\frac{VP_{aT}}{VP_{xT}}\right)\left(\frac{D_a}{D_x}\right)^{0.67} (F_1)(F_2)(F_n) \tag{1}$$

where

C_{ae} = Room concentration of alcohol equivalent to that desired for contaminant x, ppm

C_x = Design concentration of contaminant x, ppm

$VP_{a,T}$ = Vapor pressure of alcohol at tank operating temperature

$VP_{x,T}$ = Vapor pressure of contaminant x at tank operating temperature

D_a = Coefficient of diffusivity of alcohol

D_x = Coefficient of diffusivity of contaminant x

$F_{1,2,n}$ = Factors to account for effects of gassing, air agitation, barrel cycling, etc.

In the form that the data and the equations are presented in this report, the concentration of alcohol that is equivalent to the design concentration of a contaminant having a higher vapor pressure or diffusivity will be less than the design concentration. This results because a more volatile or mobile contaminant will be more difficult to capture and, therefore, will require a higher exhaust flow rate than would alcohol at the same temperature. From examination of any of the figures showing room concentration of alcohol as a function of exhaust flow rate it can be seen that, as room concentration is decreased, flow rate increases; thus, it is required that the value of the alcohol equivalent be lower than the design value. This is also the case for factors such as gassing and air agitation, which increase room emissions relative to those obtained with a basic tank. The maximum value that the design concentration can assume is the Threshold Limit Value (TLV) for the contaminant. If the TLV is used, any unaccounted perturbations in the operation of the system could result in exposure of workers to excessive concentrations of hazardous materials. During the course of the field studies it was found that one large user of open-surface tanks designed for 10 percent of the TLV's and found that under production conditions this resulted in levels of 40 to 50 percent of the TLV's. Another designer feels that exposing workers to TLV levels is not in their best interest and therefore uses design values that are 25 to 50 percent of the TLV.

Having the "alcohol equivalent", the required exhaust flow rate can be determined from the appropriate experimental data presented previously.

For the basic open-surface tank without parts cycling, etc., the form of the alcohol equivalent equation is

$$C_{ae} = C_x \left(\frac{VP_{a,T}}{VP_{x,T}}\right)\left(\frac{D_a}{D_x}\right)^{0.67} \quad . \tag{2}$$

The vapor pressure of alcohol at various temperatures is shown in Figure 32. The coefficient of diffusivity for alcohol is 0.40 sq. ft/hr. The vapor pressure and diffusivity coefficient for other bath constituents must be obtained from handbooks or measured. For proprietary solutions these data may be available from the manufacturers.

Having the value for C_{ae}, the design flow rate is found on Figure 15, interpolating as needed for temperatures and widths not shown. For tank widths greater than 3 to 4 feet, more efficient operation – i.e., reduced exhaust flow rates – can be achieved by using a push-pull system. For tanks longer than 4 ft the required flow rate is determined as explained in the discussion of Figure 16.

With air agitation the equation becomes

$$C_{ae} = C_x \left(\frac{VP_{a,T}}{VP_{x,T}}\right)\left(\frac{D_a}{D_x}\right)^{0.67}\left(\frac{1}{F_{aa}}\right) \quad . \tag{3}$$

The value of F_{aa} is found in Figure 33.

With gassing, determination of C_{ae} requires an iterative computation since the effect of gas evolution on room concentration is a function of exhaust flow rate (see Figure 34). The steps in the iterative calculation are as follows:

(1) Calculate C_{ae} as if there were no gassing

(2) Determine exhaust flow rate from Figure 15

(3) Determine gassing factor (F_g) from Figure 34

(4) Recalculate C_{ae}, inserting the gassing factor in Equation (1) in the form $1/F_g$

(5) Determine new exhaust flow rate from Figure 15

(6) Repeat Steps (3) - (5) until satisfactory convergence is reached.

Processing of small parts in barrels constitutes a major usage of open-surface tanks. For operations involving parts barrels the equation for determining the "alcohol equivalent" is

$$C_{ae} = C_x \left(\frac{VP_{a,T}}{VP_{x,T}} \right) \left(\frac{D_a}{D_x} \right)^{0.67} \left(\frac{A_t}{A_p} \right) \left(\frac{t_t}{t_p} \right) , \tag{4}$$

where

A_t = Area of test barrel, 17.6 sq ft

A_p = Area of actual parts or barrel, sq ft

t_t = Fraction of total cycle time that barrel was lifted out of tank in laboratory studies, 0.5

t_p = Fraction of total cycle time that actual parts of barrel are to be lifted out of tank.

The exhaust flow rate for the "alcohol equivalent" room concentration is found on Figure 17 for a single barrel tank – e.g., 2 ft wide by 4 ft long – with the exhaust hood on the long side and the barrel rotating with the top moving toward the hood at 10 fpm. The effect of reversed barrel rotation on room emissions is shown in Figure 21. For a single barrel in a 4 by 4-ft tank the exhaust flow rate is found from Figure 22 using the curve which corresponds to the expected location of the barrel in the tank. The flow rate needed at temperatures other than 170 F are obtained by determining the percentage increase in room concentration relative to an identical open-surface tank and applying this value at the design temperature (Figure 15). The effects of gassing and air agitation are accounted for in the same manner as was described for the open-surface tank. The effects of cross drafts on a barrel in the raised position are such that the emissions cannot be controlled by a realistic increase in the exhaust flow rate. Therefore, baffling to eliminate cross drafts may be the most expeditious alternative.

Push-pull exhaust system flow rate is determined by calculating the alcohol equivalent room concentration using Equation (2) for the basic open-surface tank and then obtaining the exhaust flow rate from Figures 29 or 30. The exhaust flow rate for intermediate tank widths are obtained by interpolation between the two figures. The push-air flow rate to be used is then determined from Figure 31.

The exhaust flow rates needed to control mists of fluids having little or no vapor pressure are determined using Figure 37. The curve in Figure 37 shows the concentration of alcohol measured in the room as a function of exhaust flow rate when 0.375 lb per min. of mist was being generated by the action of the gas bubbles. Of this 0.375 lb per min., 4 percent (or 0.015 lb per min.) was alcohol.

The room concentration of alcohol that is equivalent to the design concentration of any other contaminant can be found from the following expression, assuming the volume of mist generated is a function only of gassing rate:

$$K_{ae} = K_x \frac{\rho a}{\rho x} \frac{Wa}{Wx} \frac{Ga}{Gx} \tag{5}$$

where

K_{ae} = Room concentration of alcohol equivalent to that desired for contaminant x, mg/cu in.

K_x = Design concentration of contaminant x, mg/cu in.

ρa = Density of alcohol-water mixture, 61.6 lb/cu ft

ρx = Density of contaminant x, lb/cu ft

Wa = Percent by weight of alcohol in bath, 4.0

Wx = Percent by weight of contaminant x in bath

Ga = Gas generation rate in laboratory tank, 0.4 cfm

Gx = Gas generation rate in tank x, cfm.

The exhaust flow rate needed is obtained from Figure 37 using the alcohol equivalent to the design concentration.

For tank widths other than 4 ft the exhaust flow rate obtained from Figure 37 is adjusted by a factor obtained from the room emission curves used in connection with vaporizing fluids. The value of the factor is determined by determining the ratio of the exhaust flow rate needed for the desired width tank at the alcohol equivalent concentration to that needed for a 4-ft-wide tank, knowing that a concentration of alcohol of 1 ppm is equivalent to 1.9 mg per cu meter. *

For fluids having low volatility – i.e., a low vapor pressure – the required exhaust flow rate should be determined by considering the fluid to be both volatile and nonvolatile and selecting the higher of the two exhaust flow rates.

COMPARISON OF EXHAUST FLOW RATES BASED ON DESIGN STANDARDS VERSUS STUDY DATA

The magnitudes of the effects of using the data obtained in this study versus using existing design standards in References (1) and (2) were determined for 12 commonly used open-surface tank operations. For the examples, it was assumed that small parts were being processed and that a parts barrel therefore would be used in a 2-ft-wide 4-ft-long tank equipped with a lateral hood.

Table 2 shows the selected processes and the exhaust flow rates required. The last column shows the ratios of required flow rates with the values based on present standards expressed in terms of the values obtained from laboratory data. These ratios can also be thought of as "safety factors". The ratios vary from a factor of 1.1 to a factor of 68. The variation is mostly due to the use of actual evaporation rate rather than categories and to stepwise classification of hazard potential and tank width/length ratios that are a part of the present standards, as

*See NIOSH Project Officer's Note, page iii

TABLE 2. COMPARISON OF EXHAUST-FLOW RATES BASED ON STANDARDS AND PROGRAM DATA PROCESS

		Temp, F	Bath	Class	$C^{(1)}$, ppm	$C_{ae}^{(2)}$, ppm	Exhaust Flow Rate, cfm/sq ft: Lab Data(3)	Design Standards(4)	Ratio
1.	Pickling, iron and steel	70	HCL	A-2	5	78	37.5	340	9.0
2.	Pickling, monel and nickel	180	HCL	A-2	5	90	175	340	1.9
3.	Bright dip, aluminum	200	HNO_3	A-1	2	940	81	340	4.2
4.	Pickling, stainless steel	180	HF	A-2	3	14	306	340	1.1
5.	Pickling, stainless steel	170	HNO_3	A-2	2	354	90	340	3.8
6.	Electropolish, aluminum	200	HF	A-2	3	713	98	340	3.5
7.	Descaling, stainless steel	150	HF	B-1	3	380	66	225	3.4
8.	Descaling, stainless steel	150	HNO_3	B-1	2	735	45	225	5.0
9.	Predye dip, magnesium	180	NH_4OH	B-3	50	2,960	22.5	170	7.6
10.	Anodize, galvanic	140	NH_4OH	B-3	50	15,900	~2.5	170	68
11.	Pickling, cast iron	70	HF	A-2	3	76	36	340	9.4
12.	Electroless, copper	75	HCHO	A-1	5	11.4	88	340	3.9

(1) Design room concentration; for these examples, TLV's are used.
(2) Alcohol equivalent of actual bath.
(3) Required flow obtained from Figure 17; barrel cycling in a 2 by 4-ft tank.
(4) Design flow obtained from design manuals.

was shown in Figure 1 and 2. The procedure used to determine the exhaust flow rates based on the laboratory study data is illustrated in the following example.

Selecting pickling of stainless steel (Line 5, Table 2) with the emission of nitric acid and having defined the specific process – i.e., processing of small parts in barrels in which the cycle time is 50 percent – the alcohol equivalent of the selected design concentration is determined using Equation (4). The values of the variables in the equation are

C_{ae}	To be determined
C_x	Design room concentration, TLV for nitric acid, 2 ppm
VP_{aT}	Vapor pressure of alcohol water mixture at 170 F, 76 mm mercury (Figure 32)
VP_{xT}	Vapor pressure of nitric acid in bath at 170 F, 0.37 mm mercury (Reference 5, p 169 – Table 16 interpolated)
D_a	Diffusivity of alcohol, 0.4 sq ft/hr (Reference 5, p 539)
D_x	Diffusivity of nitric acid, 0.5 sq ft/hr (Reference 5, p 538)
$\frac{A_T}{A_p}$	Area ratio (assumed to be 1)
$\frac{t_t}{t_t}$	Cycle time ratio (assumed to be 1).

Substituting the above values in the equation the alcohol concentration (C_{ae}) equivalent to the 2 ppm is found to be 354 ppm. The required exhaust flow rate of 90 cfm/sq ft is obtained from Figure 17 – i.e., a concentration of 354 ppm and a bath temperature of 170 F.

OTHER CONTROL TECHNIQUES

Lateral-slot hoods or variations thereof are widely used because they offer a minimum of interference to process operations, particularly in connection with barrel and parts handling. Their major shortcomings are their susceptibility to flow disturbances by parts being processed and the difficulty in controlling emissions from parts or barrels suspended above the tanks.

Other types of exhaust systems that were not evaluated in this program which may be more effective than lateral-slot systems in specialized situations include canopy hoods, enclosing hoods, and traveling hoods. Where they do not interfere with handling operations canopy hoods are very effective relative to the amount of exhaust air required, particularly with higher temperature tanks where the natural buoyancy augments the action of the exhaust air. For operations involving highly hazardous materials the use of enclosing hoods (which completely surround a tank) and traveling hoods (which enclose parts being transported from one location to another) will provide excellent control with a minimum of exhaust air. Of course, the economy of operation with respect to air requirements must be balanced against the increased complexity of the system.

Emissions from operations involving low temperature, low evaporation rate, and low-toxicity baths can be controlled in many cases with general room ventilation.

DATA UNCERTAINTIES

Determination of room concentrations of alcohol contaminant as a function of exhaust flow rate required measurements of flow rates of exhaust air, agitation air, gassing air, and push air, bath temperature, amount of alcohol in the bath, and concentration of alcohol in the room. All of the measurements (with the exception of room concentration) had an uncertainty of ± 2 percent or less. The uncertainties in the measurement of room concentrations were greater because of the nature of the variations which could not be controlled and which for barrel cycling were inherent in the operation being studied. Although the studies were conducted in a closed room with makeup air supplied through a perforated ceiling, the air movement induced by the thermal updraft resulting from the heated tank caused variations in the concentrations of alcohol at the inlet to the sampling probe. Therefore, it was necessary to take time-averaged readings, which was done by recording the analyzer output on a strip-chart recorder from which an average value was obtained. When the record was particularly hard to interpret, the average value used was deliberately biased so as to be conservative; that is, a somewhat high value was used. Using the many chart records, an estimate was made of the uncertainties in the room concentration measurements. Figure 38 shows the estimated uncertainty in the room concentrations as a function of the magnitude of the values.

CONCLUSIONS AND RECOMMENDATIONS

The data presented in this report were obtained under laboratory conditions where undesired disturbances were controlled or did not exist. While it is known that the results are repeatable, field conditions will in most cases not be ideal; therefore, some compensation must be made for these nonideal conditions. The amount of compensation should be determined by comparing actual system performance with that expected by design and then incorporating this into the design standards.

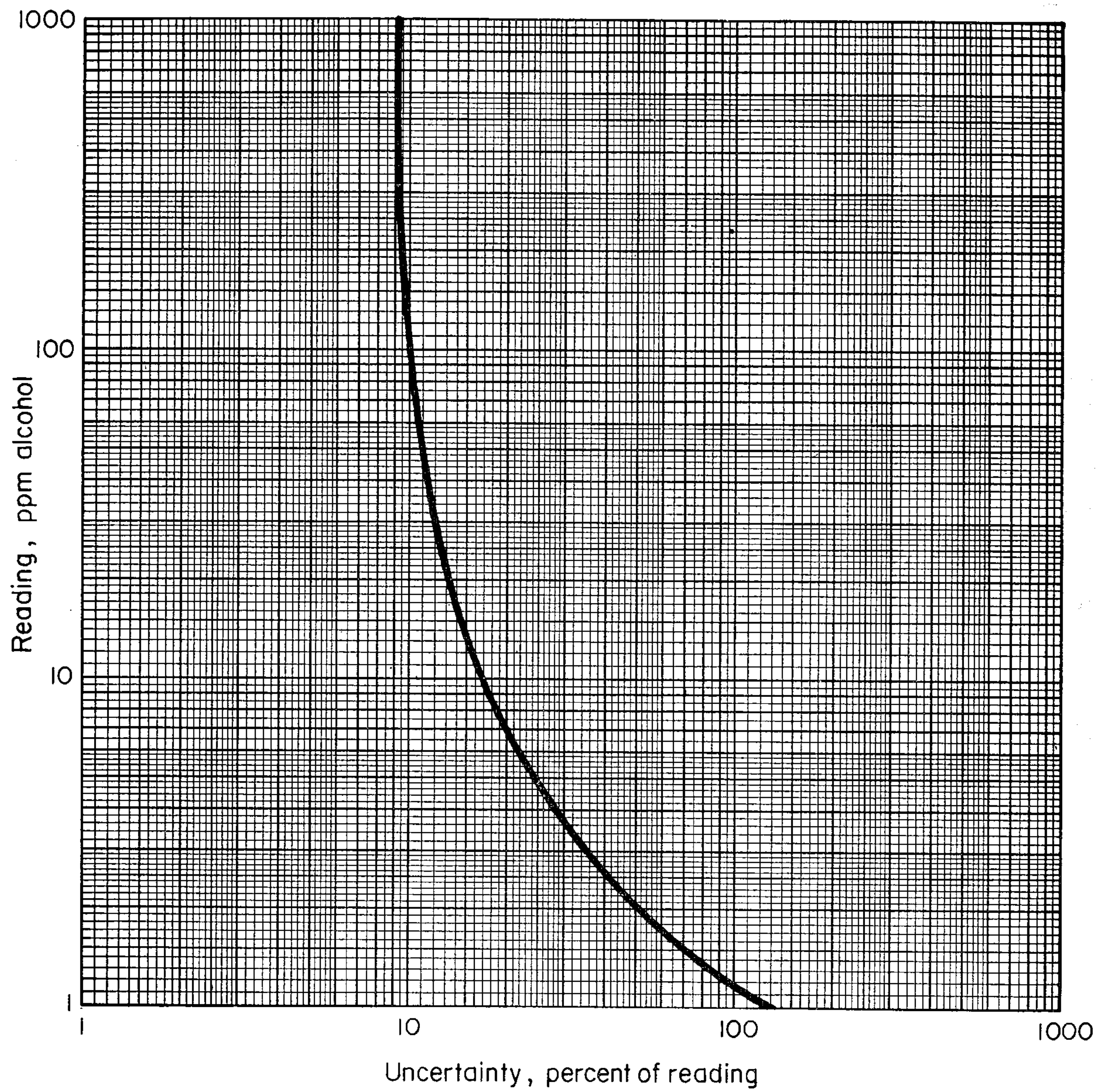


FIGURE 38. ESTIMATED UNCERTAINTY OF ROOM-CONCENTRATION MEASUREMENTS

The form in which these study results are presented permits the design of exhaust systems specifically tailored for the application. This is in contrast to the present standards, in which ranges of design parameters such as tank sizes, contaminant hazard potentials, and contaminant evaporation rates are used. The use of design ranges requires that for each range the design be adequate for the most hazardous conditions that are within that range. This results in a large number of overdesigned systems. If these ventilation data are used together with TLV data for defining hazard potentials, there remains only one set of design data which needs upgrading and that is the evaporation rate data. In the examples shown in Table 2, the evaporation rates – i.e., vapor pressures and diffusivities – were calculated. While it is felt that this is more desirable than using the present groupings, there is an uncertainty regarding accuracy, particularly for multi-component baths. In order to derive the maximum benefit from the results of this program, a study should be undertaken to define the actual evaporation rates. The study would be most useful if an apparatus and test method could be developed whereby tank users could make the determinations using actual bath solutions.

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