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CONTROL OF SOLVENT VAPOURS IN A PAINT FACTORY

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MSc in Occupational Hygiene
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August, 1986

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<u>TABLE OF CONTENTS</u>	page
Acknowledgements	i
Abstract	ii
1 Introduction	1
2 Methods and Materials	3
3 Results	5
Terms and Abbreviations	5
3.1 Preliminary Investigation (May 12)	6
3.2 Solvent Vapour Concentrations	10
3.3 Mill 1	11
3.4 Mill 2	13
3.5 Mill 3	20
3.6 Mill 4	23
3.7 Sand Grind	24
3.8 Premix Room	34
3.9 Mix 1	42
3.10 Mix 2	44
3.11 High Speed Dispersion	45
3.12 Small Orders	47
3.13 Centri Mill	50
3.14 Colour Matching	52
3.15 Cleaning Shed	54
3.16 Evaporation Experiment	58

4 Discussion	63
4.1 Overview	63
4.2 Safety Policy and Training	64
4.3 Mechanical Containment	64
4.4 Extraction Ventilation	67
4.5 Work Practices	74
4.6 Solvent Vapours	75
5 Conclusions	78
6 Recommendations	81
7 References	82
8 Appendices	
A Calibration of Organic Vapour Analyser	84
B OVA Solvent Vapour Surveys	86
C Magnehelic Calibration	89
D Evaporation Experiment	91
E A Standard Hood for Mixers	95
F Push Pull Hood Design	100
G Ventilation Costs	103
H Diffusive Samplers	106
I Noise	110
J Factory Detail	111
K Pressure Monitoring Points	114
L Pitot Traverses	116
M Interim Report June 1986	119
N Testing of Ventilation Systems	122
O Duct Design	125

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ABSTRACT

An investigation into primary control of solvent vapours in a paint factory indicated that containment of vapours with lids and local exhaust ventilation using a standard hood design would control most emissions. A push pull design was demonstrated. Modelling experiments suggested that heat and solvent losses associated with the present ventilation system cost the company £100,000 per year. Other recommendations included the extraction at source for other processes, limiting cleaning solvent usage and further investigations into the use of solvents for cleaning, the chronic effects of solvent exposure on worker health, and the acute effects of exposure to more potent solvents.

1 INTRODUCTION

The factory manufactures paints, thinners and gun wash for the automotive refinishing industry, though the processes used are standard to the paint industry (1).

The manufacturing process may be divided into dispersion (ball mills, bead mills, sand mills and cavitation mixers) and mixing, which is a less energetic process. Transfer of solvents to vessels is achieved by a tank farm feeding a series of carousels which in turn feed many mixers. Other vessels are loaded by the use of 500 litre wheeled vessels ('mobiles') or directly from 200 litre drums. Solvent emissions occur from all vessels, the amount depending on whether the vessel has a lid, how well the lid fits, the efficiency of the vapour extraction, temperature and agitation. Other vapour emissions occur from spills, solvent cleaning of machines and floors, and during can and tin filling operations which may involve filtration in an intermediate vessel. Associated with the manufacturing plant were laboratories, offices, stores and a resin plant. A recent survey (2) revealed that solvent vapour concentrations were excessive in some areas.

This investigation aimed at determining the appropriate methods of primary control of solvent vapour. Since the factory had about 50 extraction systems (Appendix J), and nearly 200 wages employees, an investigation into the whole factory was considered too large for the resources available. Investigations of representative ventilation systems in a large part of the manufacturing plant was proposed along with a study of work practices. This covered

the main area of solvent usage and recommendations are based on this work. Coupled to the investigation were surveys using a portable organic vapour analyser, TENAX diffusive samplers and a modelling experiment to simulate different types of mixer extraction under different operating conditions.

2 METHODS AND MATERIALS

A section of the factory was chosen on the basis of a previous report (2) and a walk through survey (Section 3.1). This included most areas of high solvent concentration, but excluded the resin plant and the laboratories.

Ventilation

In ducts

- pitot tube traverses (3)
- static pressure monitoring. A mechanical, calibrated (Appendix C) set of magnehelic gauges was used:

0-10 inches of water (0-2500 Pa)

0-2 inches of water (0-500 Pa)

0-0.5 inches of water (0-125 Pa)

Face and Capture Velocities

- In view of electrical safety considerations in a solvent vapour atmosphere, only smoke tubes and a kata thermometer were used (Appendix N) to estimate air speed and direction and visualise air flow into hoods.

Temperature

- A thin walled laboratory thermometer was used extensively.
- A sling psychrometer was used to estimate relative humidity.

Evaporation

- Crude models of mixers with hoods were constructed from paint tins and rubber gasket material, and evaporation under varying conditions of extraction, temperature and agitation compared (Appendix D).

Hood Design

- A hood was examined near a mixer in which fine ($\sim 1\mu$) pigments were dispersed into solvents. An alternate push pull hood was designed and constructed from 3mm hardboard and a length of waterpipe. Its performance was evaluated.

Solvent Vapour Concentration

- A BASEEFA certified, calibrated (Appendix A) OVA was used extensively to give a continuous indication of solvent vapour concentrations.

- A trial with diffusive samplers (Appendix H) demonstrated their application for personal monitoring in this industry.

Work Practices

- These were observed during the investigation.

Details are given in the Results and the Appendices.

3 RESULTS

TERMS AND ABBREVIATIONS

SI units are used wherever possible.

RH :Relative Humidity

mobile:a 500 litre wheeled vessel

Solvent

BZ :breathing zone of worker. Nominally within 30cm
of nose and mouth

OVA :organic vapour analyser. A portable instrument
giving a direct readout in ppm

OEL : UK Occupational Exposure Limit (4)

ppm :parts per million

TLV :USA Threshold Limit Value (5)

Temperature

Ta :air temperature (°C)

g :temperature of a 150mm globe thermometer

Ventilation

g :pressure loss per meter of duct at a
certain flow rate (6)

k :inlet or outlet pressure loss, expressed
as a fraction of Pv (6,7)

Ps :duct static pressure (Pa)

Pt :total pressure, the sum of Ps and Pv

Pv :the velocity pressure due to air movement

Q :air flow (m³/s)

\bar{v} :mean air velocity (m/s) in duct

Fans

AP :air power of a fan, the product of Pt and Q

I :the measured current (A) through a fan motor

n :the nominal (0.90) electrical efficiency of
the fan motor

PF :nominal (0.95) power factor of the fan motor

V :supply voltage (415V)

P : $n \times \sqrt{3} \times V \times I \times PF$, the power delivered to the
fan by the motor

3.1 PRELIMINARY INVESTIGATION (MAY 12)

1) Discussions were held with factory management regarding the proposed investigation. An out of date plan was obtained of the factory. An updated plan using shortened names for areas is overpage (eg Mill Room number 1 became MILL 1).

2) No plans, specifications or maintenance schedules for the extraction system were available.

3) A list of major solvents was obtained (Appendix J) -later to be accompanied by usage and unit costs for all the solvents used.

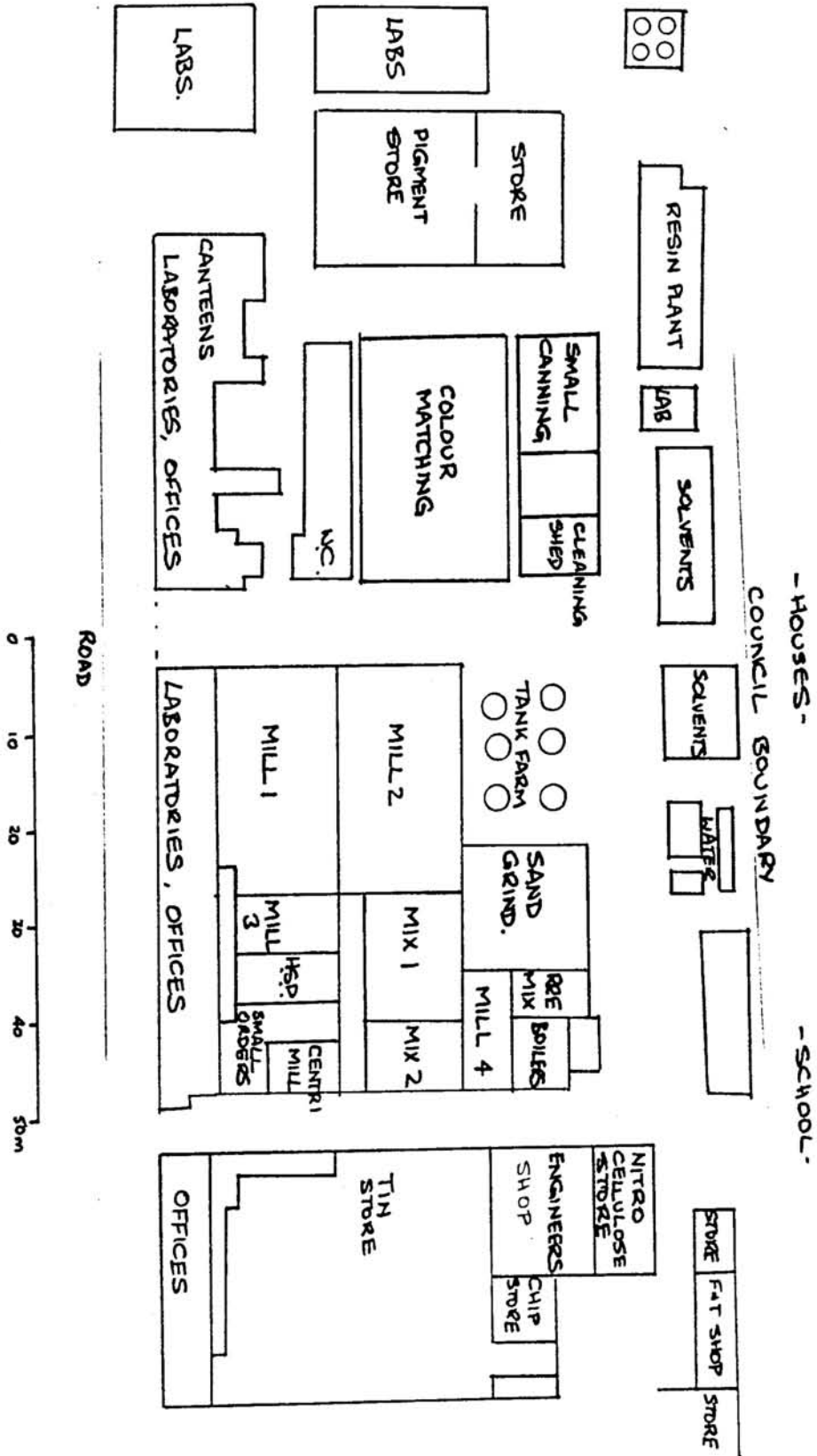
4) A copy of the company Safety Policy dated April 1984 was obtained. A Safety Officer position was listed but it was not filled.

5) Walk Through Survey

- The laboratories, stores, resin plant and factory were inspected. An immediate decision was made to limit the scope of the investigation to the factory so that some depth could be attained. This was again limited to the general building housing the mill and mixer rooms, and the cleaning shed because of the high solvent concentrations there (2).

- A general impression was formed of the work practices and

SITE PLAN



processes. Tank farm carousels fed mixers and a couple of stations for filling 'mobiles'. Some mixers had no feed pipe and all ball mills had to be loaded by hand. Less used solvents, liquid additives and dispersed pigments were transferred between vessels with 500 litre 'mobiles'.



In the photograph above a 'mobile' is loading mixer 32 with resin. The size of the mixer opening is much greater than needed for the operation. The mixers seldom had lids but some were seen to have welded lids with a small loading port.

- Notices ordering mixer lids to be kept closed proliferated but mixer lids were missing or left open as a rule, with sampling tins dangling on strings into the mixers, draining on the safety grilles across the openings

or dripping from hooks over the opening. If a lid was closed it was usually obstructed by a toe rail or buckled. Several mixers had good lids.

- Filling of paint tins was done manually by weight or automatically by machines.



The photograph above shows a typical manual canning operation - the light green paint being strained into a smaller vessel and being weighed into tins. Here the operator labels the tins in small batches. Labelled full tins are in the caged pallet. There is no extraction.

- The use of the term 'fumes' for vapours.

- Paint tins of solvent were endemic and appeared to be used for cleaning small spills of paint.

- Storage of solvent wet rags and mops was poor. Implements were either left in open topped mobiles (since the lids did not fit the number of handles protruding), or stored in the open air.



In the photograph above, solvent wet rags and mop are stored near a warm radiator. Paint samples dry on top of the paint tins on top of the radiator. No underwater storage of mops or rags was seen.

All ball mills and some mixers lacked extraction. While some of the sand mills had extraction ducts, none had hoods.

- Some extraction ducting was at the floor level. Most was connected to small hoods each side of the mixers (which were 2m across), or to their lids. Many rectangular ducts had sharp bends and joined at right angles without gussets. Slot extraction for 500 litre mixers was rarely at mixer lip height.

3.2 SOLVENT VAPOUR CONCENTRATIONS

1) An OVA was calibrated for some factory solvents (Appendix A). Many of the common solvents had around 100% instrument response, so the direct instrument reading (ppm) is used throughout this report.

2) The use of diffusive samplers was demonstrated. The diffusive uptake rate for the solvent vapours was not determined nor were many chromatographic retention times. The results were not of direct application, but the relative figures were used (Appendix H).

3) A series of solvent vapour surveys was conducted through the selected part of the factory (Appendix B). Coupled to these surveys were estimates of air temperature, and horizontal and vertical air movement.

The results of these surveys can be divided into two groups

- a) the general pattern of solvent vapour concentrations
- b) the effects of work practices.

These are discussed more fully by work area (Sections 7.3-7.15).

OVA Survey - General Observations

- Solvent vapour concentrations rose rapidly with work and dropped overnight to around 30ppm. Levels were higher in small rooms and on higher levels where there was little air movement.

- Charging and cleaning ball mills, not rotation, caused higher levels.

- Higher levels occurred where solvent was agitated or spread in thin films.

3.3 MILL 1

Large quantities of paints and solvent mixtures are canned in small batches by hand. A four station machine is used for canning thinners in screw top tins.

<u>Date</u>	<u>vessel</u> (litres)	<u>material</u>	<u>DEL</u> (ppm)	<u>OVA</u> (ppm)	<u>comment</u>
June 12:	25	gun wash	100	40	-BZ
		-recovered		90-200	-tin tops
		solvent		150	-floor
July 15:	20	thinners	100	40	-BZ
	am (breeze 2m/s)			20-90	-room
	pm 20	thinners	100	120	-BZ
	(air 0.2m/s, Ta 30°)			60	-room
	: 5	paint		100	-BZ
		-xylene	100		
		-white spirit	100		
	: 5	thinners	100	200-300	-BZ ladder
	(Masterfill machine)			(cyclic)	
				120	-BZ loader

table 1 MILL 1 OVA measurements

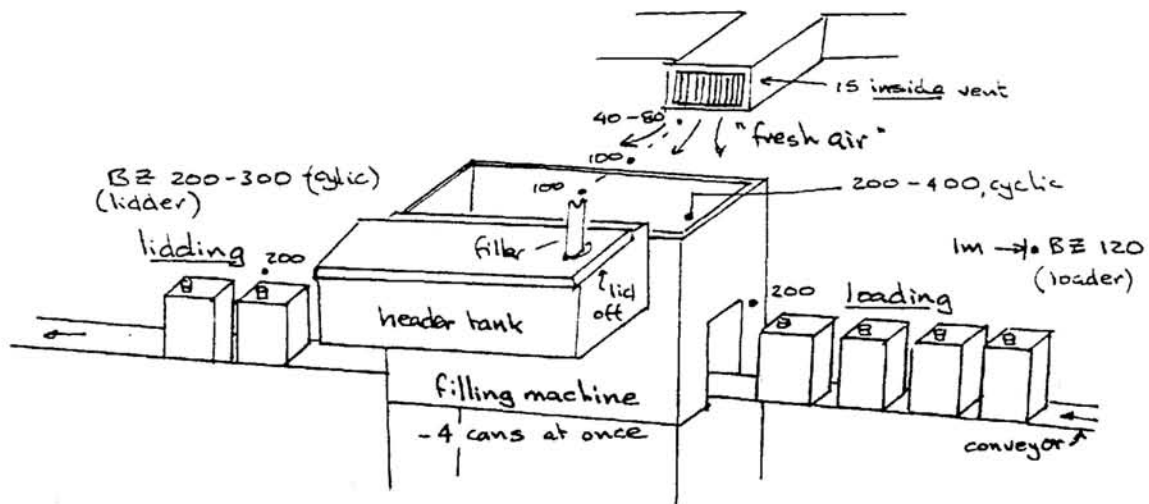


figure 1 OVA measurements - Masterfill

The lidding operator was being exposed to excessive solvent vapour. The best extraction would sit on the filling mechanism and capture all air displaced from the tin by the solvent. An extraction flow in excess of the filling rate would be required.

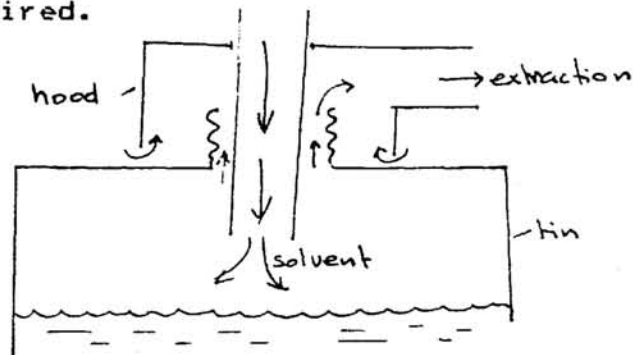


figure 2 approach to Masterfill extraction

3.4 MILL 2

This room was more densely packed with machinery than MILL 1 due to a double row of ball mills down the middle. The western door to the room was more often shut than in MILL 1 and the potential for natural ventilation much diminished.

<u>Date</u>	<u>vessel</u> (litres)	<u>material</u>	<u>DEL</u> (ppm)	<u>OVA</u> (ppm)	<u>comment</u>
June 12:		Ind Meth Spirit		150	-BZ: tending mixer 64
		methanol	200		on level 1. No mixer
		ethanol	1000		lid or extraction.
		(air <0.1m/s, Ta 20°)			
		: 2.5 polyurethane	?	55	-BZ:operator reported
		acrylic enamel			strong desire for
		(air <0.1m/s, Ta 18°)			evening sleep with
					<u>this</u> work

table 2 MILL 2 OVA measurements

Can Filling Extraction

A canning machine was investigated with a smoke tube. During filling two operations raise the solvent levels in the air. The actual canning produces a plug flow of air and vapour from the can. This is demonstrated in the photograph below as the can fills with a lacquer, displacing the smoke placed in the can a second before the filling cycle. The second source of displaced solvent laden air is from the header tank as it periodically refills.



A small extraction hood around the filling mechanism should catch most of the solvent vapour. An airtight lid on the tank with a duct joining near the filling hood would capture the air displaced from the header tank without leading to excessive evaporation.

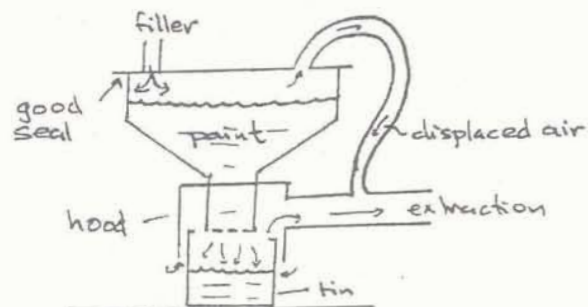


figure 3 approach to extraction

'262' run

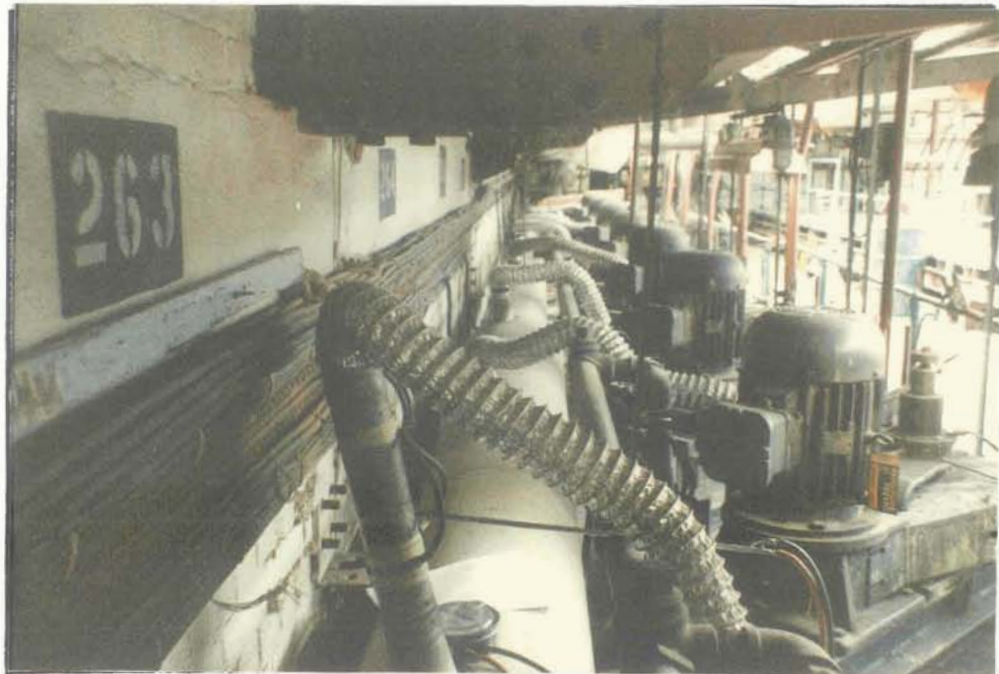
The main study in MILL 2 was the extraction above mixers 262 to 271. It was chosen as an example of a long length of duct serving a large number of mixers.

Measurements were made on the branch ducts using a specially prepared insert.



In the photograph above, two static measuring points and a reamed pitot measuring hole are visible on the insert (Appendix K). When placed on top of the long (~ 1 m) straight duct into the mixer hoods, a smooth flow of air is guaranteed. The magnehelic gauge on the right is not reading zero since it is designed for use in the vertical position.

The flexible ducting, seen in the photograph below, was easy to remove, so the insert was easy to install at each point. A 45 cm pitot tube protruding from it is visible.



For the measurements in the table over page, the insert was on the mixer end of the flexible duct. The flexible duct chokes the air flow from the mixers due to its sharp bends and corrugations.

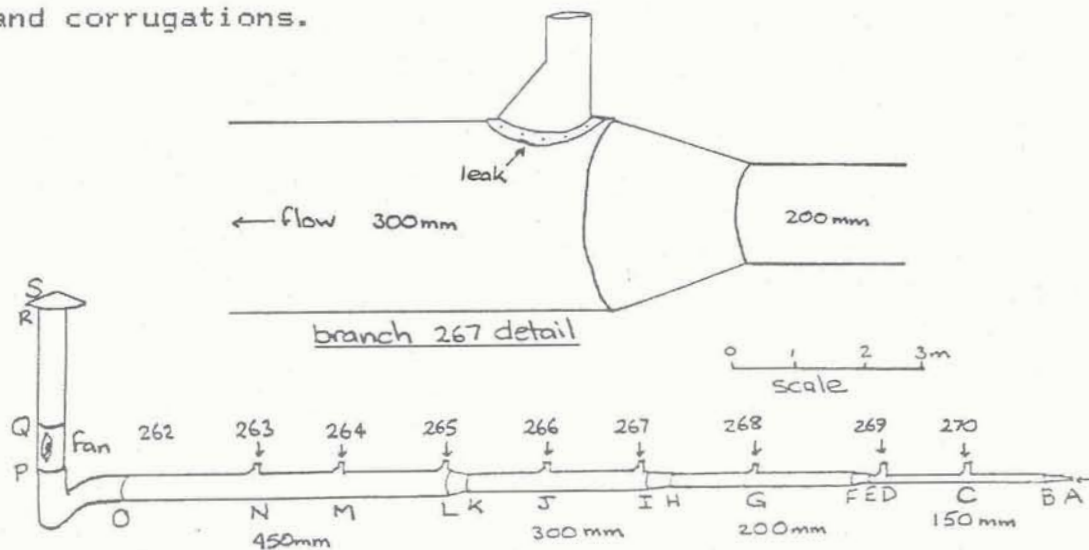


figure 4 '262' run

sect.	size	length	k	g	Q	Q	Pv	Ps	ΣPs
	(mm)	(m)		(Pa/m)	(m ³ /s)	(m ³ /s)	(Pa)	(Pa)	(Pa)
A	75inlet		.93		.147	.147	623	580	580
AB	75/150	.38	.45					-365	215
BC	150	1.30		5.5				7.2	222.2
CD	150	1.46		9.0	.046	.193	39	12.6	234.8
DE	150	1.50		13.0	.019	.212	67	2.0	236.8
EF	150/200	.21	.35			.212		-23.5	213.3
FG	200	1.46		2.8		.212	26	4.1	217.4
GH	200	1.49		4.5	.053	.265	40	6.7	224.1
HI	200/300	.21		.55		.265		-22.0	202.1
IJ	300	1.54		.9	.066	.331	12	1.4	203.5
JK	300	1.39		1.1	.054	.385	12	1.5	205.0
KL	300/450	2.30	.65			.385		-7.8	197.2
LM	450	1.51		.2	.026	.411	4	.3	197.5
MN	450	1.46		.2	.041	.452	4.5	.3	197.8
NO	450	2.22		.27	.040	.492	5.3	.6	198.4
OP	bendx2			.25		.492	5.3	.9	199.3
PQ	fan					.492			-
QR	450	2.00		.27		.492	5.3	.5	+0.5
RS	hat, 150 gap					.492			0.0

table 3 '262' run calculations

The main duct flow was measured at a point corresponding to section 'NO'.

main duct flow (measured) 10 m³/s

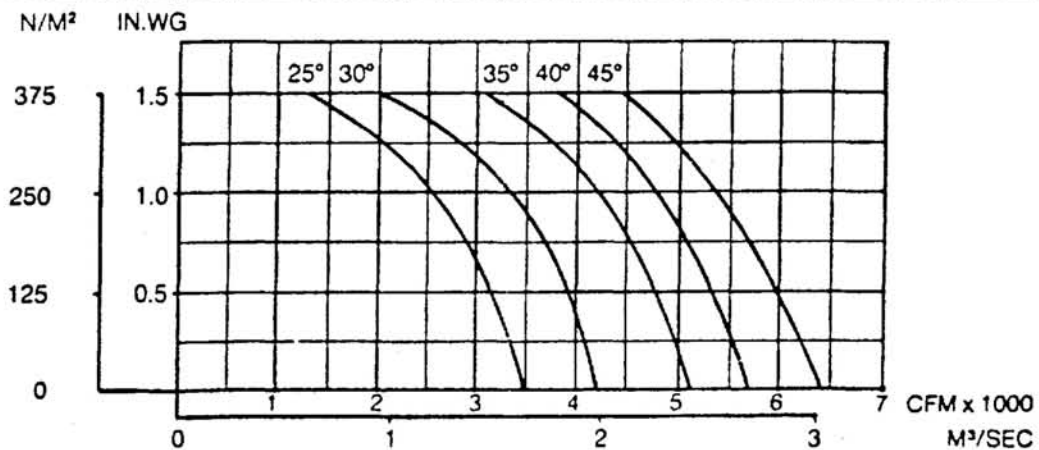
main duct flow (calculated) 5.3 m³/s in table 3.

The difference may be attributed to the summation of

measurement errors and leaks downstream of the insert in the joint from the flexible ducting and in the flange on the main pipe.

A fan curve was obtained from the manufacturers for the 10 bladed axial fan. The curve below is for the current 8 bladed version which the manufacturer claims to have similar performance.

40 CM DIA, 8 BLADE, 2900 RPM



	BLADE ANGLE	25°	30°	35°	40°	45°
2900 RPM	PEAK HP	0.9	1.4	1.9	2.3	2.8
	dBA AT 3x DIA's	75	77	80	83	85

figure 5 METRICO axial fan curve (45° blades)

Taking the pitot data from the main duct as the better estimate, the duty point of the fan is off the page. The fan efficiency was 34% (table 4).

Lifting the flexible branch ducting to form a smooth curve between the mixer riser and the main duct flange doubles the branch flow. It would be literally possible, with sticky tape and string, to effect a major increase in the efficiency of the system. A better way would be to replace the ducting with a larger size, smooth bore ducting, or better still, to replace the whole hood arrangement with

the Standard Hood designed in Appendix E.

<u>System</u>	<u>P_s</u>	<u>P_v</u>	<u>P_t</u>	<u>Q</u>	<u>AP</u>	<u>I</u>	<u>P</u>	<u>E</u>
	Pa	Pa	Pa	m ³ /s	W	A	W	%
'262' run	625	60	685	0.670	460	2.2	1352	34
Attritor (rev.)	67	7.4	74.4	0.349	25.8	2.8	1530	1.7
Attritor	950	82	1032	1.1593	1196	2.8	1530	78
Attritor Mixer	1495	44	1539	0.27	415.5	1.5	819	51
Premix	112	-	112	0.589	66	0.5	307	21

table 4 fan efficiencies, E

3.5 MILL 3

The room has eight ball mills, no mechanical extraction and little natural ventilation. A number of measurements were made.

<u>Date</u>	<u>vessel</u> (litres)	<u>material</u>	<u>OEL</u> (ppm)	<u>OVA</u> (ppm)	<u>comment</u>
May 29:		mixture		150-350	-BZ:ball mills 406,
		-toluene	100		407, 412, 414
		-xylene	100		rotating
		-etc			
				300	-level 1
July 15:		mixture		35-50	-BZ:ball mills 412,
am					413,414 rotating
				42-50	-level 1
pm :		mixture		35-45	-BZ:414 rotating
				45-55	-level 1
July 29:		pre work		10	-BZ:ball mills
				10	-level 1

table 5 MILL 3 OVA measurements

Diffusive sampler results from May 29(Appendix H) are shown below for the operator and a static sampler at shoulder height near ball mill 406.

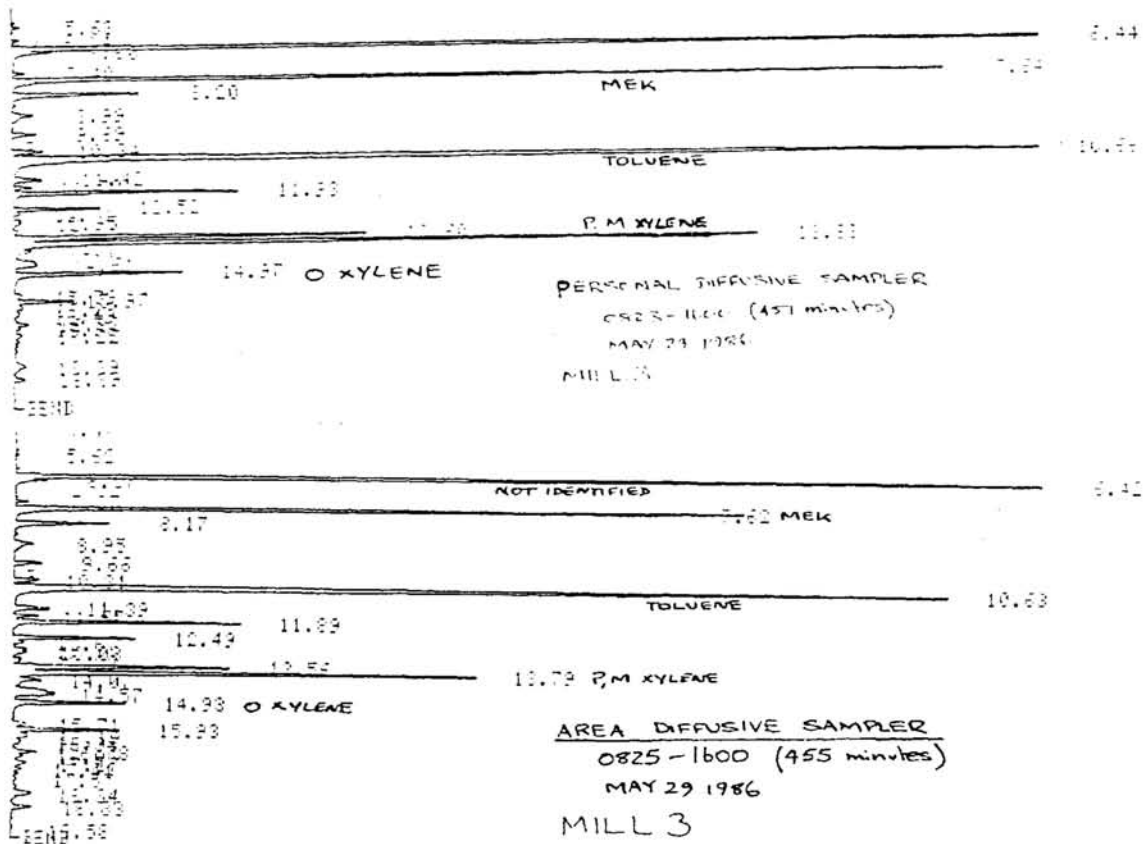


figure 6 May 29 diffusive sampler results

The results shown in the figure above are remarkably similar, since a factor of 3 or more between area and personal samples is common.

solvent	RT	area:A	personal:P	ratio A:P
unknown	6.44	9.5263	7.1757	1.33
MEK	7.64	4.4879	4.1055	1.09
toluene	10.66	9.8769	6.9369	1.42

table 6 TENAX diffusive sampler results

A small number of solvents is seen to contribute to most of the solvent vapour exposure. The operator's exposure to various solvent vapours was relatively uniform throughout

the mill that day in the absence of cleaning, charging or unloading operations.

The extraction required for the ball mills was mainly for the charging and cleaning operations but additional extraction should be provided for the unloading operation.

The figure below shows an approach to local exhaust ventilation.

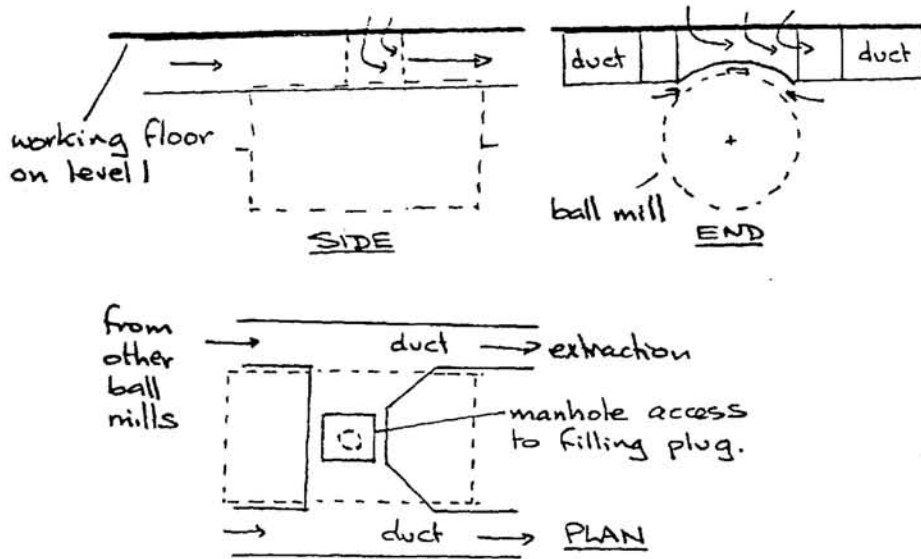


figure 7 approach to ball mill extraction

3.6 MILL 4

Except for two bead mills, there was little going on in this area. The large ball mills 409 and 410 were not used during the investigation, though they were reported as very noisy. Since the eastern door was invariably open, concentrations were around the lowest in the factory though the 'pre work' morning survey (July 29) found the vapour concentration (100ppm) near a bead mill being flushed with solvent to be the highest in the factory. There were no permanent workers in this room.

Local extraction would be desirable on the door of the ball mills during charging, cleaning and unloading.

Discharging the bead mill closer to the 'mobile' receiving vessel by a hose would reduce solvent evaporation. A lid would also help. The volume throughput would not justify extraction though the mill temperature apparently reaches 40° during use. General dilution ventilation may be appropriate.

3.7 SAND GRIND

3.7.1 Attritor extraction

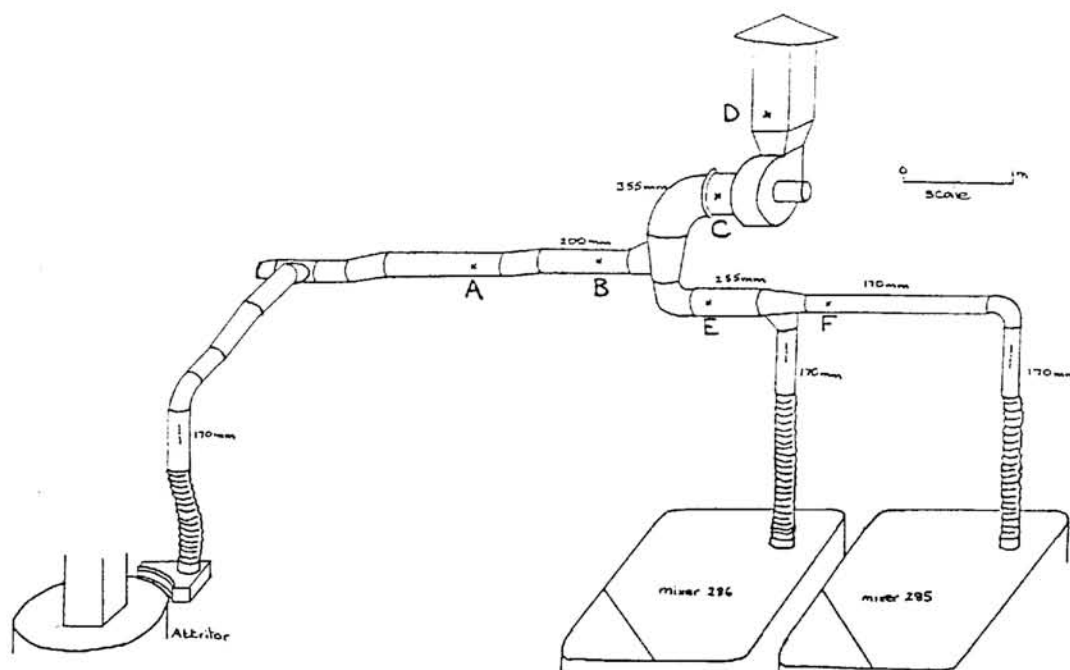


figure 8 Attritor extraction

Initial Measurements

The duct leading between point E and F to mixer 286 was found to be blocked with lumps of dry paint around a damper valve, and the flexible duct to the mixer had dropped off. These were fixed before any measurements were made.

	Area(m ²)	Pv(Pa)	\bar{V} (m/s)	$Q=\bar{V}\cdot A$ (m ³ /s)	Ps(Pa)
A	0.0314	12.5	4.56	0.143	105
B	0.0314	7.5	3.54	0.111	110
C	0.0993	(7.4)	(3.51)	(0.349)	65
D	0.0993				+2.5
E	0.0506	10.0	4.08	0.206	40
F	0.0248	11.25	4.33	0.107	37
C/D					67

table 7 initial Attritor extraction measurements

The velocity pressures were estimated with single mid duct pitot tube measurements since a slow traverse showed the flow to be almost uniform across the duct.

The condition of the ducts was investigated and the fan examined, but both were surprisingly good, considering the lack of performance maintenance (Appendix N). The direction of rotation of the fan was found to be opposite to that expected. This situation must have existed for several years. It coincided with electrical work and apparently the fan was wrongly rewired then. A decrease in the system performance was noted, but it was not known that centrifugal fans could perform in reverse direction, albeit at a reduced efficiency (1.7%, table 4).

Second Measurements

A second set of measurements (Appendix L) using 10 point traverses with a 30cm pitot tube was performed through horizontal and vertical holes drilled at A,B,E and F. The figures below are the mean of the velocities calculated for the 10 horizontal and 10 vertical measurements at each point. The fan velocity pressure was recalculated from this mean duct velocity. The data is presented in Appendix L.

	<u>Area(m³)</u>	<u>Pv(Pa)</u>	<u>\bar{v}(m/s)</u>	<u>$Q=\bar{v}\cdot A$(m³/s)</u>	<u>Ps(Pa)</u>
A	0.0314		10.32	0.3240	775
B	0.0314		10.59	0.3325	775
C	0.0993	(82)	(11.67)	(1.1593)	800
D	0.0993				+150
E	0.0506		16.34	0.8268	700
F	0.0248		16.68	0.4137	600

the numbers in brackets are calculated figures

table 8 second Attritor extraction measurements

The difference between the volumes at A and B is 0.0085 m³/s, or 2.5%, confirming the placing of the pitot tube holes and the flow measurement technique.

The fan efficiency rose from 1.7% to 78% (table 4), a very good figure for a forward bladed centrifugal fan. A fan curve was not obtainable, but a fan curve for similar fan size, power and type derived from specifications for a METRICO 370 CMV forward bladed centrifugal fan is presented below.

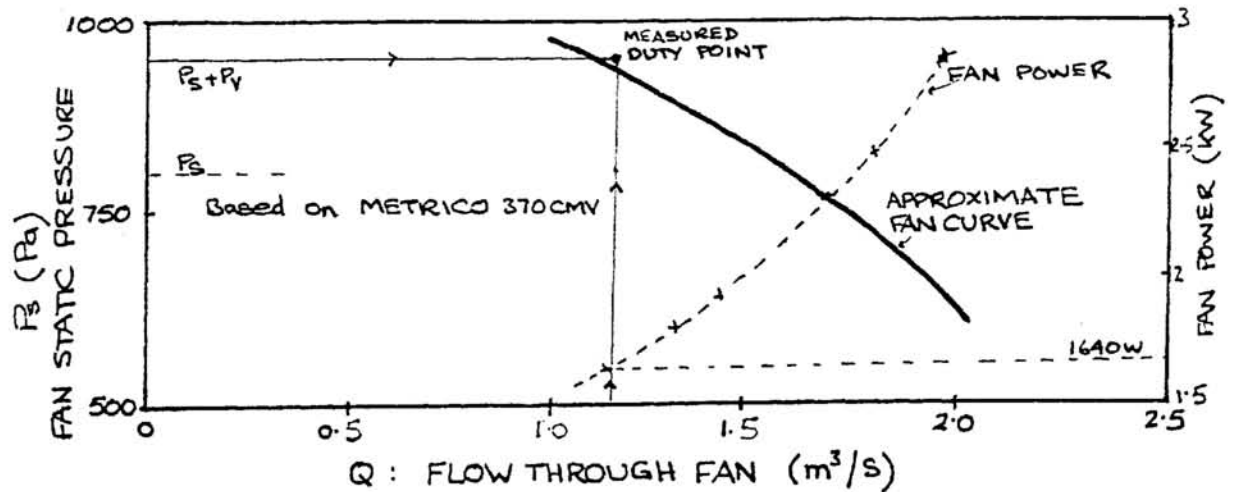


figure 9 METRICO 370 CMV fan curve

The duty point now falls on the fan curve above and confirms the choice of fan for that ducting and hood system.

If the extraction at the Attritor was insufficient, then it may be thought that closing the damper valves on the other leg would help. In fact, the opposite occurs and the duct velocity from the Attritor drops from 10.3 to 10.0m/s and the duct static pressures also drop. This is shown in table 9 below.

	<u>Ps(Pa)</u>		
	<u>All Open</u>	<u>E.F Closed</u>	<u>Difference(Pa)</u>
A	775	700	75
B	775	700	75
C	800	700	100
D	+150	+75 (50-100)	75
E	700	675	25
F	600	675	-75

table 9 effect of closing dampers

The fluctuations at D with the damper closed and the reduction of the flow from the Attritor are sure signs that the fan is stalling. The fan efficiency will have dropped from 78% to 17.5%.

That the fan and ducting were made to perform efficiently does not mean that their performance in removing solvent vapour was effective.

Smoke tube tests on the two mixers with the lids open and closed showed a slow movement of air, indicating a face velocity at the mixer opening of perhaps 0.2m/s, insufficient to contain vapours, especially during mixing and filling operations.

The Attritor hood also performed poorly. The photograph below shows how the Attritor hood pulls smoke from behind. Capture over the Attritor vessel was not as good at the same distance and complaints of 'fumes' can be well understood. An enclosing hood, a wrap around hood or even substantial flanges on the existing hood would make a

significant difference to its performance.



3.7.2 Irritant solvents

Only two instances of use of irritant solvents were quantified, both with the loading of cyclohexanone into the Attritor mixers. Material is cycled through the Attritor to either mixer and may be pumped between mixers. The mixer is charged with solvent and then pigments, clays and talc added. Since calibration of the OVA (Appendix A) was in good agreement with the manufacturers figures for a range of solvents, this cyclohexanone response (100%) is used.

The limits for cyclohexanone (ppm) are

DEL (4)	25
10 minute limit (4)	100
eye, throat, nose irritancy (8)	75

July 18 0830 (T globe 18.5°, T air 20.2°, RH 52% sling)

A background level of 100ppm unidentified vapour rose to 250ppm in the operator's breathing zone during loading of mixer 32 with cyclohexanone from 200 litre drums.

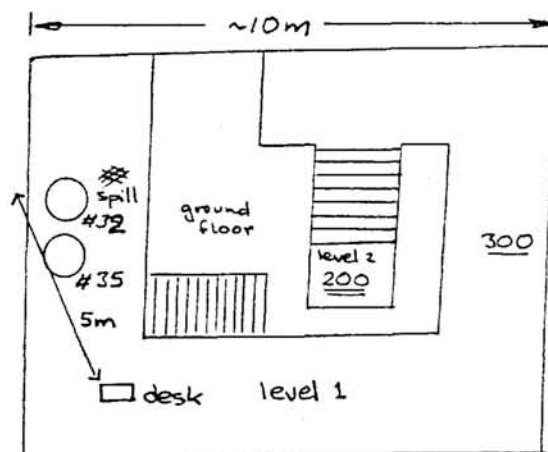
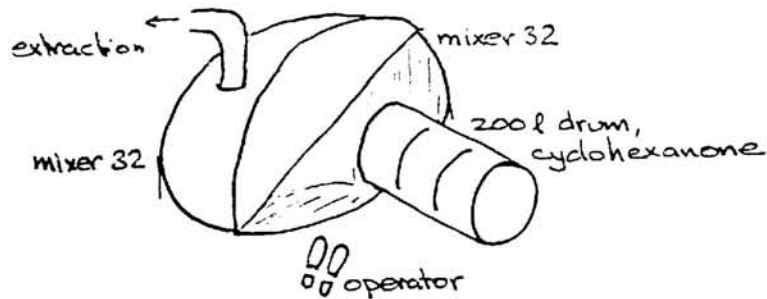


figure 10 cyclohexanone filling operation

At this level the smell was quite pungent and the irritant effect on eyes, nose and throat noticeable. Air movements were slight and vapour concentrations in the room rose. Some cyclohexanone was spilt and mopping with a mop, damp with 'recovered solvent', resulted in a concentration of 200ppm in the operator's breathing zone.

The exposure continued during addition of powders from bags during which the operators wore a Martindale aluminium

frame mask and an unidentified rubber ori nasal mask. The nasal fit of the rubber mask was poor. Up to 200 bags of pigment are reported emptied into mixer 32 and mixer 35 each week.

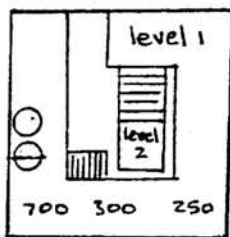
The Attritor Mixer bag filter was operated before the filling and the operators felt that it greatly reduced the dust levels.

The level at the operators desk on the first floor at 0900 was 200ppm. The measurements were made at a distance from the mixer since the air was dusty and the dust could affect the OVA. The operation lasted about 30 minutes.

July 22 1720 (T globe 18°, T air 20°, light rain)

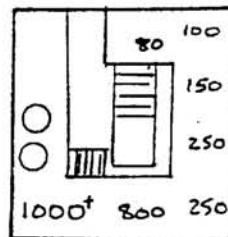
A similar operation was performed with the sister Attritor mixer 35. The changes in cyclohexane vapour concentration during the operation are shown below.

0720



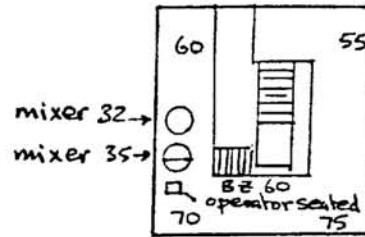
- extraction off
- mixer 35 lid up
- filling

0725



- extraction on
- lid down
- no air movement (level 1)

0747



- extraction on
- lid open
- mixer off

figure 11 second cyclohexanone operation

The estimated maximum concentration (the OVA reads to 1000ppm) was 1500 in the breathing zone of the operator.

Irritancy was high and the smell strong. The operation lasted about 30 minutes.

The operator commented that the worst job was a formulation called ACR1 and that the solvents were then mixing in mixer 115. The irritancy of this mix could be from the ketones (MEK, MIBK) and 2 ethoxyethanol acetate (5) but time did not permit an investigation.

3.7.3 Attritor Mixer extraction

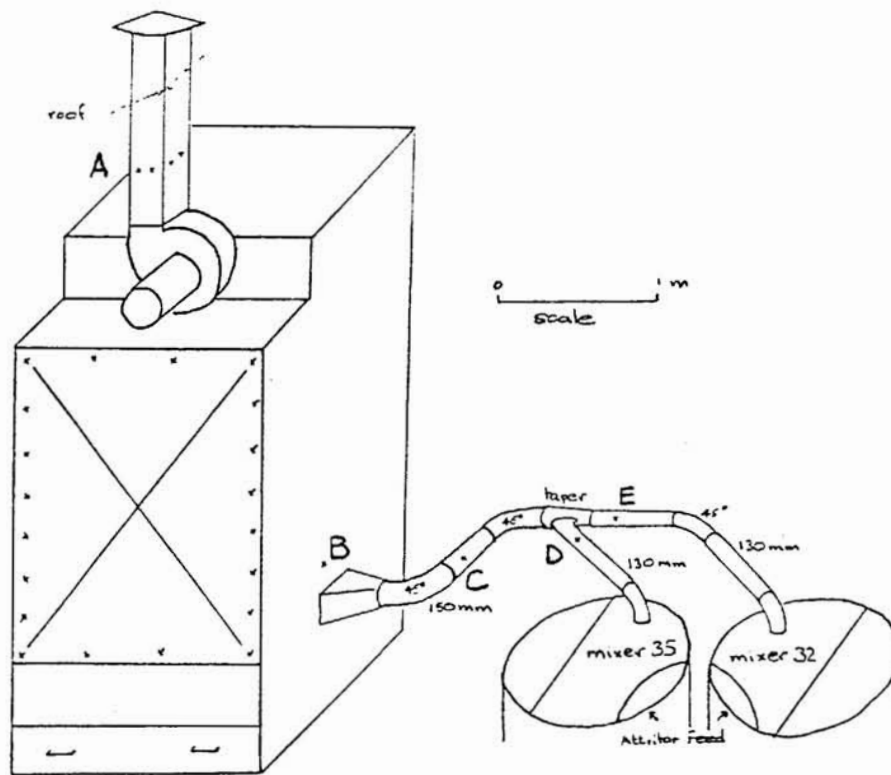


figure 12 Attritor Mixer extraction

A 5mm thick layer of chalky pigment had to be removed at C, D and E to reveal the ducting. Pitot traverses would not be satisfactory because the lumens of the ducts were thick with material and no suitable straight lengths existed. An estimate of performance is made below based on two point orthogonal traverses.

	<u>Area(m²)</u>	<u>Pv(Pa)</u>	<u>\bar{v}(m/s)</u>	<u>$Q=\bar{v}.A$(m³/s)</u>	<u>P_s(Pa)</u>
A	0.0315	44	8.6	0.27	+45
B	1.12				1450
C	0.0140	37	7.9	0.111	1175
D	0.0127	30	7.1	0.09	63.8
E	0.0127	161	16.4	0.208566	62.5

table 10 Attritor Mixer extraction

The measurement at C is probably in error since the stack flow at A correlates well with the sum of the branch flows at D and E.

The fan efficiency was 51% (table 4) which was surprisingly high, considering that flow in the duct to mixer 32 is twice that through the same sized duct to mixer 35 and the poor condition of the ducting. The lumens at D and E may be partially occluded and so the volumes here overestimated. The stack flow was probably correct. The missing flow would be made up by leaks into the bag filter. No further investigations were attempted.

3.7.4 Other observations

-A worker was observed drying a solvent wet rag with compressed air.

-A drip tray under the sand grind carousel needs modification.

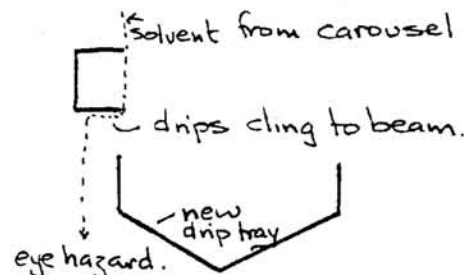


figure 13 drip tray in sand grind

3.8 PREMIX ROOM

One extraction system served four cavitation mixers to disperse pigments in solvents. This system was taken as an example of lip extraction and of rectangular cross section duct.

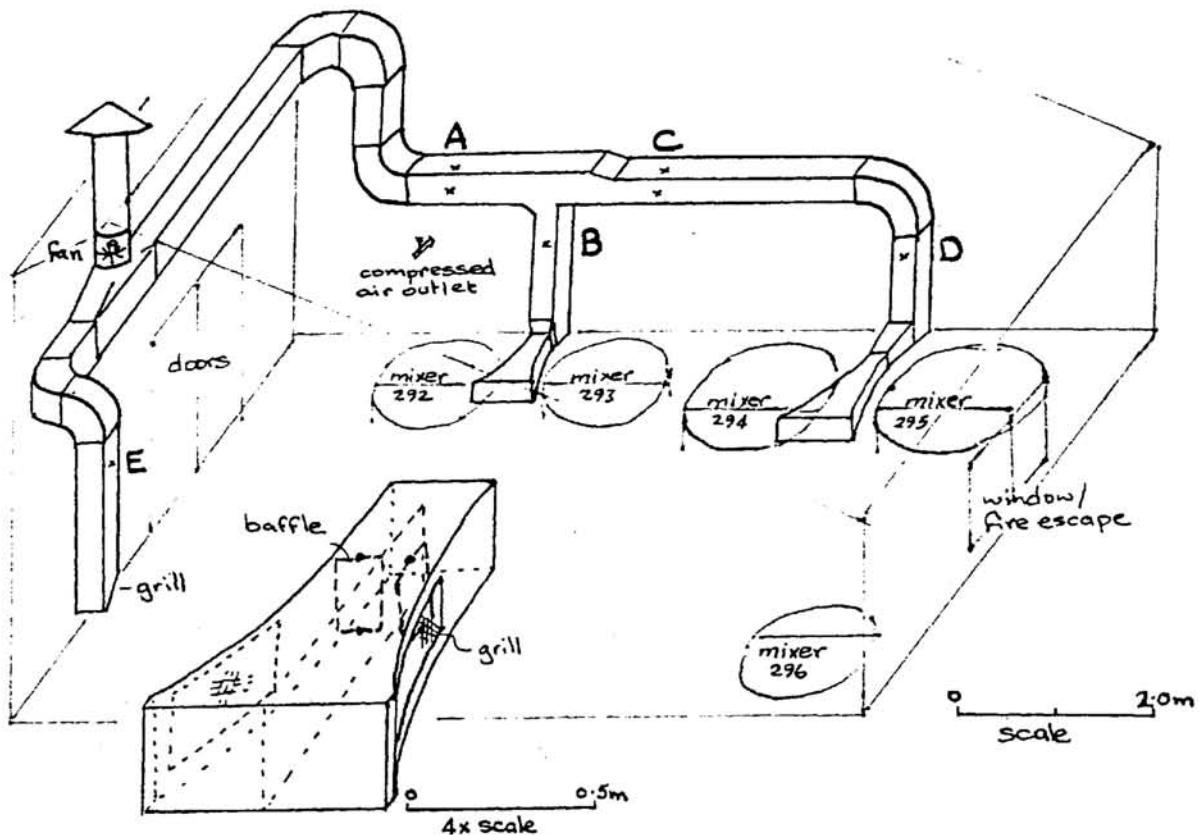


figure 14 PREMIX room extraction

3.8.1 Inspection

The fan was inspected via a removable plug and was bright red from very fine ($\sim 1\mu$) red pigment, though it was only 2mm deep on the duct and blades of the axial fan. The condition of a hood shown from mixer 293 is shown in the photograph below.



The hood grille was first cleaned and later the hood was removed and a 5cm deposit cleaned out, filling a bucket. The dampers had broken handles from operating them against the buildup of material.

A new hood was designed (Appendix F) and constructed and a push pull extraction system constructed and tested.

3.8.2 Effect of cleaning grille

Smoke tube measurements on the mixer 285 hood before and after cleaning the grille were dramatic. A simple model using grille data from Daly (6) is presented in the absence of actual measurements.

<u>grille condition</u>	<u>f</u>	<u>k</u>	<u>k hood</u>	<u>rel.vel</u>	<u>flow</u>
dirty grille	0.73	8.5	9.0	1.0	1.0
2mm buildup	0.61	3.5	4.0	1.5	2.2
1mm buildup	0.36	0.65	1.05	2.9	6.9
clean grille	0.25	0.38	0.88	3.2	8.9

table 11 effect of buildup on hood grille

where f = fraction of inlet occluded by grille

$k \text{ hood} = k \text{ inlet loss (about 0.5)} + k \text{ grille}$

$\text{rel. vel} = \text{face velocity relative to dirty grille}$

$\text{flow} = \text{total flow relative to dirty grille}$

The expected increase in flow was 8.9 times, assuming the hood static pressure is constant. Note the large increase in hood performance as buildup was reduced from 2mm to 1mm.

3.8.3 System performance was measured with pitot tube traverses with the system in the state usually used (ie with only the damper to mixer 293 open).

<u>hood</u>	<u>flow(m³/s)</u>
dirty grille	estimated 0.026
cleaned grille	0.240
cleaned out	0.347
new hood	0.549

table 12 summary of flow through hoods (Appendix L)

Simple maintenance produced the biggest change, but the new hood significantly outperformed the old hood, though it lacked a safety grille.

No static pressure measurements were made across the fan because it was inaccessible but a reasonable estimate is the highest measured static pressure of 112Pa at point E. The fan operated at 21% efficiency (table 4). This would be expected from inspection of the fan curve (figure 15). The flow resistance is high for the 26° pitch blades - off the page, in fact.

Note the drop in duct static pressure as the airflow increases. Just cleaning out the system may be sufficient to increase the fan performance from 21% to somewhere near its maximum, 74%, at Ps of 75Pa and flow of 0.87m³/s.

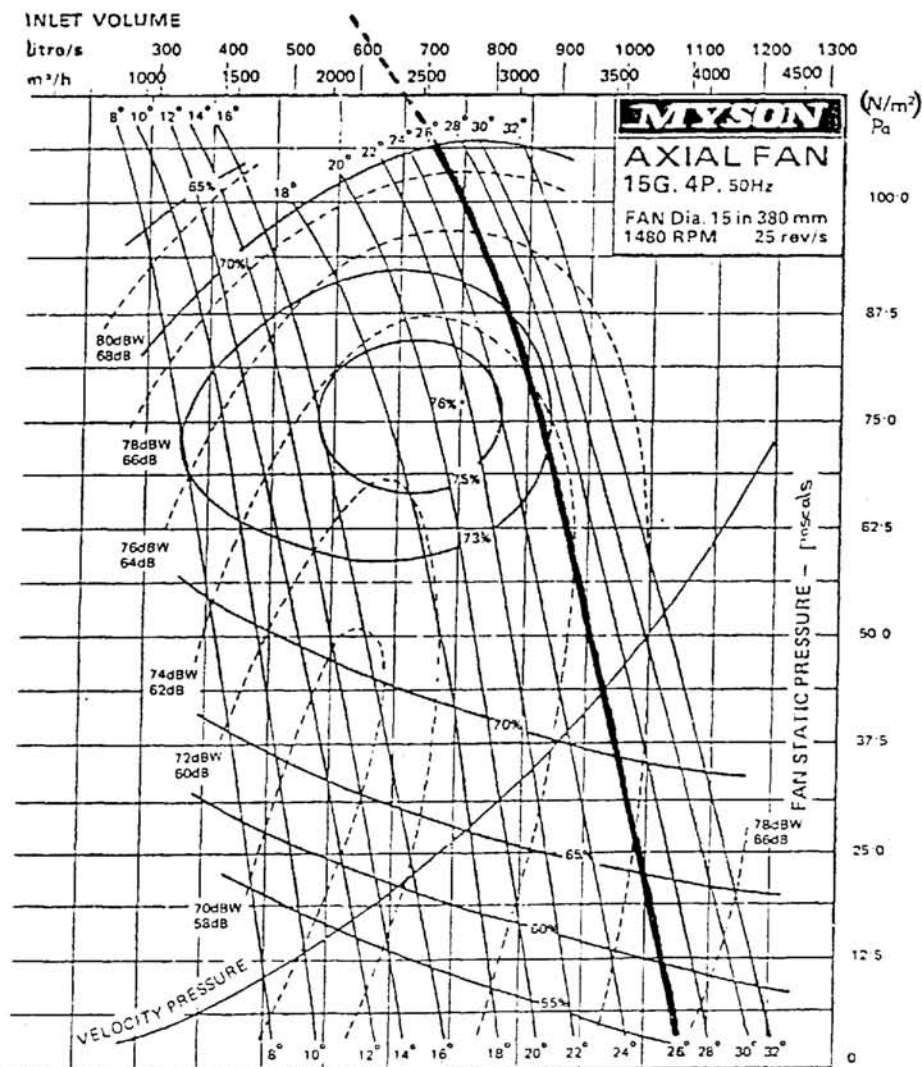


figure 15 MYSON fan curve

3.8.4 'Push pull' hood performance

The 'push' part of the system was just a piece of 37mm waterpipe with 3mm holes drilled at 150mm intervals. Connected to the shop compressed air, it produced a knife of air across the top of the mixer and into the hood. The efficacy of the system is easily seen with a dusty atmosphere such as in the photograph below where white powder has just been tipped into mixer 289 following several bags of red pigment. The band of white powder on the hood flange near the lid and a white discolouration of the lower part of the grille are visible in the photograph.



The rising dust cloud was lopped by the airstream and capture was almost complete with the new hood since it was designed to operate over the entire width of the lid opening. The old hood, as mentioned, did not collect all the dust near the lid, and some missed the hood since it did not extend out far enough. The presence of the operator emptying bags into the mixer did not appear to affect the

performance of the new hood.

An attempt was made to quantify the performance of the hood using the only instrument safe and sensitive enough, a katab thermometer. This is visible, along with a mercury thermometer in the photograph below, on the right side of the new hood opening. The thermos flask is for heating the katab thermometer. A manometric pressure gauge has been attached to the water pipe to estimate the supply air pressure.

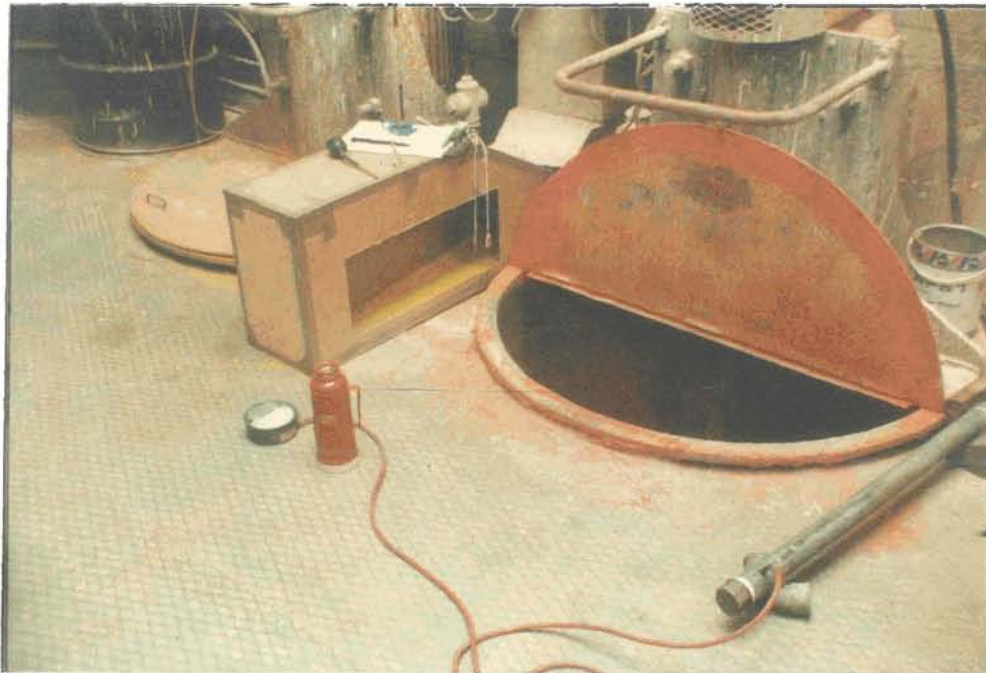


Figure 16 on the next page shows the effect of supply air pressure on the performance of the 'push pull' system.

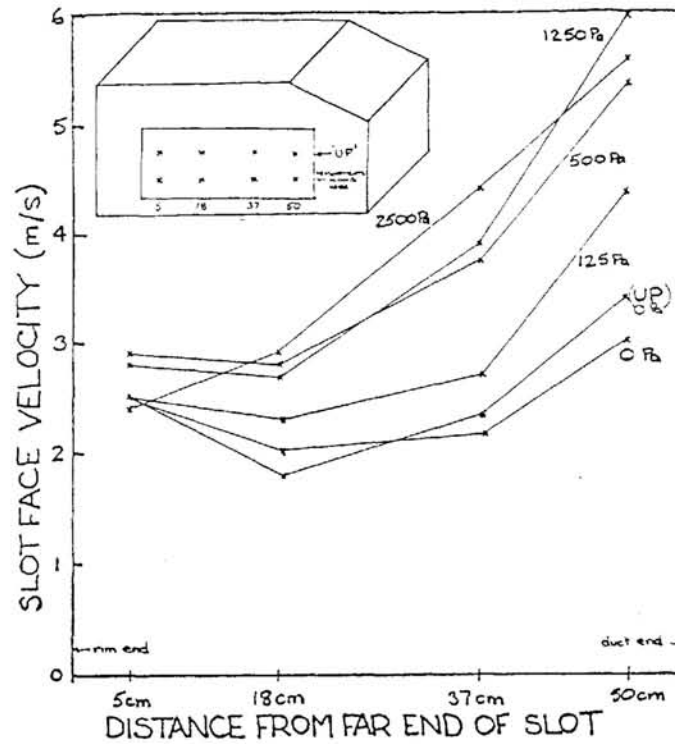


figure 16 effect of air supply pressure on face velocity

The air velocity was estimated 3cm above the centre of the mixer rim for the new hood at different air pressures.

supply air pressure (Pa)	2500	1250	500	125	0
air velocity (m/s)	2.7	2.4	1.8	0.9	0.1

The kata thermometer appeared unreliable at low wind speeds since it over estimates air movement (0.5m/s) with extraction off and doors and windows closed. An estimate of 0.1m/s with a smoke tube has been given in its place in the data above.

Limited confidence should be placed on the kata thermometer data for another reason. The flow through the hood based on the face velocity and from pitot traverses in the duct differ:

	flow(m ³ /s) - with new hood
kata	0.30
pitot	0.41

This represents a drop of 25%, but some of it may be explained by leaks in the duct to hood seal (loose), leaks between the baffle and hood or perhaps other unknown systematic errors in either estimate.

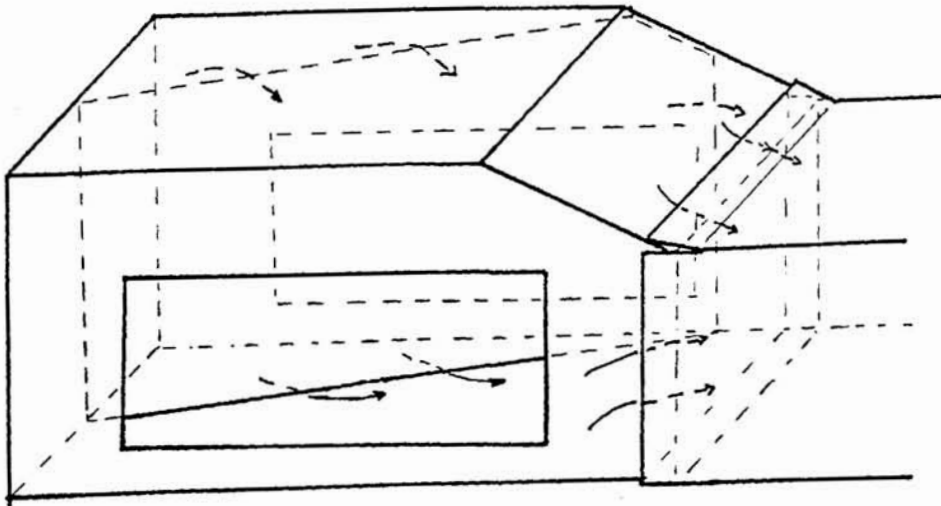


figure 17 possible hood leaks

3.9 MIX 1

The mixers in this room were used exclusively for pigmented paint and there was usually at least one manual canning operation. The solvent vapour concentrations (ppm) were :

<u>height</u>	<u>May 29</u>	<u>June 12</u>	<u>July 15 am</u>	<u>July 15 pm</u>	<u>July 29</u>
floor		80			
0.5m		75	600		
BZ	60-124	40-75	35-120	15-30	20-35
2.0m		70			
level 1	70-85	70		40-80	35-40
level 2		65		40	45

table 13 Mixer 1 solvent levels

The high level (600ppm) on July 15am was near a solvent spill of a few litres under mixer 118.

Most of the mixers had an attempt at lip extraction.

The efficiency of the extraction was investigated with a smoke tube, seen on the floor in the photograph below. A diffusing cloud of smoke is seen drifting above and to the left of the hood. A feeble pull occurred about 5 cm from the hood. The hood is about 60 cm long.

Another point evident in the photograph is the effect of the toe rail on the seal of the mixer lids. The lids close and overlap the toe rail by at least 10 cm leaving at least a 5 cm gap between lid and mixer. Almost all the lids were open despite many notices to the contrary.



The relatively low solvent vapour levels on the ground level were not due to good practice or mechanical ventilation, but the throughflow of air through two doors which were always open.

3.10 MIX 2

A volume of lacquers and paints were canned in this room. The solvent vapours were generally much lower than in MIX 1 due to better natural ventilation - two doorways had no doors and the other two doors were often open. Level 1 had little natural ventilation and the solvent vapours were about twice as high here.

A tortuous system of ducting had been installed under the outlets of mixers 300 to 303. It served no useful purpose and the numerous abrupt bends in the ducts would have led to a very high resistance to flow.

Inspection of the lid extraction on all the mixers revealed that all the flexible ducting connecting mixers 304 to 307 had been disconnected. The extraction fan was on and serving no useful purpose.

3.11 HIGH SPEED DISPERSION (HSD)

This room serves two functions - the dispersion of small (500 litre) volumes of paint and the dispensing of solvents into 'mobiles'.

The photograph below shows the feed pipe at the solvent dispensing pipe.



A 1 cm layer of solvent lies on top of the 200 litre drum lid. A small hole in the lid would allow the solvent to drain inside the drum without significant evaporation from the drum. The slot in the background is typical of the extraction for the dozen 500 litre mixers in the room. The value of the extraction, especially when not matched to the lip of the mobiles, is dubious.

Solvent vapour concentrations were invariably between 100

and 150 ppm even if the mixers were off, though the pre work survey (July 29) saw the levels drop to 30 ppm.

An operator reported that the lack of use of lids was related to the vibration in the first few hours of mixing. Unattended, the lids were said to fall into the mixers. Modifying the lids in a manner similar to that below could overcome that objection to their consistent use.

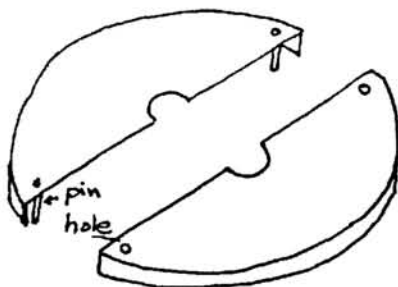


figure 18 small mixer lid modification

If the solvent vapour concentrations do not drop significantly below 100ppm with these modifications then extraction near the mixer shaft rather than the present slot extraction is suggested.

3.12 SMALL ORDERS

Small batches of paint are formulated in this room. The design of two identical fume hoods as seen in the photograph below, is poor. The small grilles will extract from a hemisphere 0.5 m across, leaving large areas of dead air. They cannot effectively extract from a hand mixing vessel the lip of which would be at the height of the scale dial. Since the worker has to bend over the vessel to add solvent or mix the batch, the extraction at the top of the hood serves only to draw solvent vapours past the worker's face.



A relatively simple modification is to install an adjustable plenum with full width slots, as shown in figure 19.

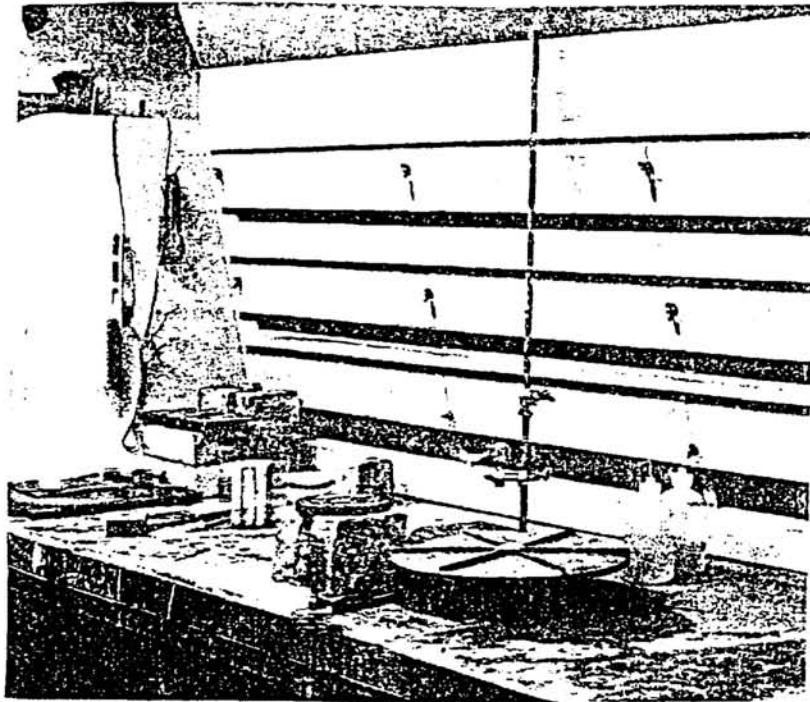


figure 19 plenum with adjustable full width slots (9)

A further factor which reduced the effect of the fume hoods was the annoying noise since the background noise was low (65 dBA, Appendix I). Much of this would be due to mechanical coupling of the fan through the duct, the hood acting as an effective resonator. Decoupling the fan (it was installed too close to the hood) as shown below, may reduce the noise sufficiently to make the use of the fume hoods more acceptable.

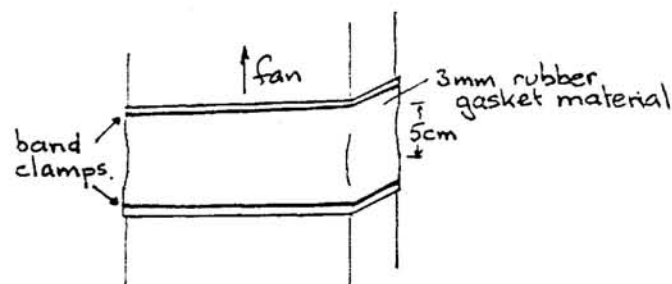


figure 20 decoupling fan noise from hood

The main workbench was serviced by a duct with eight under-bench inlets and a floor level inlet near the wall. All

these inlets did little to reduce the solvent exposure to the paint formulator. The most appropriate extraction is above-bench and should be directed at the work process but not get in the way. A 'Nederman arm' arrangement is suggested, but duct flows and fan capacity calculations have not been done to see if one could be directly connected to the existing duct.

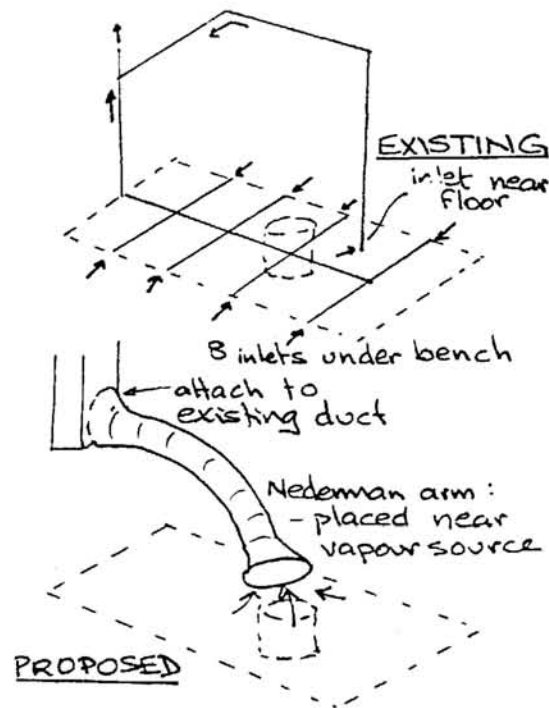


figure 21 workbench extraction

Little work was being performed in this room and solvent vapour concentrations were moderate during the investigation. This area has medium priority.

3.13 CENTRI MILL

The two cavitation mixers in this room had the best examples of extraction in the factory - slot extraction across the width of the mixer.



The lid was well fitting and mechanically linked to a damper. The extraction fan was outside the room and the bag filter which preceded it automatically cleaned itself. The efficiency of the unit must have been greatly reduced by the use of flexible ducting between the hood and the main ductings:

- 1) there is an unnecessary downward bend at the end of the metal duct
- 2) the flexible ducting is sagging, creating an extra downward loop and making the bend from the mixer

sharp.

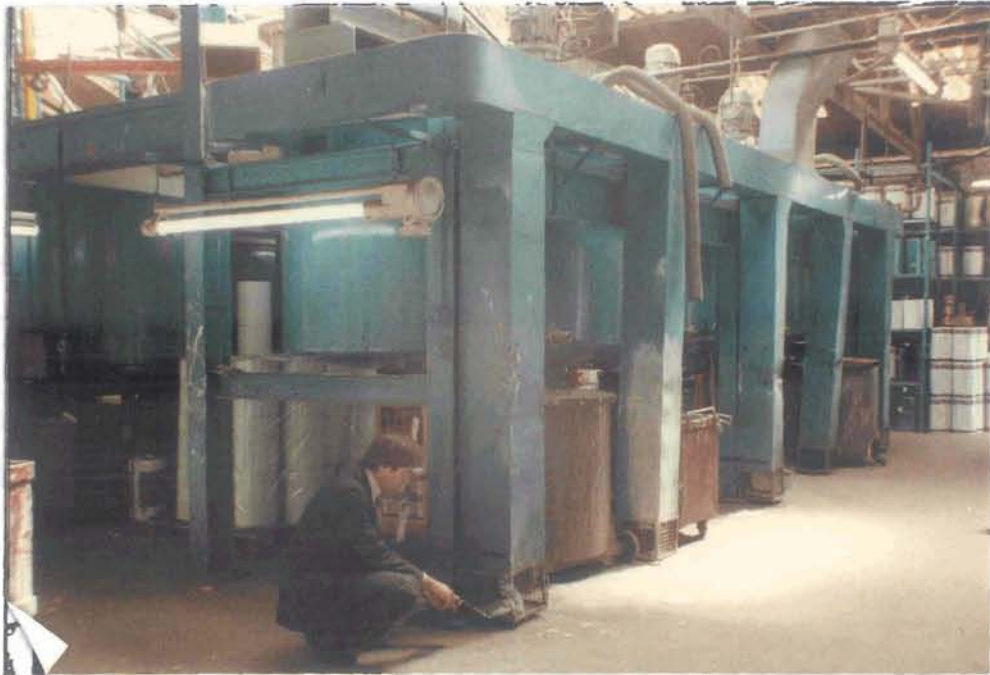
The effect of sagginess in flexible ducting was demonstrated in MILL 2 on the '262' run where holding the ducting into a smooth curve doubled the flow. Though it is doubtful that the flow and hence the hood face velocity would double here, it may increase the transport velocity in the system sufficiently to reduce the pigment buildup seen in the slot. Suspension of the duct could be achieved with two elastic cords from the roof girders and canvas slings. This would allow the necessary vertical movement of the mixer.

Two bead mills were the only other machines in the room and they had no mechanical extraction.

The solvent vapour concentrations in the room were generally 100-150 ppm though a number of measurements in the worker's breathing zones exceeded 300 ppm (Appendix B). Local extraction, especially during cleaning operations could be provided, but if the operations are brief, opening the doors should be encouraged. Work in this area would have a similar medium priority to the SMALL ORDERS room.

3.14 COLOUR MATCHING

The reason for including part of this area was for an example of floor extraction and here the investigation is restricted to this aspect.



The photograph above shows a hygienist with a smoke tube demonstrating poor capture by the floor inlet. Face velocities were, from left to right:

1.5 <0.2 2.2 2.5 0.5 m/s

This range of velocities also indicated flow imbalance between the inlets.

The vertical vapour gradient distant from the extraction was insignificant (Appendix B, May 29).

The flow through this ducting could be used more productively for efficient extraction on the lips of the mixers.

The existing lip extraction on top of the mixer was quite inefficient and can be seen in the photograph below.



Since the capture range of the hood was only a few centimeters, it provided no protection from solvent vapours from the mixer for the worker scraping paint near the top of the mixer. There is a large buildup of paint on the lid from the practice of hanging sampling tins to drain on the hooks provided. This also meant that the mixer lid was normally left open.

The floor extraction served no purpose and the lip extraction was of poor design. An alternate extraction for this type of mixer is the Standard Hood in Appendix E.

3.15 CLEANING SHED

A consultancy report (2) found this to be the worst area. Room solvent vapour concentrations (Appendix B) were generally 200-300ppm though the diffusive sampler results (Appendix H) indicated that personal exposure was higher than the DVA results suggest.

The operator reported he usually worked weekends giving a working week of 60 hours. The U.K. exposure limits (4) are based on American figures (5) which assume a 40 hour working week, and the weekend for the body to recover. With overtime, this limit must be proportionately derated.

This room is fraught with examples of bad housekeeping, poor work practices and bad extraction.





The photographs above are self explanatory but the range of sizes and shapes of vessels for cleaning is large.



The extraction in this area was quite powerful but it drew the solvent vapour up past the worker's face, particularly if he was bending over (see photograph above). Horizontal slot extraction could be used but there would be problems adapting it to the variety of vessels and tasks, as seen in the first two photographs.

Solvent was used as if it were water in the cleaning shed. Spills were frequent and the general ventilation was quite inadequate. The solvent vapour concentrations would be higher in situations where the doors were closed.

The photograph below shows the small extraction unit on the wall and mopping up a solvent spill estimated at 10 litres.



Some alternatives to reduce solvent vapour exposure:

- 1) substitute the solvents used for cleaning to those less hazardous to health
- 2) automate the process
- 3) rotate workers through the shed. In addition levels must be reduced.
- 4) clean up housekeeping and install an horizontal extraction hood giving an air movement of 0.5 m/s into the hood at any point above the vessel being cleaned. This option would be coupled with high heat losses in winter and high solvent losses which may not be environmentally acceptable in the future.

3.16 EVAPORATION EXPERIMENT

The task of demonstrating different types of lip extraction and their performance under different operating conditions was well beyond the scope of this investigation. However simple laboratory models, approximately scaled, served to give similar data in a short time and at far less cost. The mixer capacities were between 450 and 11000 litres.

Five, one litre paint tins were chosen to represent five approaches. They were:

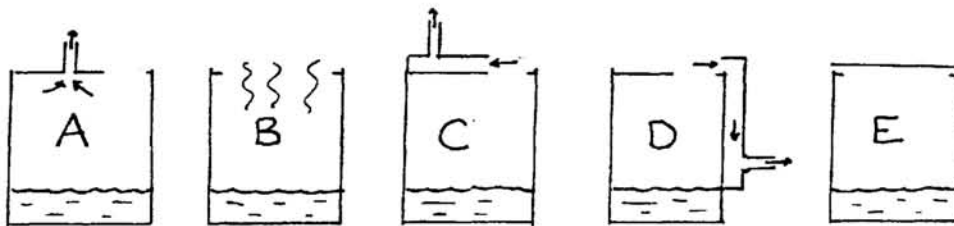


figure 22 mixer extraction models

- A: lid extraction to simulate a very common approach to extraction in the factory
- B: open vessel, not uncommon in the factory
- C: slot extraction. The only example of this in the factory is on the cavitation mixers in the CENTRI MILL
- D: lip extraction by a wrap around slot
- E: loosely fitting lid with no extraction, also not uncommon in the factory

The evaporation of 200g of industrial grade toluene was determined gravimetrically in the five vessels at arbitrarily long intervals (usually several hours) under set operating conditions. The temperature was raised with a waterbath, but unfortunately its thermostat was unreliable so the results are shown relative to the open vessel, B. Simulation of the action of a mixer was done with a

airstream bubbling through a glass laboratory pipette into the liquid. Laboratory pipettes were chosen for bubblers since their tips had uniform narrow bores and the extra flow impedance would tend to equalise flows in all bubblers. The air supply was the output of the vacuum pump for the hood extraction, and the temperature rise about 1° C. Two manifolds to equalise suction and pressure were fabricated from white plastic jars.



Since only three tins had hoods and five tins had bubblers, and one extra line bled into the fume hood, the air volume bubbled into the extracted hoods was about half that extracted.

A later modification divided the pressure line before the pressure manifold to reduce the bubbler flow by a further factor of two.

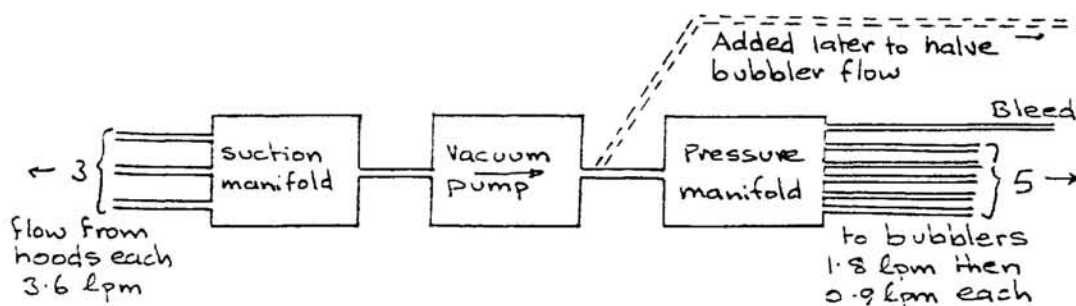


figure 23 manifold schematic

A further precaution to maintain uniform conditions was to minimise airflow above the tins, a situation corresponding to the low airflow at the mixer lid level in the factory. This was achieved without compromising the laboratory air quality by raising the fume cupboard door 0.5m, using the cupboard on the low fan setting and by placing a baffle behind the water bath.

Air flow and quality measurements are in Appendix D.

<u>Run</u>	<u>Solvent Temp.</u>	<u>Extraction</u>	<u>Bubbler</u>
i-two runs	20°	off	off
ii	?	on	full
iii	20°	on	off
iv	19°	on	half
v	?	on	full
vi	?	on	full
vii	?	on	full
viii	?	on	full
ix	?	on	full

table 14 experiment temperature and air movements

The waterbath regulation was unreliable but solvent

temperatures as high as 75° were recorded. In the factory, mixer temperatures of 90° were reported and some processes must be controlled to much lower temperatures to keep a wax additive from melting.

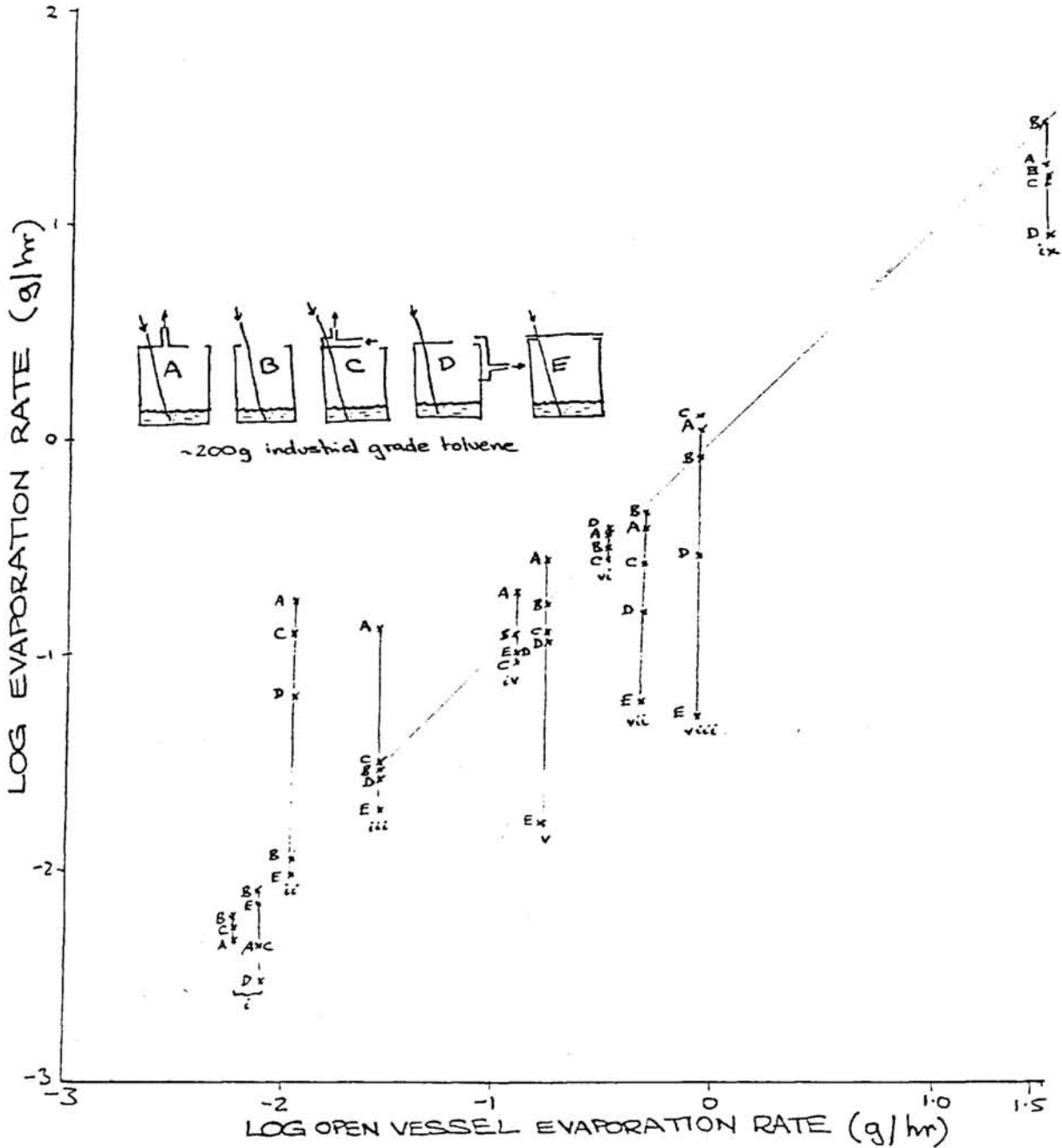


figure 24 evaporation rates

Performance of vessels

A) Lid Extraction: This was invariably associated with

the highest solvent loss, though under conditions of high rates of solvent evolution (eg run ii), the other extracted vessels also showed enhanced losses. Without agitation (run iii), lid extraction increased losses by a factor of five.

B) Open Vessel: The large surface area led to high loss, particularly when enhanced by agitation or temperature.

C) Hood Extraction: The results of C were erratic and varied unpredictably, but were reasonably close to that of an unextracted, open vessel. Since the face velocity was about 0.25m/s, one can conclude that little extraction of vapour saturated air from inside the tin occurred. A test with a smoke tube indicated that air was being drawn horizontally close to the slot, but the range of the hood could not be determined accurately at this scale.

D) Lip Extraction: This type of hood was longer than C but did not have to draw air as far. It would be expected to be more easily damaged than C but to operate more efficiently and not be affected by constraints of space on top of a mixer. Crudeness of model construction made the slot width vary between 3 and 5mm. An average width of 5mm gave a slot face velocity of 0.1 m/s, somewhat less than C. The solvent losses were invariably lower than for C.

E) Loose Fitting Cardboard Lid: The solvent losses for this type of hood were remarkably low and uniform under all conditions of temperature and agitation. This indicates that close fitting lids in the factory are probably the best primary method of control. However lids do have to be opened for sampling and addition of materials, so some form of local extraction is necessary.

4 DISCUSSION

4.1 OVERVIEW

The aim of this investigation was to study the primary control of solvent vapours. Only sufficient solvent vapour measurements were done to allow a reasonable approach. Past and ongoing solvent vapour monitoring by the London School of Hygiene and Tropical Medicine (2) should complement this investigation.

A basic principle of Occupational Hygiene is whenever possible, to control a hazard at its source. In the factory, the hazard under investigation was solvent vapour and the main solvent, toluene, was the dominant vapour in most instances (Appendix H). Substitution for less hazardous solvents is not feasible, except for some glycol ethers (2) so the options of mechanical containment, ventilation and change of work practices were the key elements of this investigation.

An attempt was made not to ask leading questions which may agitate the wages workforce. However my presence and obvious interest in their working environment did affect attitudes towards their responsibilities.

-a wall fan in the cleaning shed was reportedly broken for several years. Questioning the maintenance procedure regarding how things get fixed and who was responsible, I was given an unenthusiastic reply by a worker. However a new fan was seen installed two weeks later.

-a duct flange was observed disconnected from a mixer lid near the Attritor extraction. The operator may

have observed work on this extraction which included cleaning out and reconnecting a duct for he later showed me the flange, weighted in place with short lengths of pipe.

These indicate the potential for motivation on health and safety matters.

4.2 SAFETY POLICY AND TRAINING

The present Safety Policy is dated April 1, 1984 (and lists a Safety Officer, a position at present unfilled). The Health and Safety Commission (10) views the main point in reviewing a Safety Policy as "keeping it alive" though the HSAWetc Act (Sect 2(3)) only requires regular revision "as often as may be appropriate". There were no copies of the company Safety Policy on any of the factory Health and Safety noticeboards.

Training is reported to be restricted to fire drills but the wages workforce is long term and stable and so know their jobs. This does not imply a good grounding in health and safety matters.

This investigation did not attempt to cover personal protection, but overalls, gloves and footwear were freely issued. No solvent vapour respirators were seen but dust masks were regularly used with pigments and other dusts.

4.3 MECHANICAL CONTAINMENT

There are two aspects to mechanical containment.

One is the prevention of emission of solvent vapour during transfer from one vessel to another. If this could be done through a tube then solvent vapour emissions would be minimised.

- eg, -use of longer delivery pipes on the bead mills, particularly during flushing operations
- use of air operated pumps to bail vessels, particularly in the CLEANING SHED. This would also eliminate the need for stooping into a vessel
- use of air operated pumps to transfer material from 200 litre drums to mixers. It may be possible, if safety permits, to air pressurise the drums, to push the liquid out through a tube into the mixer.

The other aspect of mechanical containment is the use of close fitting lids on all solvent containing vessels. With effective lidding (see model E, Section 3.16) the solvent losses from vapours and aerosols must drop and solvent vapour levels in the workplace must also drop. The only valid reason for removing a lid is to add liquids and powders, or to take a sample. Extraction ventilation during these operations is discussed in detail in the Section 4.4. The factors which stop the effective lidding of vessels are discussed in decreasing order of vessel size.

1) Mixers

Where a vessel had a lid (some didn't) production orientated supervision allowed instructions on numerous notices to close lids to be ignored. It is quicker to check the factory operation and take samples if the lids are open. Recent additions of safety grilles on the mixers (apparently at the insistence of the Health and Safety Executive), rather than adding a smaller trapdoor in the hinged portion of the lid for addition and sampling, has reinforced this habit.

The hinged portion of the lids were often caked or splattered with paint (see photographs in Sections 3.10 and 3.14). The splattering was reported to 'sweat' during mixing and discolour subsequent jobs, especially for light tones. The caking was from the draining of sampling tins on hooks above the mixer.

The addition of pipes into many mixers from the tank farm has stopped easy removal of lids for cleaning since the pipes usually pinion a lid rather than take the more tortuous path between lid sections - the lid always splits about the mixer shaft. A hole in the lid much larger than the tank farm pipe was common.

A practice, now discontinued, was the regular cleaning of paint from lids in a caustic bath. Less regular contract paint chipping of the mixers is now done.

Many lids were buckled or could not close properly because of a toe rail, buildup of paint on the mixer rim or the new safety grilles over the mixer openings.

2) Small mixers and 'Mobiles'

Lids from small (500 litre) mixers were reported to be left off from the fear of them falling into the mixer during the first few hours of operation when vibrations were more intense. A modification to lock both parts of the lid and overcome this objection is given in Section 3.11.

No real reason for not lidding 'mobiles' could be found, especially during transportation when surface agitation was visible. Measurements in the breathing zone of the worker pushing the mobiles (Appendix B) showed that a two or three fold increase in ambient solvent vapour concentration was

not uncommon.

3) Small vessels

The copious use of solvent for cleaning minor spills is an investigation on its own. Though it has kept the factory tidy, it may be a significant source of the higher background level of solvent vapour once work starts. Most filling stations had an open paint tin of solvent and a rag. Lidding this tin would stop only a fraction of the evaporation. A change in the procedure for cleaning spills or a way of reducing spills (eg automation) could be considered, but they are beyond the scope of this investigation.

Another type of small vessel with solvent is a small 'mobile' with mops and scrapers. Invariably the lid is ill fitting because too many handles protrude. Reduction of solvent emissions from this source will depend on either changing the procedure so that volatile solvents are not used as a cleaning agent or by at least making the lids fit better.

4.4 EXTRACTION VENTILATION

The bulk of the investigation was on this topic. As mentioned, the only real need for extraction ventilation is when access to a vessel is required. The evaporation experiment in Section 3.16 demonstrated the effect of different modes of extraction on solvent losses, and the costing figures in Appendix G show the high direct costs of heating losses, solvent losses and electrical running costs. Evaluation of a representative selection of extraction systems indicated that extraction ventilation in

the factory was ineffective, mainly due to poor hood design and poor maintenance. Suggestions were also made for extraction at the source of several filling machines and for modifications to extraction for fume cupboards and bench extraction (Section 3.12).

4.4.1 Fallacies

There are two common fallacies in extraction ventilation, and both are strongly rooted in the company.

The first fallacy is that hoods can draw air a significant distance away from the hood openings. All lip extraction (except those built in as a slot in the cavitation mixers in the CENTRI MILL) fall into this class. While a jet of air takes thirty duct diameters to fall to 10% of its initial velocity, this occurs at only one diameter with extraction. It appears that most local extraction design in the factory was done by those conversant with airconditioning but who knew little about hood design for industrial hygiene applications.

The second fallacy (9) is that heavier-than-air vapours collect on the floor and so floor extraction is worthwhile. On page 5 of a booklet "What you should know about Flammable Liquid Safety", which is distributed by the company it states

"Vapours are heavier than air and can sink to floor where they may not be seen or smelled".

Its apparent roots are in fire safety films which show a sequence where an open container of ether is placed at the top of some stairs and an ignition source at the bottom. In a short time the vapours flash. Here a number of factors

apply which do not occur in this factory. The first is the use of a material such as ether.

	<u>ether</u>	<u>toluene</u>	<u>acetone</u>
vapour pressure (Pa)	58500	3730	24000
boiling point (°C)	34.5	110.7	56.5
flash point (°C)	-45	4.4	-17
exposure limit (ppm)	400	100	750
smell threshold (ppm)	100	<5	100
lower explosive limit (ppm)	18500	13000	29000

table 15 properties of selected solvents

For the ether to flash, the lower explosive limit must have been reached, a level in ppm which is not found in the workplace, particularly near the floor where there are always drafts, however slight. The high vapour pressure and very low flash point also contribute. However the main reason why vapour does not collect on the floor is very simple. The vapour usually moves from the tops of vessels at a concentration of around 100ppm. The worst case found in this study was around 1000ppm (Section 3.7). Consider one of the most volatile substances actually used in the factory, acetone.

Density of acetone vapour = 2.0 (air = 1)

At 1000ppm, density = $\frac{1000 \times 2 + 999,000 \times 1}{1,000,000}$

= 1.001

A difference in density of 0.1% is so insignificant that random air currents will disperse the materials through the

room. This has been demonstrated in repeated measurements from ground level to 5 meters up (Appendix B).

4.4.2 Hoods

The evaporation experiment (Section 3.16) revealed a number of points:

- 1) Extraction through the hood of a mixer increases the rate of evaporation about five times.
- 2) Having the mixer on, as simulated by a bubbler in the models, increased the evaporation rate a further four times. In practice this would be from an increase in surface area of the liquid, increases from raised mix temperature and increases from evaporation of solvent aerosols. Aerosols may be a major mechanism for enhanced solvent loss when the extraction is on. A simple, loosely fitting cardboard lid (model E) worked remarkably well at reducing losses even though air and vapour were being displaced from the tin, suggesting that simple solvent vapour losses were not the main mechanism.

Release of aerosols from an agitated surface may be pictured as spheres - floating in the air if they are very small, and travelling a distance before stopping if they are larger. The through-lid extraction (model A) vacuums them from the space above the mix where they evaporate in the ducting or the outside air. This concept could be demonstrated by measuring solvent vapour concentrations through a filter. The solvent vapour concentration would be lower since the filter stops the aerosols.

- 3) An alternative to lid extraction is horizontal slot extraction, either from the mixer rim or along the lid

hinge. The evaporation experiment demonstrated that this greatly reduced solvent losses and offered some protection. The experiments with a push pull hood in the PREMIX room showed this could be achieved with the same hoods or simple modifications to them, but a standard hood of the type designed in Appendix E is more desirable since it is simpler to use and does not need the operator to intermittently set it up. It also is in line with a policy of keeping lids on all vessels so that the requirements for extraction ventilation are minimised. The push pull approach does not encourage smaller mixer apertures nor closing of lids and may also incur large costs through compressed air wastage.

Studies with smoke tubes to visualise the flow of air into hoods were quite revealing and are best seen in a photograph in Section 3.7 where a smoke tube shows air being pulled from well behind a hood with small flanges. This performance may be more easily understood if the hood mouth is seen as a point or a two dimensional plane. Air movement will be from all directions to this low pressure zone. Flow from behind the hood would be greatly reduced by large flanges. This was one of the major features of the push pull hood design (Appendix F) compared with the original hood which had small flanges.

The Standard Hood (Appendix E) features an approximation to the idealised bell mouth for low hood entry losses and extra long side flanges to make the inflow more directional. Many inlets around the factory were truncated ducts with no real directionality and terminated in the region of a mixer

tap but too far away to be of any effect except by drawing fresh air into the area. A pedestal fan would be cheaper and more effective.

4.4.3 Extraction Systems

It was a source of frustration trying to unearth information pertaining to the performance of the selected extraction systems, especially since around 15 years had elapsed since their installation and no factory records were kept. An essential document for assessing the potential of an extraction system is the fan curve. Fan curves for the exact fan model or of a near identical model were obtained for two of the systems being investigated but for the third (the Attritor extraction) only an approximation could be obtained by matching fan type, dimensions and motor with another brand. An attempt was made to trace the fan manufacturer from the motor plate. Numerous telephone calls over England and Wales eventually traced the motor to the motor factory, the reseller, the unit assembler and a customer who used it with a pump. It was apparently then refitted with an unbranded fan for use in this factory. A great deal of effort would have to be made to just assemble a complete record of the curves for the fans in the fifty extraction systems in the factory. Even in the absence of a fan curve it was discovered that the Attritor extraction fan, a forward bladed centrifugal fan, had been running backwards for two years. The fan and ducting were checked for blockages when the motor power consumption did not tally with the difference between theoretical and measured performance of the fan. Reversal

of the motor wiring saw a huge increase in performance of the system though fan efficiency does not equate to extraction efficacy at reducing workplace solvent vapour concentrations.

Visual inspection of a number of extraction systems around the factory revealed reasonable looking fan installations and duct runs, though often ducts had sharp bends and joined at right angles, without loss reducing gussets.

4.4.4 Maintenance and Testing

Where extraction of very dusty air was occurring, a heavy buildup of material was noted in the ducting. This applied particularly in the Attritor Mixer ducting before the bag filter and the PREMIX extraction, where 5cm of material was evident at the bottom of the ducts. The material would be expected to be electrically insulating and the movement of new material (at a higher velocity because of the reduced lumen) could be expected to cause electrical charge separation or static electricity (11). The factory management were fully aware of the consequences of static discharge when earthing straps were installed on all vessels in the factory and perhaps this observation may give extra impetus to regular cleaning of dirty ducts and installation of dust collectors for the PREMIX room.

The results in the PREMIX room (Section 3.8) show how progressive maintenance - cleaning the hood grill, cleaning the hood and upgrading the hood each make significant changes to the performance of the extraction system.

The Attritor extraction system was fitted with a number of static pressure monitoring points labelled A to F on the

ducting, and pitot traverses for A, B, E and F are documented in Appendix L. Static pressure measurements at points A to F are documented in Section 3.7. This system had perhaps the best designed ducts in the factory and a baseline was established for its performance. It is a suitable candidate for trials with the 'Standard Hood' on mixers 32 and 35 and for a hood with a larger flange and longer slot on the Attritor itself.

The determination of system performance with smoke tubes and static monitoring points is detailed in Appendix N.

When viewed from the roof, an array of short stacks and 'chinese hats' or variants of them were seen. This arrangement, which deflects the stack emissions downwards and also mechanically reduces the efficiency of the ventilation system, could be changed, as shown in Appendix O. Other alternatives were mentioned in a previous report (2).

4.5 WORK PRACTICES

Work practices involved the physical handling of solvents. The vessel filling operations by 'mobiles', and paint and solvent can filling operations which were discussed in the results (Section 3), are in fixed locations and are routine operations so local exhaust ventilation can serve to protect the worker. Other operations such as moving 'mobiles' were demonstrated to produce a cloud of solvent in the absence of a lid. The use of solvents for cleaning minor spills was reviewed in an earlier part of this discussion (Section 4.3).

Two other work practices which give rise to copious solvent

vapour emissions are the mopping of floors with solvent and the cleaning of mechanisms and vessels with solvent. All routinely occur in the CLEANING SHED which accounts for the excessive levels there. In the factory the flushing of ball mills and bead mills were demonstrated to produce high solvent vapour concentrations. Cleaning of filling machines and sand mills was observed but no measurements made. Since these operations are routine it would be desirable that the worker exposure is lessened. This may be one case where containment and local exhaust ventilation is impracticable and appropriate respiratory protection devices should be mandatory. To protect other workers the smallest amount of solvent of the lowest toxicity should be used.

4.6 SOLVENT VAPOURS

The wide range of solvent vapours are demonstrated and discussed in Appendix H and generally this will not affect the approach to control since many of the solvents used have an exposure limit around 100ppm (Appendix J). However some solvents have a much lower exposure limit and the reasons for this are not always irritancy as for cyclohexanone (Exposure Limit 25ppm, (4)). Though concentrations of cyclohexanone were well in excess of 1000ppm in the operator's breathing zone (Section 3.7), the operator reported that a formulation, ACR1, was much more irritant. The US documentation (5) which underlies the UK exposure limits states for a significant component of this formulation, 'oxitol acetate' or 2-ethoxy ethyl acetate:

"there are no records of adverse worker experience attributable to 2-ethoxy ethyl acetate, possibly for

the reason that its vapours are objectionable at concentrations necessary to cause effects".

The following Exposure Limits or TLV's are listed below.

	TLV (ppm)	Notation (sk = skin)
HSE (4)	100	sk
ACGIH (5)	5	sk
OSHA (12)	100	sk

table 16 2-ethoxy ethyl acetate TLV's

The 1986 US TLV of 5ppm may be eventually copied in the UK since the 1986 OEL (4) still refers to the 1982 US TLV. It is based on testicular atrophy and leucopenia in mice and was reduced in analogy with methoxy ethanol and because a 'no observable effect' level had not been defined.

If an exposure to cyclohexanone at 20 times its irritant threshold was considered acceptable by the workers, but ACR1 was found objectionable, then it suggests high levels of this compound and it is possible that adverse effects could be found.

These direct and indirect observations on a limited number of solvents show the need for further investigations into use of the more biologically harmful solvents used in low volumes and not generally found in the factory atmosphere.

The computer generated sheets giving the menu for manufacturing paints have the blanket statement

"Safety Instructions : wear full safety equipment during weighing and manufacture".

These instructions are echoed by signs showing a man

wearing a full protective hood and clothing but are not enforced. It is more credible to concentrate on the few highly irritant and biologically damaging solvents (and additives) than to attempt a blanket cover on all materials. If good practices are established for what is reasonable, then it may be possible to change general attitudes towards care with material handling.

5 CONCLUSIONS

The factory Health and Safety Policy is an inoperative document and is reflected in the lack of health and safety motivation by the wages workforce. There is a need for health and safety awareness of the materials used and in what can be done to limit exposure to them. Since the information is used in an inhouse computer system for the product labelling requirements, the same mechanism should work to inform the wages employees of the hazards of the components. A training programme aimed at supervisors is appropriate at this stage.

The investigation showed at times there were local pockets of high solvent vapour concentrations, but generally the levels were uniform because of air movements and many sources of solvent vapour. These included lidless vessels, vessels with poorly fitting or open lids, mixers with little or no effective extraction ventilation, solvent cleaning of machines and floors, transferring solvents from one vessel to another and regular use of copious amounts of solvents for cleaning purposes. The more of these factors present, the higher the solvent vapour concentration in the room.

A belief that solvent vapours are heavier than air is a myth and the ground level extraction does little to reduce solvent vapour concentrations for reasons of health or safety.

Another myth is evident in the design of most extraction hoods, that of the capacity of hoods to draw air into them from a distance. This infers that all extraction mounted

near the rims of mixers is ineffective.

The approach to extraction ventilation in the factory has a large hidden cost, estimated to be in excess of £100,000 per year from solvent losses, heating losses and electrical running costs. A deeply hidden but significant cost is the effect on product quality due to enhanced evaporation.

Much of this problem is related to hood design. Experiments showed that extraction of the airspace inside mixers could increase solvent loss five times in the absence of agitation and a further factor of four if the mixers are on. These losses were shown to be a lot less if slot extraction on the rim of the mixers was used and if the lids were kept closed when addition of materials or sampling is not being performed. A push pull hood was successfully demonstrated but a standardised new design of hood which limited the size of the opening and promised lower running costs was preferred.

Extraction at the source is desirable for filling machines and bench operations. The approach to this for two filling machines and a bench in the SMALL ORDERS room was shown.

Maintenance of hoods, ducting, fans and stacks is currently breakdown maintenance and performance monitoring of ventilation systems is nonexistent. The risk of static discharge inside dirty ducts favours regular cleaning of ducts extracting dusty air. Simple maintenance, such as replacing flexible ducting on flanges or clearing paint blockages in ducts was not apparent but it would be immediately beneficial.

Design of some duct runs, branches and inlets is poor. This

is seen in the use of a small size of flexible, floppy branch duct, branch ducts which join the main duct at right angles without loss reducing gussets and sharp bends in rectangular ducting.

Whilst instances of acute exposure to solvent vapours were noted, concern should be directed towards hearsay reports of irritability, drowsiness and alcohol intolerance, backed by measurements of levels in the factory.

6 RECOMMENDATIONS

In order of importance:

- Update Health and Safety Policy.
- Effectively lid vessels containing solvent so that a near airtight seal is achieved and the lids can be removed for cleaning.
- Use slot extraction on mixers. A standard hood is suggested in the report. Then revamp the rest of the extraction chain.
- Follow the report guidelines for local extraction ventilation in the CLEANING SHED, SMALL ORDERS room, filling machines and Attritor.
- Investigate systematic maintenance on ventilation systems coupled with a performance monitoring programme.
- Pump solvents between drums, mobiles and mixers.
- Further investigate:
 - a training programme for supervisors
 - the use of solvents for cleaning
 - the chronic effects of solvent exposure on worker health
 - the acute effects of exposure to potent but less used solvents (eg glycol ethers).

7 REFERENCES

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APPENDIX A

CALIBRATION OF ORGANIC VAPOUR ANALYSER

The method used follows a standard technique (13).

Temperature of atmosphere was 26° before and after the calibration run.

The figure below shows the nominal instrument response against the true response to industrial grades of the solvents. Dial setting on the instrument was 300.

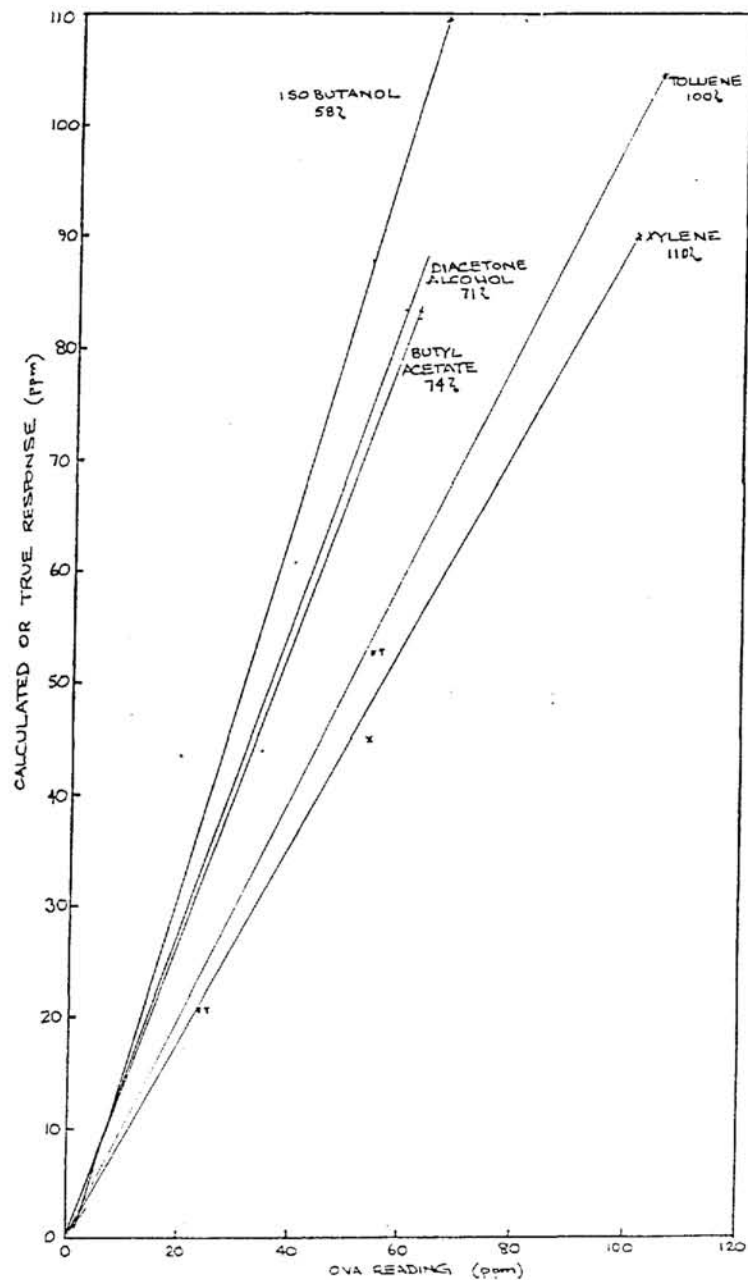


figure 25 OVA calibration(ppm)

The nominal figures for a range of solvents are given below

<u>Compound</u>	<u>Rel. Response(%)</u>	<u>Compound</u>	<u>Rel. Response(%)</u>
Acetone	60	Methyl Isobutyl Ketone	80
n-Butanol	50	Octane	80
2-Butanol	65	n-Propanol	40
n-Butyl Acetate	80	2-Propanol	65
Cyclohexanone	100	Styrene	85
Ethanol	25	Toluene	110
Ethyl Acetate	65	1,1,1 Trichloroethane	105
Heptane	75	m-Xylene	111
Hexane	70	o-Xylene	116
Methyl Alcohol	12	p-Xylene	116
Methyl Ethyl Ketone	80		

table 17 OVA nominal response (CENTURY INSTRUMENTS)

DVA SOLVENT VAPOUR SURVEYS

ENVIRONMENTAL CONDITIONS

Temperature

date	time	outside	factory	level 1	level 2	grad.
May 29	1000	14	14-19	20	-	6
June 12	0930	16.5-19	17-19.5	17.5-20.5	20-21.5	3
July 15	0700	22-25	23-26	26	24-26	1
July 15	1600	29	29	32	35	6
July 29	0640	-	-	18	-	-

table 18 temperature ($^{\circ}$ C) during DVA surveys

The temperature on July 29 is a globe thermometer measurement. The survey thermometer had broken, but other measurements indicated that below 20° globe (radiant) and air temperatures were close.

A larger temperature gradient would be expected in winter from subjective reports of conditions on level 2 and the use of ceiling heat recovery ventilation in the factory.

NOTATION1) Solvent concentrations using organic vapour analyser

xx : reading taken at carousel, effectively two floors up, corresponding to operator's breathing zone

xx : reading taken on first floor (giving access to mixers and ball mills), corresponding to operators breathing zone

xx : reading taken on ground level at a height corresponding to breathing zone

zero : no solvent vapour detected

xx BZ : measurement taken in workers breathing zone whilst performing a task

xx ym : measurement taken Y metres from the floor (ground measurements taken 5mm from the floor)

2) Air movement and temperature


y m/s → : air moving at Y metres per second, as estimated from movement of a chemical smoke

↔ : no air movement evident from lack of movement of chemical smoke

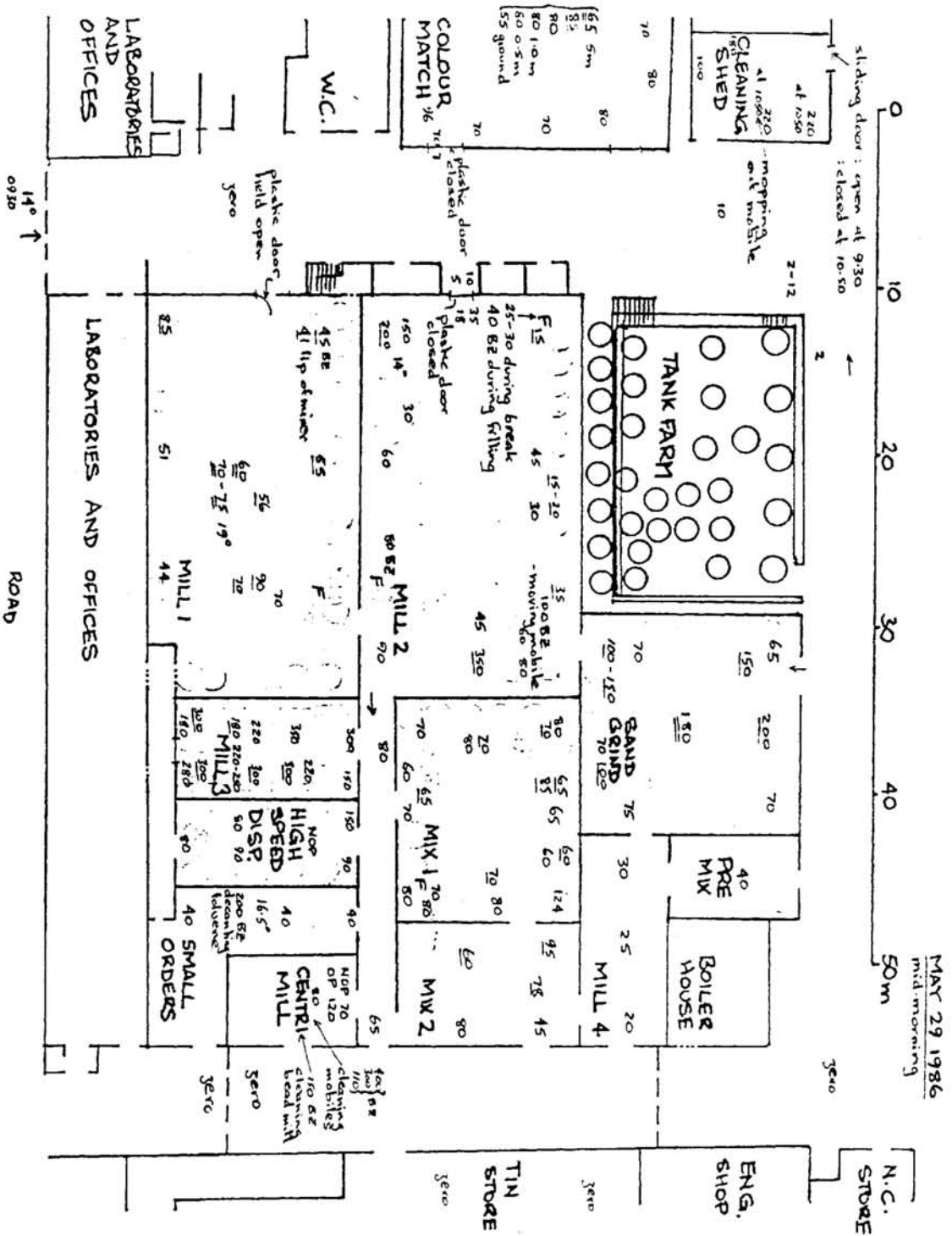
↔ : where drawn close to figure indicates lack of air movement where measurement was made

Y° : Y degrees centigrade at indicated floor. A thin walled thermometer was used to give fast response

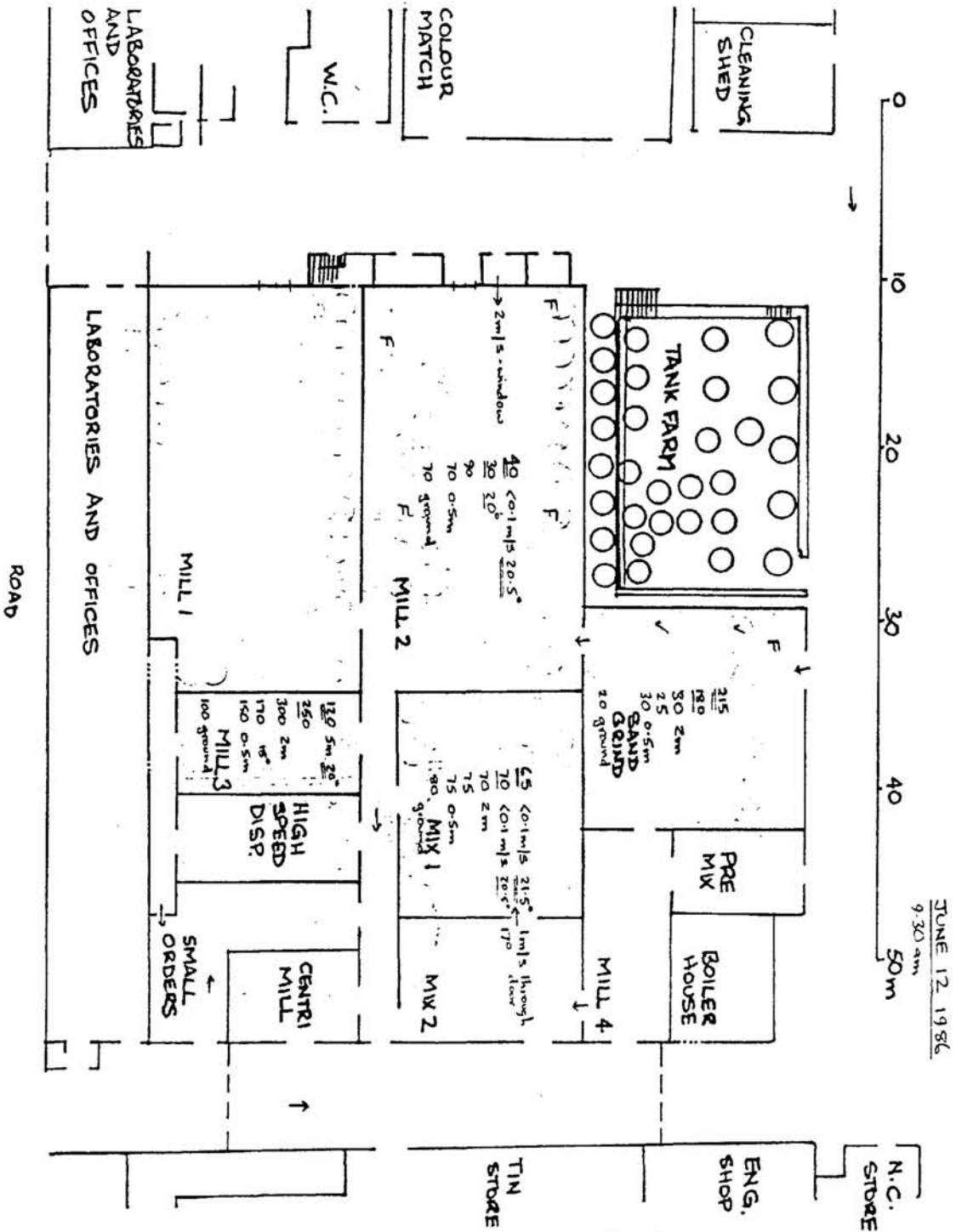
3) Other

- F x.x l :filling x.x litre cans
- OP :operations or work being done involving solvents
- NOP :no operations or work being done involving solvents
- ~~OP~~ :wall extraction fan
-  :500 litre wheeled vessel
- ✓ :ball mill or mixer on

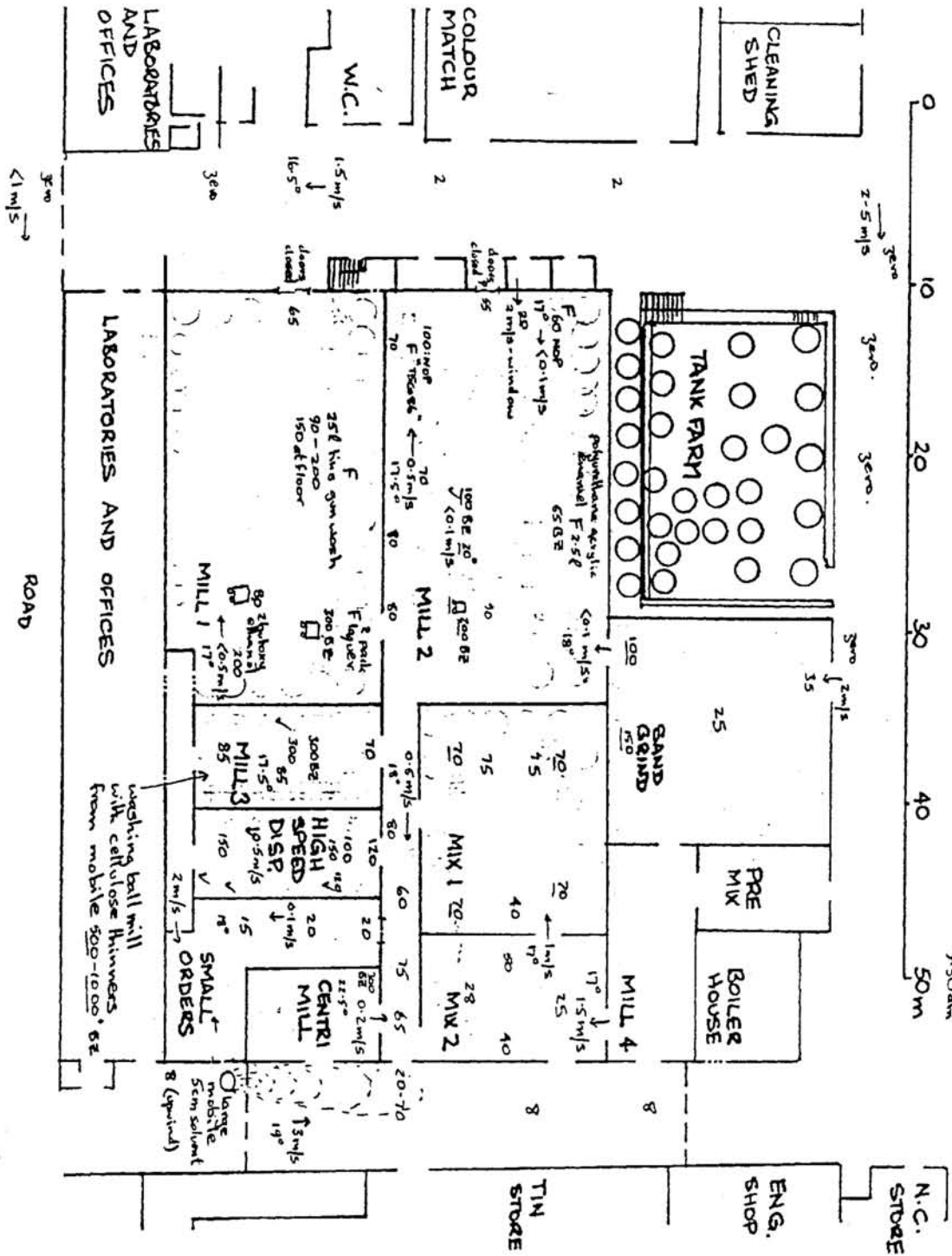
OVA: MAY 29



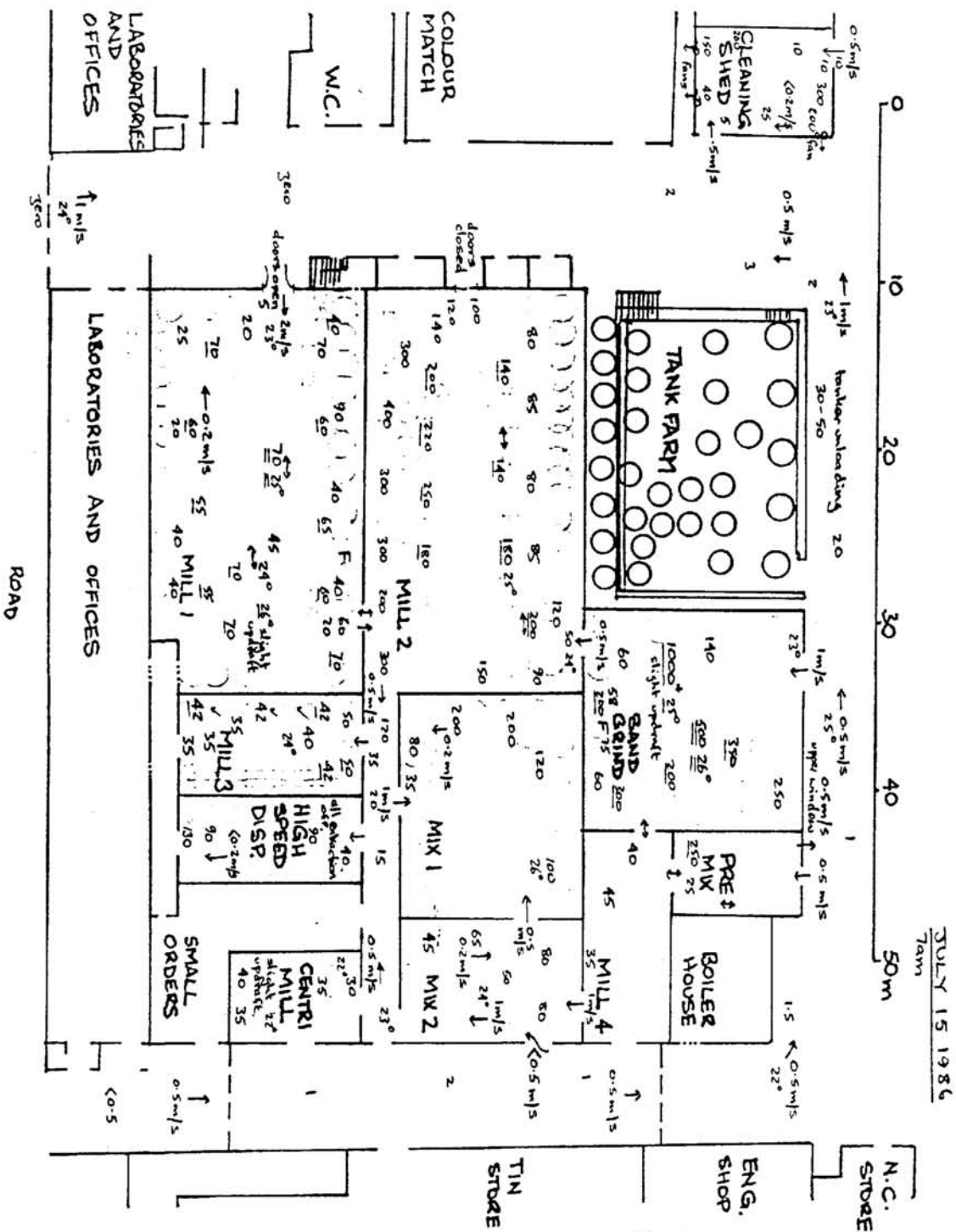
OVA: JUNE 12
VERTICAL GRADIENTS



OVA: JUNE 12



OVA: JULY 15 am



JULY 15 1986
7am

APPENDIX C

MAGNEHELIC CALIBRATION

	start	finish
Temperature	22° C	22° C
Pressure	1018mb	1018mb

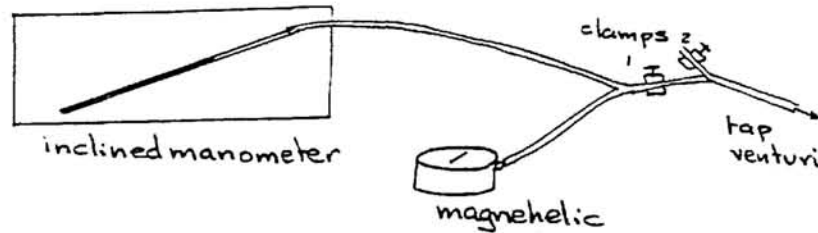


figure 26 calibration schematic

A Mk 4.5 Airflow Testing Set (Serial Number 26512) made by AIRFLOW DEVELOPMENTS was used. It was mainly used on the 0-2" scale which gave an increase of 10 in sensitivity. The first clamp limited the fluctuations in pressure and was adjusted to give a steady reading. At certain clamp positions a slight resonance was set up and this had to be avoided. The second clamp controlled pressure in the system.

0-10" meter	0	2	4	6	8	10			
manometer	0	2.0	4.0	6.0	8.0	10.2			
0-2" meter	0	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00
manometer	0	0.24	0.48	0.76	1.04	1.28	1.53	1.84	-
0-0.5" meter	0	0.10	0.20	0.30	0.40	0.50			
manometer	0	0.10	0.20	0.30	0.40	0.50			

table 19 magnehelic calibration

One gauge was found to be erratic and inspection of the mechanism revealed corrosion in the magnetic linkage. This gauge was not used, but all the other gauges were examined

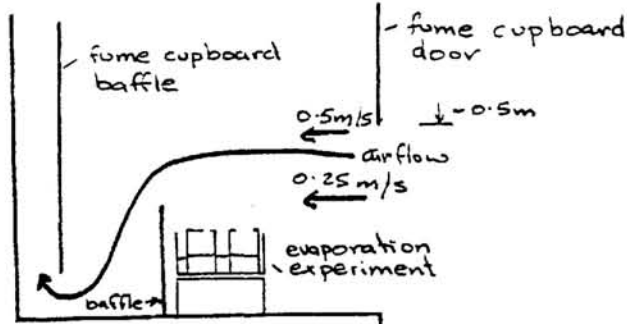
for corrosion. None was found. All meters had scales in 'inches of water'.

A further test performed in the field was akin to testing bicycle valves with slight suction to see if the seal was patent. This is particularly important on the pressure inlet of the gauge where slight leaks may occur on the sealing 'O' ring.

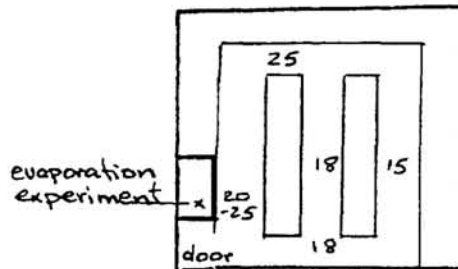
EVAPORATION EXPERIMENT

1) Experimental Conditions

Air flow into fume hood (kata)

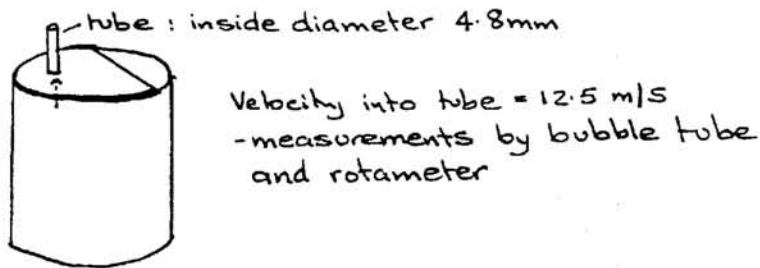


Laboratory air quality (toluene ppm)

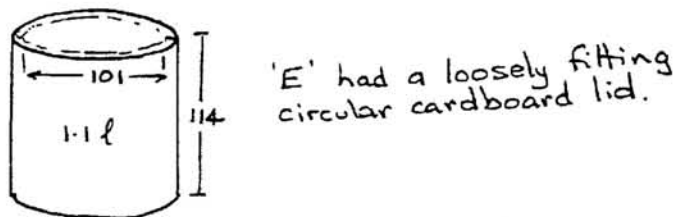


2) Sizes (all dimensions in mm)

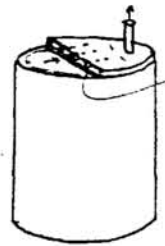
A



B, E



C



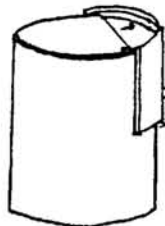
flow distributing vanes

effective slot length 82

slot width 3

slot area $2.46 \cdot 10^{-4} \text{ m}^2$ face velocity 0.243 m/s

D



slot length 125

slot width ~5

slot area $6.25 \cdot 10^{-4} \text{ m}^2$ face velocity 0.1 m/s

figure 27 model dimensions

The above velocity estimates are derived from rotameter and bubble tube measurements of flow (3.6 lpm).

3) Performance

The tins were filled with chemical smoke and the clearance times noted.

The unextracted tins retained the smoke for minutes, though not much longer than the tins with slot extraction.

The tin with lid extraction (A) cleared in about 10 seconds

For: extraction 3.6 lpm

volume above toluene = 0.90 l

100% efficient extraction = $0.9 \times 60 / 3.6$

= 15 seconds

which suggests very efficient exhaustion of the entire tin volume.

On each model three points were assessed for toluene vapour using the DVA, one each side of the opening one 3cm above the rim.

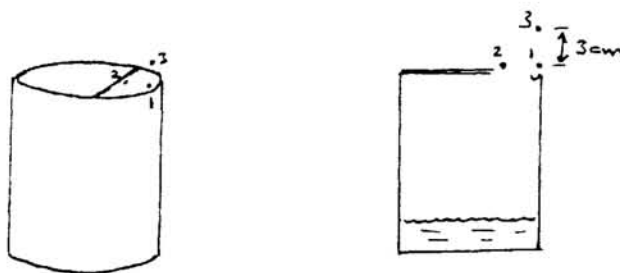


figure 28 solvent vapour monitoring points

The models were sequentially removed from the room temperature (21°) water bath and placed 'upwind' of the experiment so that no interferences could occur. The photograph below shows the DVA probe approaching position '3' above model D. The DVA scale reads 20ppm toluene. The bubbler and extraction are on.

A table showing the results for each model is shown below. The solvent background near the tin position was 80ppm.

<u>model</u>	<u>position</u>		
	<u>1</u>	<u>2</u>	<u>3</u>
A	500	400	150
B	>1000	>1000	1000
C	>1000	>1000	80
D	>1000	>1000	80-300
E	80	80	>1000

table 20 solvent vapour (ppm) at monitoring points

The toluene vapour concentration across the lid aperture was greater for C and D than for A or E. The slow movement

of air into the tin for A and the 'lid' on C account for this. The solvent vapours above B were high but a vertical gradient existed.

The important results are those at position '3', corresponding to an operator's breathing zone. Greater protection was afforded by C and D than A, though the low (0.1m/s) face velocity was disrupted when the laboratory door opened and a cross draft allowed a momentary rise to 300ppm. The concentration at position '1' and '2' above E were low but since air was being displaced by the bubbler, the level at '3' was high.



A STANDARD HOOD FOR MIXERS

A robust hood design is presented which will work, can fit most mixers and will allow loading of the mixers from 60 cm wide bags and all mobile vessels. 200 litre drums should be pumped into the mixer or a funnel used. The design is intended to minimise evaporation losses and warm air losses in winter.

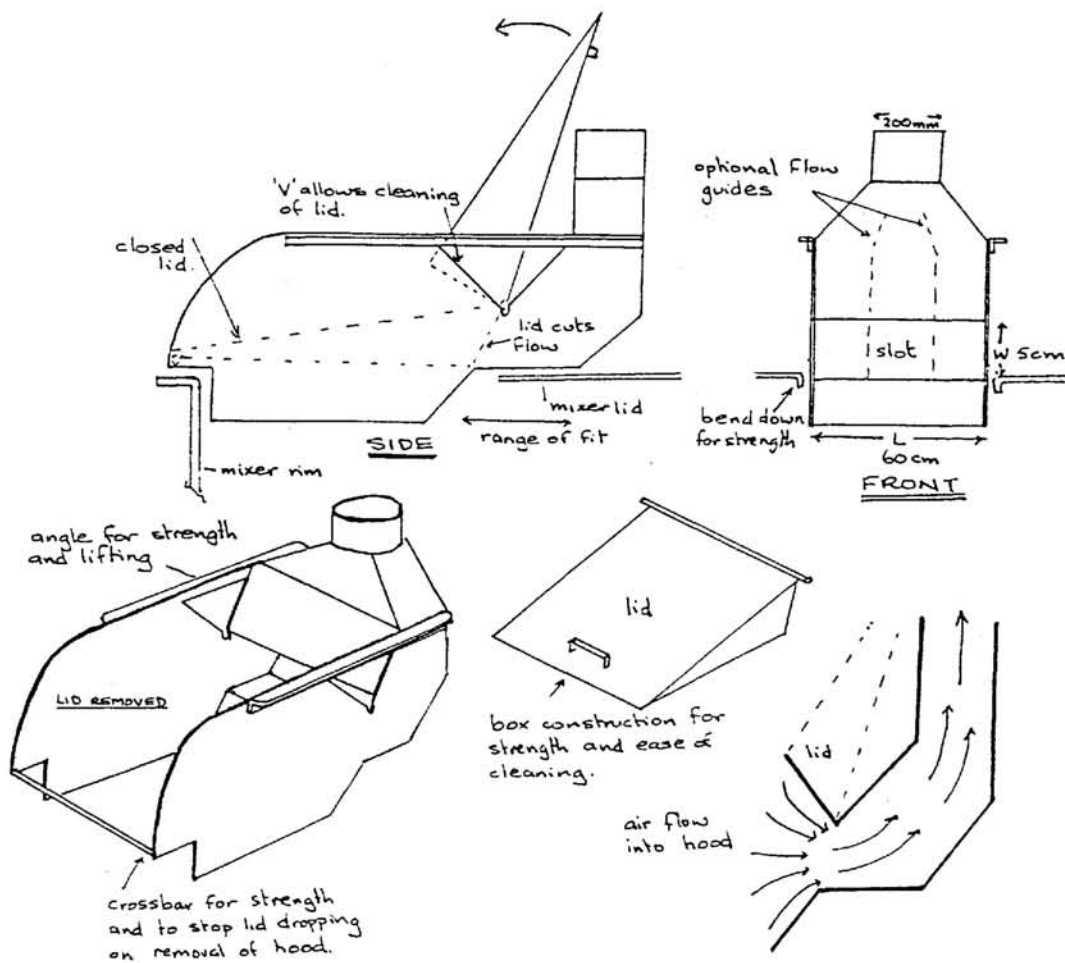


figure 29 standard hood design

The design will produce a capture velocity of 0.5m/s at the rim of a mixer and requires 0.5m³/s to operate. Connection to a main duct must be by 200mm, smooth ducting, but it may be flexible and curves must be smooth.

CALCULATIONS

$$\begin{aligned}\text{Slot aspect ratio} &= 0.05/0.6 \\ &= 0.08 \quad (\ll 2)\end{aligned}$$

The air flow required is given by

$$Q = 2.6 \times L \times v \times X \quad (8)$$

where

$$\begin{aligned}L &= 0.6\text{m, length of slot} \\ v &= 0.5\text{m/s, capture velocity} \\ X &= 0.6\text{m, distance hood to mixer rim} \\ Q &= 0.468 \text{ m}^3/\text{s}\end{aligned}$$

$$\begin{aligned}\text{Slot face velocity} &= Q/A \\ &= 0.468/0.030 \\ &= 15.6 \text{ m/s}\end{aligned}$$

If flange angle θ is 90 then

$$K \text{ entry} = 0.26 \quad (7)$$

Assume $K \text{ hood} = 0.4$ because of upward bend.

The smoother the upward bend, the more efficient the hood will be, hence the chamfers.

DUCT DIAMETERS

Consider two duct diameters, 3m long to a main duct.

Size(mm)	Area(m ²)	L(m)	\bar{v} (m/s)	Pv(Pa)	q(Pa/m)	Ps total(Pa)
150	0.0176	3	26.6	405	75	390
200	0.0314	3	14.9	133	18	110

table 21 connecting ducting and smooth bends (6)

where g = pressure drop per meter

P_s total = hood and duct pressure loss

$$= (0.4 \times P_v) + (3 \times g)$$

(assuming smooth branch duct and smooth bends)

If the hoods were installed for mixers 262 to 271 using existing fan and main ducting, then the existing fan could only properly operate one hood at a time with 150mm connecting ducting. Since there is a noted tendency to leave lids open, the larger diameter connecting ducting is suggested. The main duct should then be resized, assuming (say) four hoods and a total flow of $2\text{m}^3/\text{s}$. This would involve extending the 300mm section of the duct the remaining length of the run.

It would be possible to extend the main duct further, to serve mixers 272 and 273 at the end of the room. These mixers have no extraction.

If the hoods on 270, 271, 272 and 273 were 'on', the system could cope. The schematic is shown below.

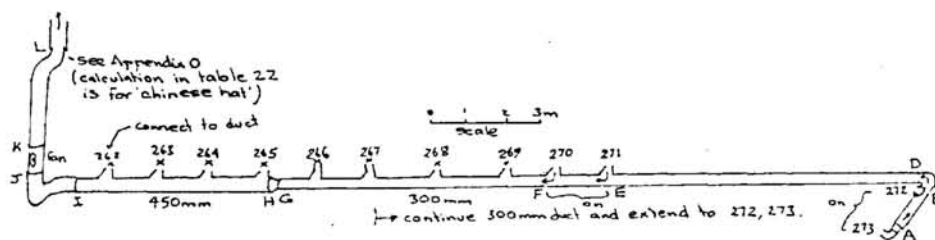


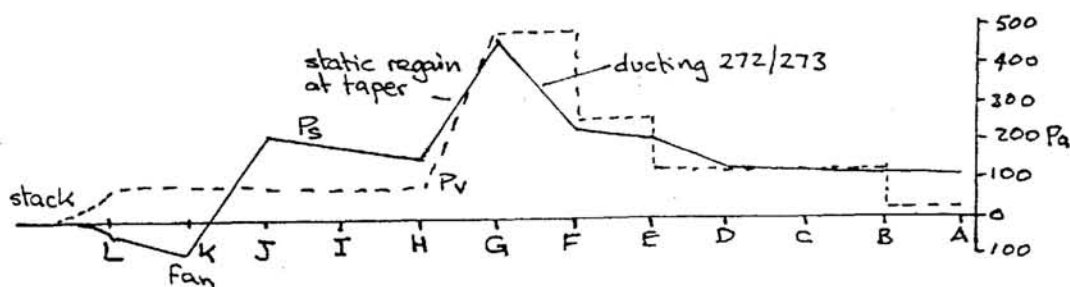
figure 30 new hoods, 4 hoods 'on'

This is backed by the calculations in the table on the next page.

	size	length	Q	g	k	\bar{v}	P_v	P_s	P_s Total
	(mm)	(m)	(m ³ /s)	(Pa/m)		(m/s)	(Pa)	(Pa)	(Pa)
A	300	branch	.5				30	110	110
AB	300	2	.5	2		7.07	30	4	114
BC	300	zero	1.0			14.1	120		
CD	300	bend	1.0		0.15	14.1	120	18	132
DE	300	10	1.0	8		14.1	120	80	212
EF	300	1.5	1.5	17		21.2	270	25	237
FG	300	8	2.0	30		28.3	480	240	477
GH	300/450		2.0		0.65			-312	165
HI	450	6	2.0	4		12.6	95	24	189
IJ	450	bend x2	2.0		0.25	12.6	95	24	213
JK	450	fan	2.0						
KL	450	2	2.0	4		12.6	95	8	

table 22 hood 270/273 calculations

This may be represented graphically.

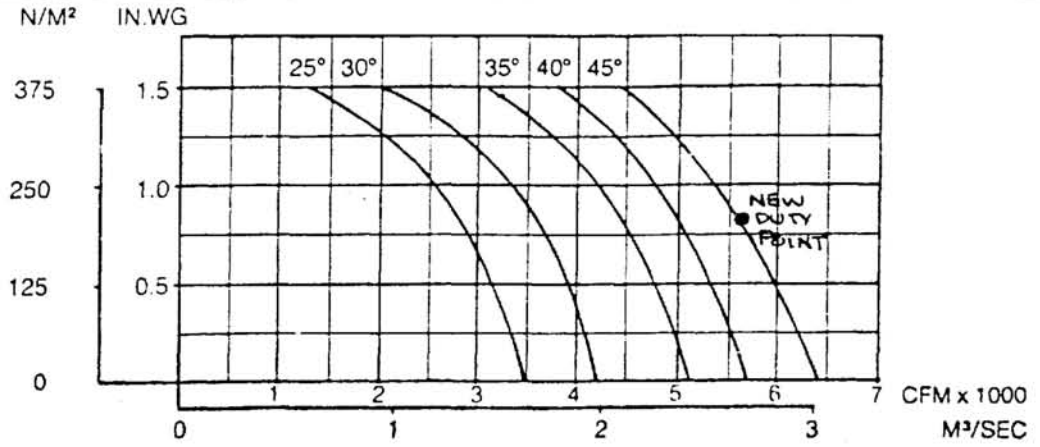
figure 31 P_s and P_v , mixer hoods 270/273

The static pressure regain at the gradual enlargement from 300 to 450 mm is important since it compensates for the losses in the long duct between mixers 272 and 271.

This produces a flow which can easily be handled by the fan and ducting with some allowance for leaks in hoods which are

off.

40 CM DIA, 8 BLADE, 2900 RPM



	BLADE ANGLE	25°	30°	35°	40°	45°
2900 RPM	PEAK HP	0.9	1.4	1.9	2.3	2.8
	dBA AT 3 x DIA's	75	77	80	83	85

figure 32 new fan duty point

PUSH PULL HOOD DESIGN

The typical extraction hood on top of a mixer in the factory is a gridded box at each side of the mixer. The hood would need an extremely powerful fan to extract efficiently the 1-2m distance across the opening. This large volume of air would dramatically increase heat losses in winter and solvent vapour losses. An alternative approach is to use a jet of air to assist the movement of air over a distance of a meter or more. The air volume extracted for the same performance is far less. The design for the hood below was developed from observations of a push-pull system on a chrome plating bath and from Industrial Ventilation (8).

For the push part of the system a metre of 37mm water pipe with 3mm holes at 150mm centres, capped at one end and fitted with a compressed air line was used. This approximated system was seen on a chrome plating bath where 25mm plastic pipe was used. The larger pipe diameter was used to ensure a more even pressure distribution.

A spread of 10° of the air jet was assumed in calculating the width of the hood slot. The length of the hood slot was determined by the mixer.

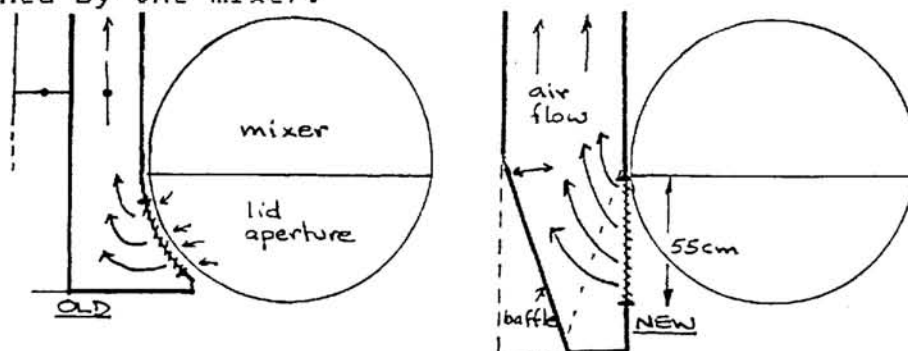


figure 33 hood design

The push-pull separation was 124cm in this case giving a slot width of $124 \tan 10^\circ = 22\text{cm}$

The rim of the mixer was 5cm above the deck and the hood width was determined by the spacing between mixers. It was felt that a 15cm flange built into the hood volume would help even the flow across the hood. Since the longer slot and flange made the hood stick out nearly 30cm further than the old hood, it was not curved around the mixer in order not to restrict access by 'mobiles'.

A further feature of the hood was that it only had one baffle to serve two mixers. The baffle was large and gave a smoother entry into the duct. Since the air flow through the fan was far less than its design flow, it was actually desirable not to be able to cut off the flow when another mixer was in use.

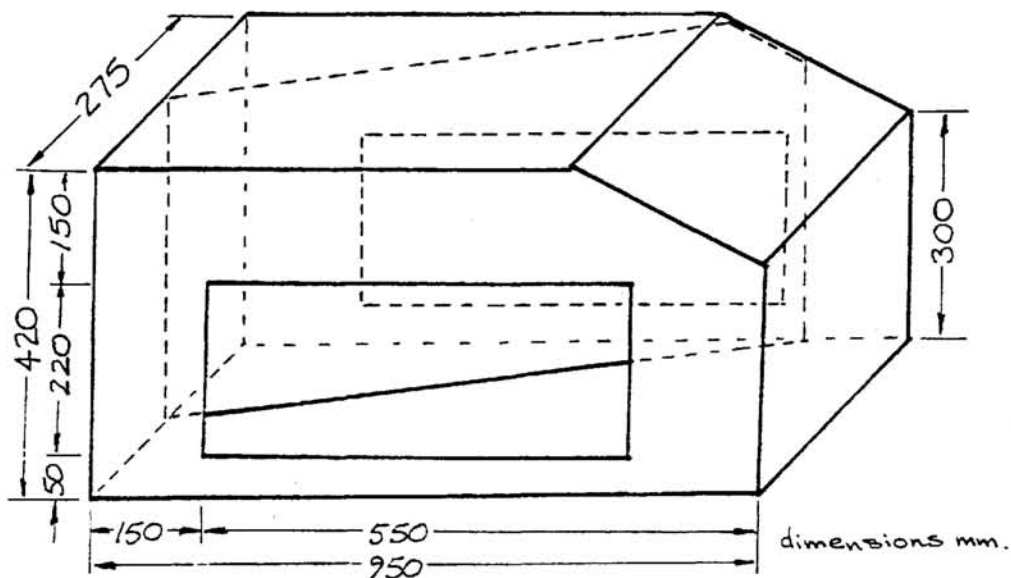


figure 34 new hood dimensions (mm)

Construction of the prototype hood was from 3mm hardboard held together with packaging tape.

It was not possible to directly measure the push manifold air flow. A formula (6) for air flow through an orifice was used.

$$Q = a \times e \times P_i / 4 \times d^2 \times \sqrt{2 \times P_s / \rho}$$

where

$a = 0.6$, flow coefficient

$e = 1.0$, expansibility factor for $P_s < 1000\text{Pa}$

$P_i = 3.14159$

$d = 0.03\text{m}$, orifice size

$P_s = 500\text{Pa}$ (nominally), manifold static pressure

$\rho = 1.2\text{kg/m}^3$, air density

giving $Q = 0.07 \text{ m}^3/\text{s}$ for six holes

also $v = Q / \text{area of orifice}$

$$= 17.3\text{m/s}$$

The design of a push pull hood (8) required the following 'entrainment factors' to be satisfied:

<u>separation (m)</u>	<u>entrainment factor</u>
0-3	2.0
3-5	1.4
5-8	1.0
>8	0.7

table 23 entrainment factors for push pull hoods

The old hood, once cleaned (table 12) could easily entrain the required volume of $2 \times 0.07 = 0.14 \text{ m}^3/\text{s}$. The high air velocity (17m/s) at a low pressure (500Pa) greatly exceeds the capture velocity requirements (about 0.5m/s).

VENTILATION COSTS

There are a number of direct and indirect costs associated with mechanical ventilation in a paint factory.

Direct costs include solvent losses, heat losses and running costs. Other costs not investigated are capital costs and maintenance (which appears only to be breakdown).

Indirect costs include the extra effort and time related to achieving the desired quality of the finished product in the face of indeterminate evaporation.

Consider only the first three direct costs:

1) SOLVENT LOSSES

The following data for 10 months to May 1986 were provided by the company for most solvents.

Usage (A)	in pounds(lb)
Density (B)	in pounds per gallon
Cost (C)	in pence per pound
Evaporation (D)	relative to butyl acetate

If the evaporation, as estimated by the factory production manager, averages 6% then the annual weighted cost of evaporation is

$$\begin{aligned} & 10/12 \times 0.01 \times 0.06 \times \Sigma(A/B) \times \Sigma(A \times C \times D) / \Sigma(A \times D/B) \\ & = \underline{\underline{£67,000}} \end{aligned}$$

Compare this with an annual outlay of about £1.15 million on solvents. (5.8%)

Similarly, the weighted value of the vapour (as liquid) is

$$\begin{aligned} & \Sigma(A \times C \times D) / \Sigma(A \times D/B) / 4.54 \\ & = 15.1p/litre \quad (\text{toluene } 16.8p/litre) \end{aligned}$$

The evaporation experiment demonstrated the effect of

extraction, especially hood extraction. Most evaporation would cease with good lids on all vessels and appropriate extraction when the lids are open. Assume 90% of the present losses are due to lack of lids and lid extraction.

$$\begin{aligned} \text{ie Cost} &= 0.9 \times 67,000 \\ &= \underline{\underline{\pounds 52,000}} \end{aligned}$$

2) HEATING LOSSES

Assume 0.2 m /s per extraction system
and 50 extraction systems

$$\begin{aligned} \text{Then, annual volume exhausted} &= 0.2 \times 50 \times 60 \times 2000 \\ &= 1.2 \times 10^6 \text{ m}^3 \end{aligned}$$

Thames Valley degree day figures are used (15):

$$\text{Degree Days} = 1187^\circ\text{C.days}$$

Consider all heating if compressed to 8 hours.

$$\begin{aligned} \text{Total wattage} &= 1.2 \times 10^6 \times 1.2 \times 1187/365 \times 1.02 \\ &= \underline{\underline{4.8 \text{ MW}}} \end{aligned}$$

Company annual figures for heating oil are $\pounds 73,000$.

Assume 200 second oil at 15.1 p/l and 38.2 MJ/l
(ie 4.83×10^6 litres)

If oil is 38.2 MJ/l then total energy is 1.85×10^8 MJ
or $1.85 \times 10^8 / 60 \times 60 \times 8 = \underline{\underline{6.4 \text{ MW}}}$

The loss estimate may be fortuitously below the actual cost since the average extraction flow estimated was crude, and the decision for heating was determined subjectively and the degree-day approach ignored wind chill. Other factors such as actual factory temperatures, hours extracted and heated, and uniformity of heating and extraction were unknown.

This estimate gives a cost of $4.8/6.4 \times 73,000 = \underline{\underline{\pounds 55,000}}$

3) RUNNING COSTS

Use a figure of 3.350 p/kW.hr

If there are 50 fans each using 2 kW for 2000 hours/year

Then annual cost = $0.03350 \times 50 \times 2 \times 2000$

= £7000

In summary, the direct losses due to poor lidding and lid extraction are estimated as:

solvent losses	52,000
heat losses	55,000
running cost of fans	7,000
	<u>£104,000</u>

The exact contribution by each of these is arguable, but the estimate is felt reasonable.

DIFFUSIVE SAMPLERS

Fourteen TENAX diffusive samplers were exposed for a whole shift, around the factory, on May 29.

Eight were worn by workers (personal samplers) to estimate their individual solvent vapour exposure, and six used at a fixed position (area samplers) to estimate the time weighted average solvent vapour concentrations.

One area sampler (from MILL 2) was misplaced until after the analytical run and one personal sampler (from the colour development laboratory) was dropped into a cup of paint and the results are highly suspect, though only the sealed end of the tube was covered. Perhaps the wearer cleaned it with a solvent soaked rag.

A control sampler - uncapped and recapped immediately - was also used.

Analysis was by thermal desorption and capillary gas chromatography. The traces are attached, paired worker and workplace, where appropriate. The analytical parameters were stored as a file, 'METHOD 6 DB BP 10 12PS.

The technique was not fully developed since the diffusive uptake rate (14) was not determined for any solvent and the retention times only determined for some important marker solvents (MEK, toluene and p,m,o xylenes).

Samples were taken in the following rooms:

- 1 : can filling operation (thinners) from mixer 262 in MILL 2
- 2 : general mill hand in MILL 2
- 3 : ball mills in MILL 3
- 4 : can filling operation (paint) from mixer 304 in MIX 2
- 5 : operator in the HSD
- 6 : CLEANING SHED
- 7 : CLEANING SHED
- 8 : COLOUR DEVELOPMENT LABORATORY (CDL)

The results, excluding the CDL results, are compared below graphically for one component, toluene.

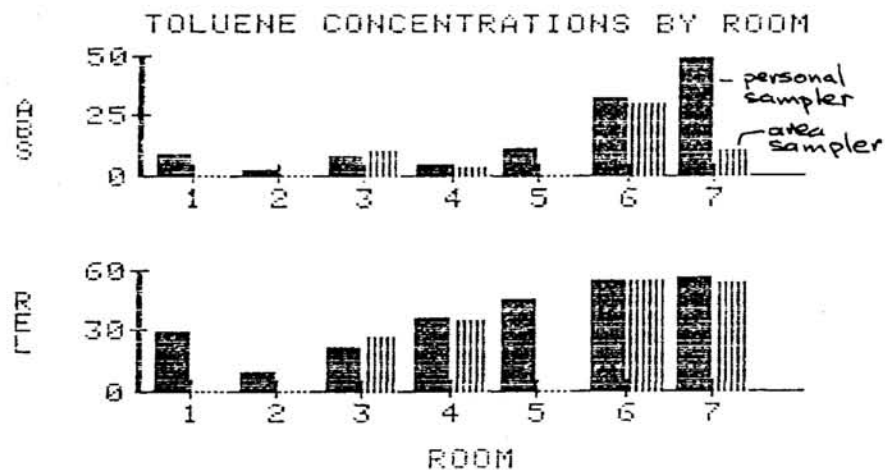


figure 35 TENAX diffusive sampler results

The upper plot labelled ABS is the area under the chromatographic peak for toluene. Scaled for diffusive uptake rate and exposure time the graph would represent the time weighted average vapour concentration of toluene. Both personal and area samples in the CLEANING SHED indicate somewhat higher vapour concentrations than other parts of the factory, though one area sampler in the CLEANING SHED

showed a much lower concentration than the others. This one was mounted on a wall fan grille in a less used part of the room. In general there was exceedingly good agreement between personal and area samples.

The lower plot labelled 'REL' is the area under the chromatographic peak for toluene as percentage of all the peak areas for that sample. It roughly corresponds to the fraction of toluene in the sample. Where samples are paired worker and workplace, the correlation is close and the fraction of toluene is between 10 and 50%. A figure of 50% correlated well with analysis of a November 1985 report (2) of the factory solvent vapour concentrations.

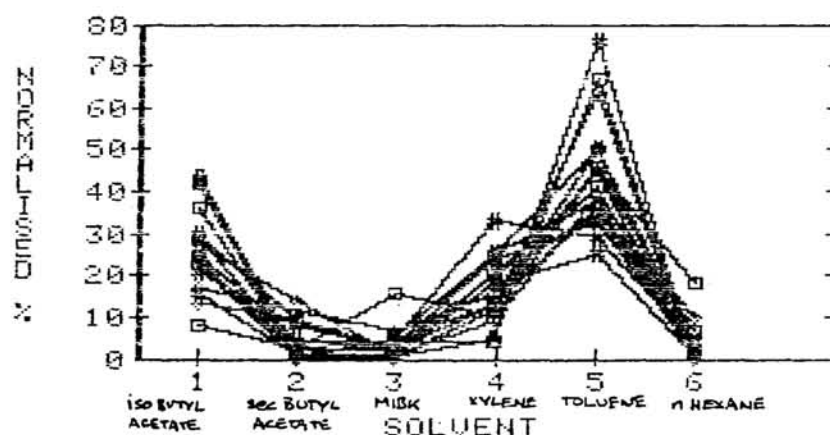


figure 36 analysis of LSH&TM 1985 data (2)

Here relative concentrations of six key solvents from pumped TENAX tubes are presented. A figure of 40% (25-75%) toluene shows toluene to be a reasonable marker solvent if only one solvent were to be analysed. The cross reactivity of xylene and toluene with DRAGER tubes would enable a toluene or xylene estimation, perhaps doubled, to be a reasonable spot measurement for a mixed solvent atmosphere. Attempts to pick a marker solvent from key alcohols from pumped tubes in the same study did not show a dominant

solvent.

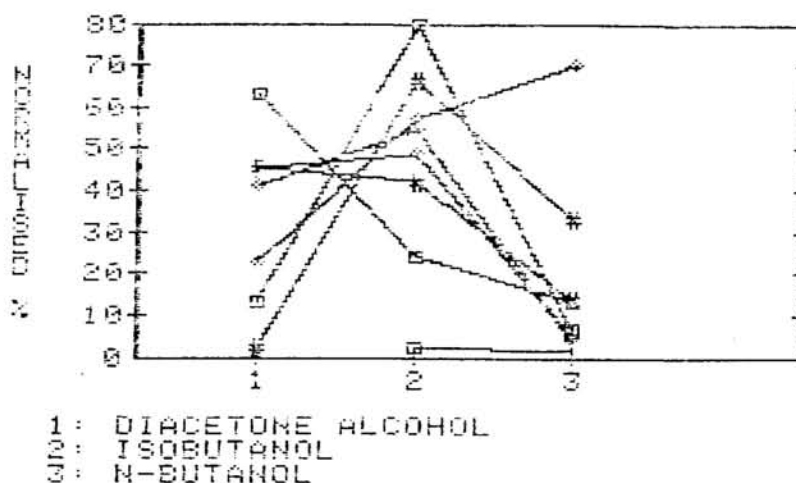


figure 37 alcohol data from LSH&TM 1985 (2)

The importance of this survey was to give some indication of the range and relative concentrations of solvents when using a non-specific instrument like an OVA to measure organic vapours (though a chromatography option is available for the OVA which will give a separation of solvents). The relative response of the OVA to different solvents (Appendix A) and the different exposure limits(4) make the value of the OVA in a mixed solvent atmosphere limited unless more is known about the mixture.

USING AN ADSORPTION TUBE

Diffusive Sampling

The tube is removed from storage, the pen clip attached and the upper storage cap replaced with a gauze diffusion cap. Organic vapours are now being adsorbed from the environment and the tube is immediately clipped to the breast pocket or lapel of the operator. Alternatively, to monitor the overall environmental level during a known period, the tube can be placed in a stationary position in a particular work area. Appropriate information on tube number, operator identity, site of exposure and exact moment of issue (to the nearest 5 minutes) should be recorded. When the period of exposure is complete (this is normally one shift period but can vary from 30 minutes to 24 hours), the tube is re-capped with the storage cap and sent for analysis.

Diffusive sampling is the more convenient method of sampling because no pumps need to be carried. It is used for most applications, the only exceptions being those listed below, where it is necessary to use pumped tube sampling.

Pumped Tube Sampling

The tube is unsealed at both ends, a diffusion cap fitted to the upper end (above the pen clip fixing) and the pump inlet tube fitted to the lower end. The calibrated pump is switched on for the exposure period. The calibration factor for the pump must also be recorded as this is used in the subsequent calculation of component uptake. This form of sampling is used when the period available for sampling is limited or the concentration of the component fluctuates rapidly. After the exposure period is complete the number of pump strokes used is recorded for each tube, the tubes are sealed with storage caps and sent to the laboratory for analysis.

Analysis of Sample

At the end of the monitoring period, the tube is sealed and sent for analysis. Unlike charcoal badge monitoring systems, the adsorbent is not removed from the tube for analysis, but thermally desorbed directly into the gas chromatograph or other analytical system.

The desorbed tube is now completely clean and without further treatment may be re-used for sample collection.

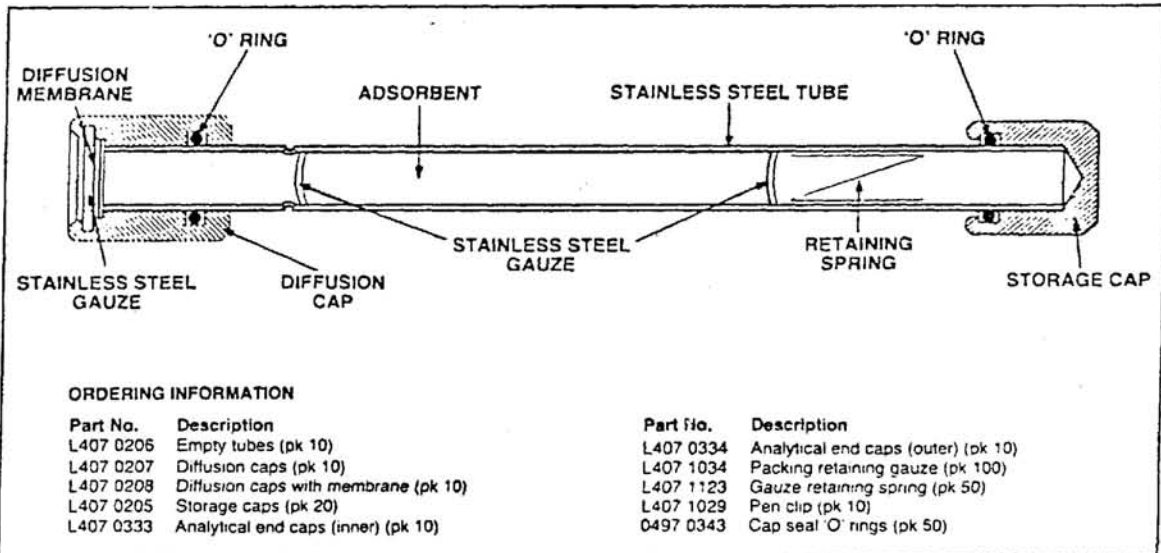
Sample tubes may be desorbed manually using single or two stage desorption. However, with the advent of the Perkin-Elmer ATD 50 microprocessor controlled Automatic Thermal Desorption system, up to 50 sample tubes can be processed automatically by single or two stage desorption.

All tubes and end caps are completely interchangeable and may be reused repeatedly without deterioration.

When necessary after prolonged use, tube seals may be replaced without the need to purchase complete fittings.

Special analytical end caps are fitted when the tubes are to be analysed using the ATD 50. These self-sealing caps ensure that no sample is lost or contaminated by further exposure of the tube either before or during analysis.

Adsorption tubes are supplied empty, with the diffusion-end gauze already positioned, so that the diffusion path length is precisely set. The tubes are easy to pack, and a wide range of adsorbents suitable for all applications is available.



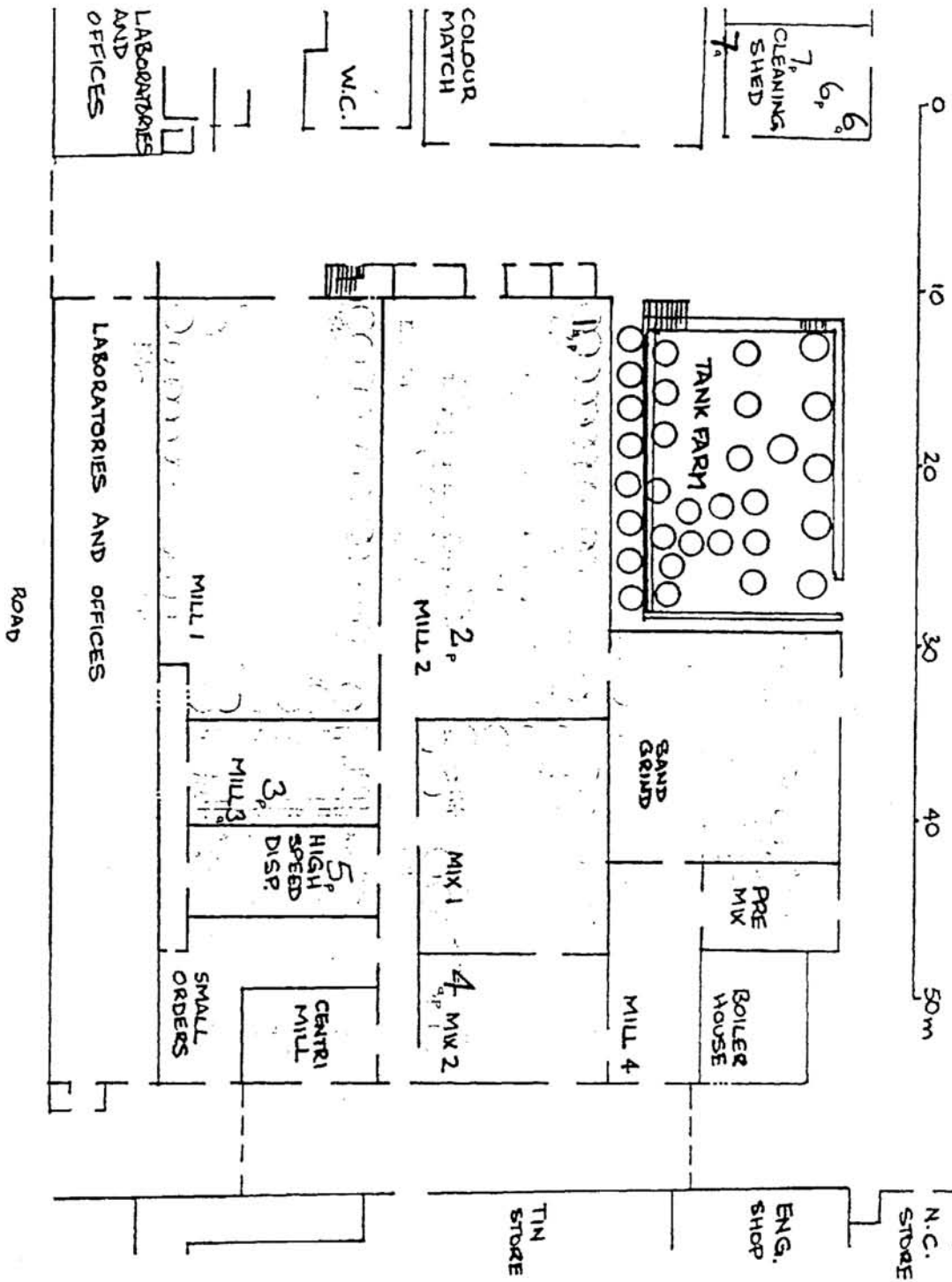
PERKIN-ELMER

Perkin-Elmer Limited, Beaconsfield, Buckinghamshire HP9 1QA, England
 Instrument Division, Perkin-Elmer Corporation, Norwalk, CT 06856, USA
 Oakbrook Instruments Division, 2000 York Road, Oak Brook, IL 60521, USA
 Bodenseewerk Perkin-Elmer & Co. GmbH, D-7770 Überlingen, Bundesrepublik Deutschland

K3-11-02158

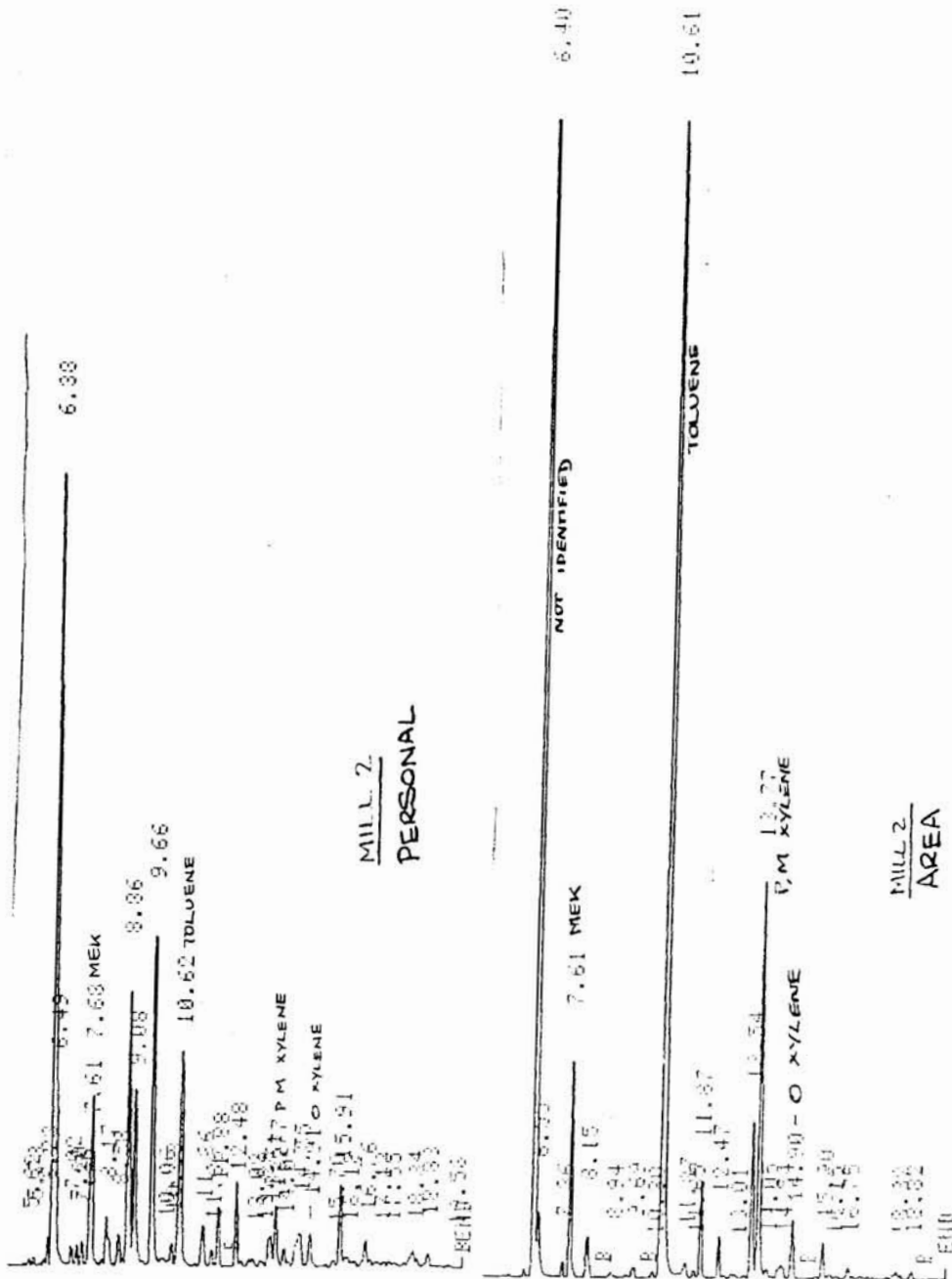
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DIFFUSIVE SAMPLER LOCATIONS

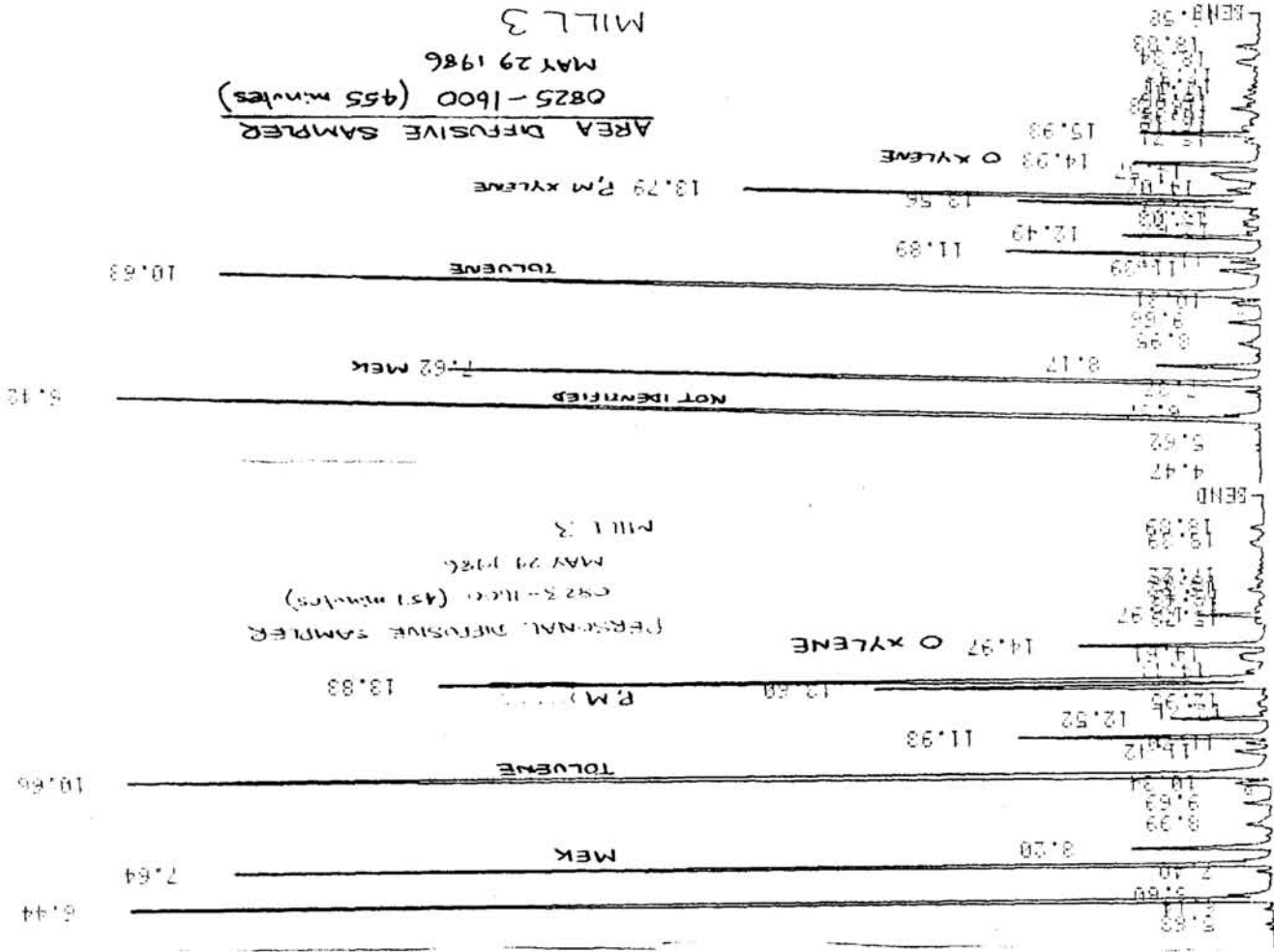


DIFFUSIVE SAMPLERS
MAY 29 1985

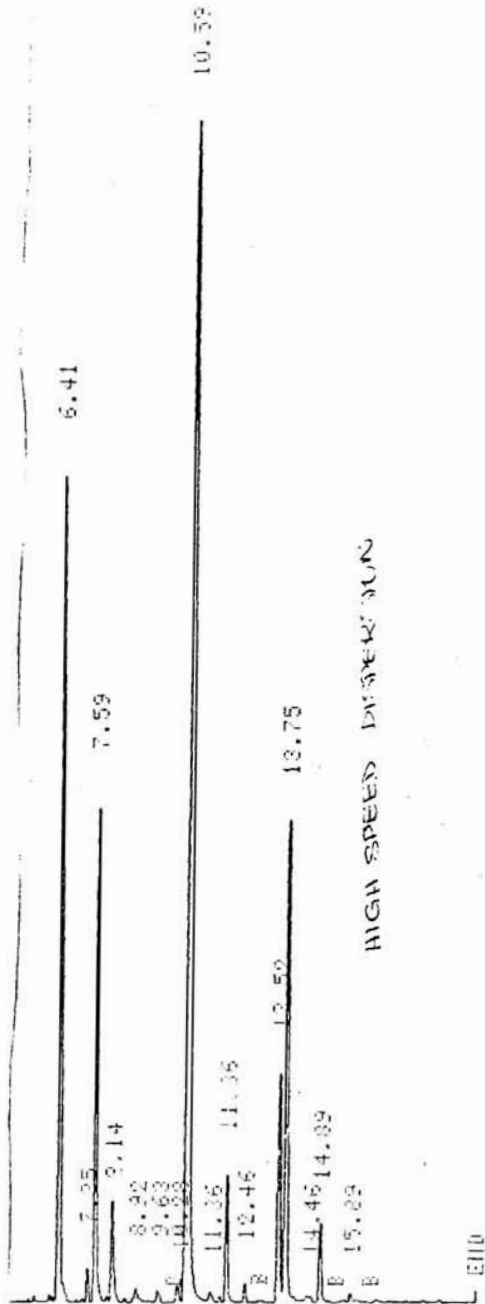
MILL 2



MILL 3

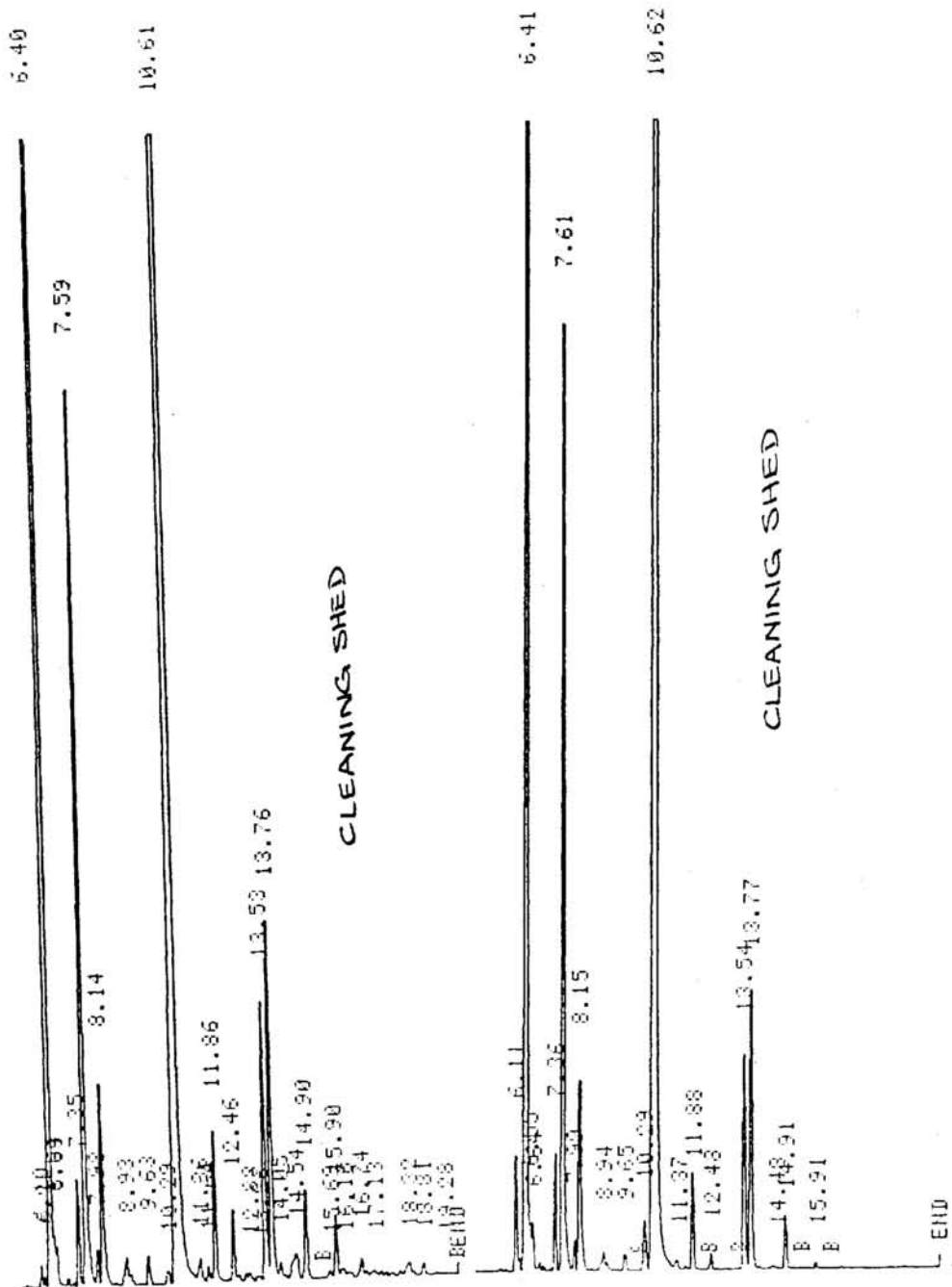


HSD

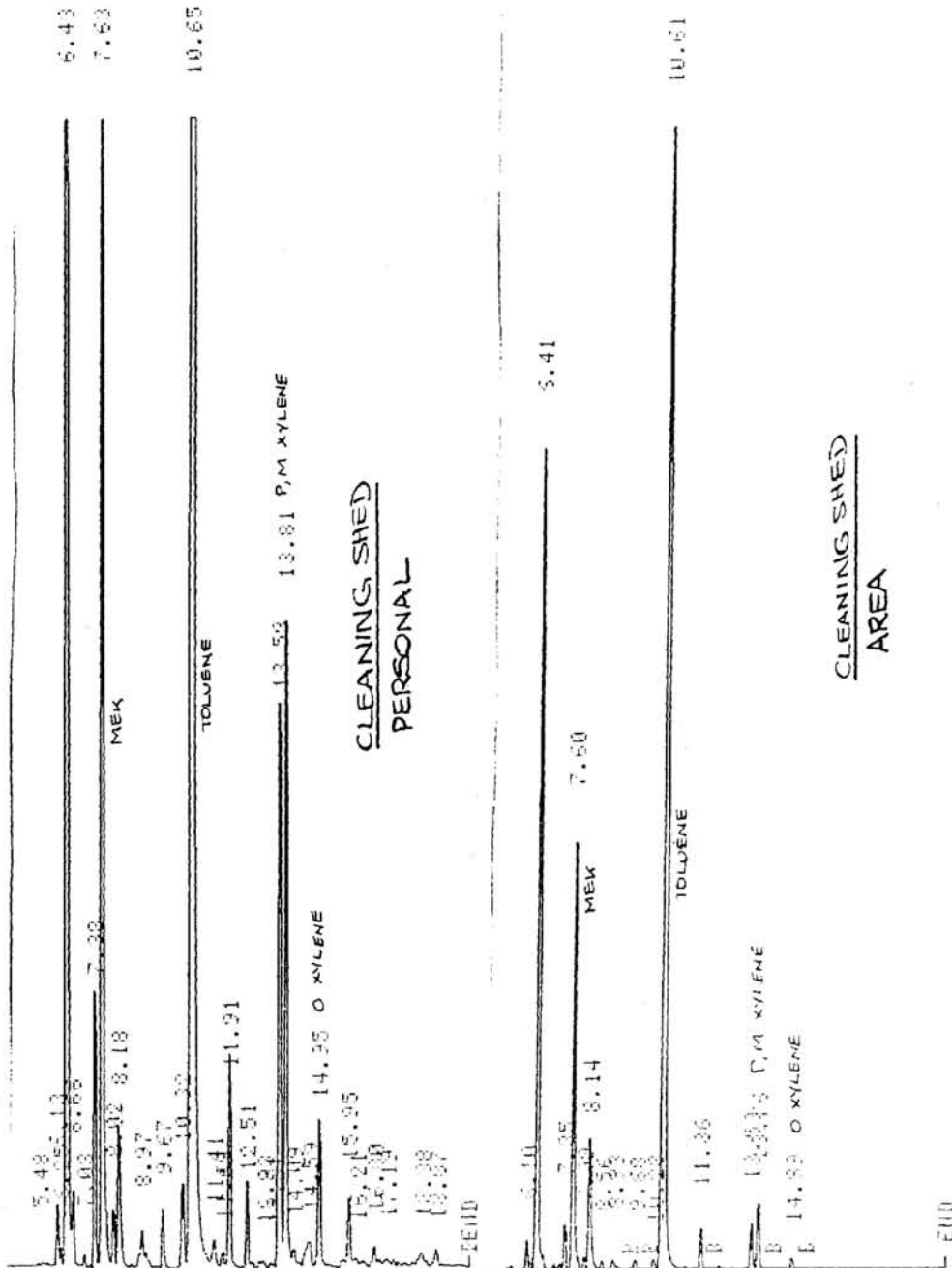


HIGH SPEED DISPERSION

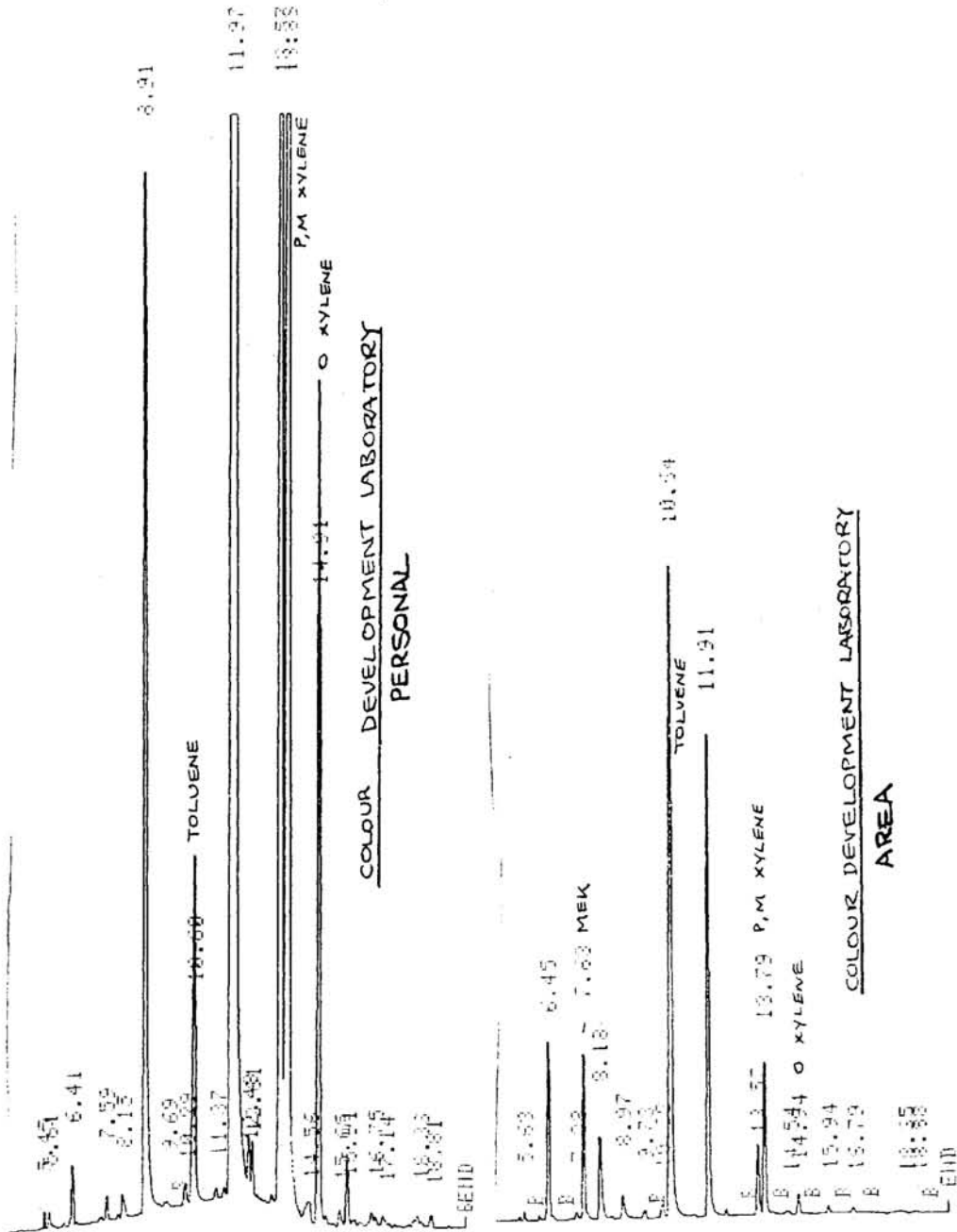
CLEANING SHED



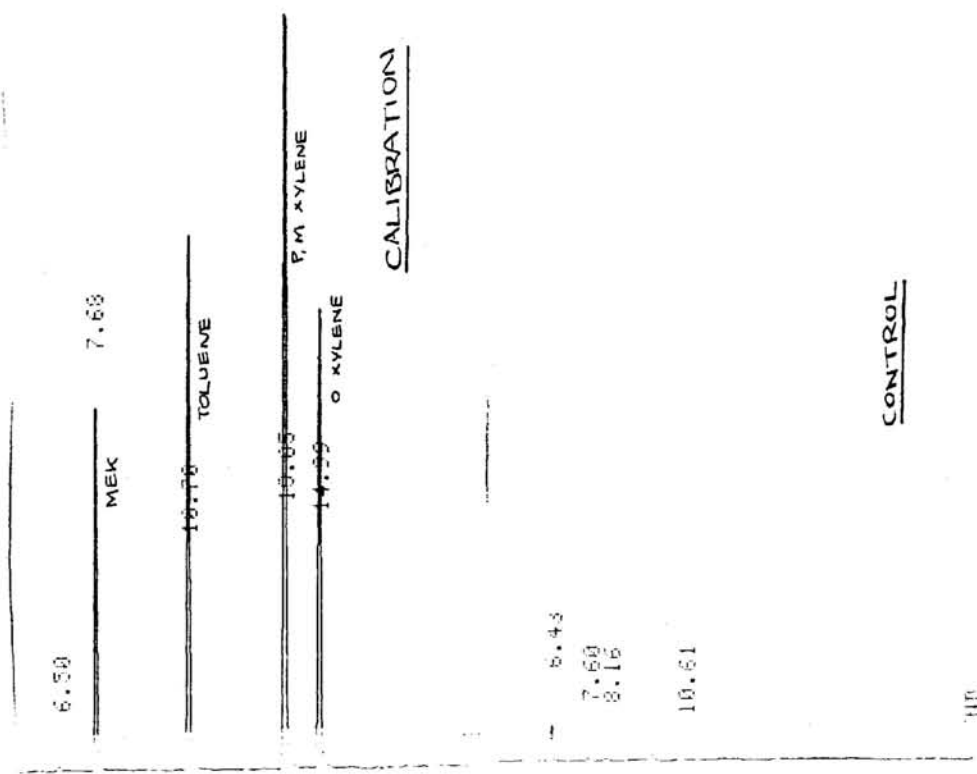
CLEANING SHED



CDL



QC



APPENDIX INOISE

A brief noise survey was done with a CEL 224 noise analyser (serial number 020050). The meter was checked a day before the survey and gave 89.9dBA for 90.0dBA.

A sheet is attached showing the noise levels around the section of the factory being investigated. Numerous filling operations were in progress, ventilation on and a number of ball mills on as indicated by a tick.

The ball mills 409 and 410 in MILL 4 were reported noisy but were not used during the investigation period. The mixer 273 in MILL 2 was noted to be noisy (subjectively > 90 dBA) after the survey. Noisy gears and lack of a cover on the gear train would account for this.

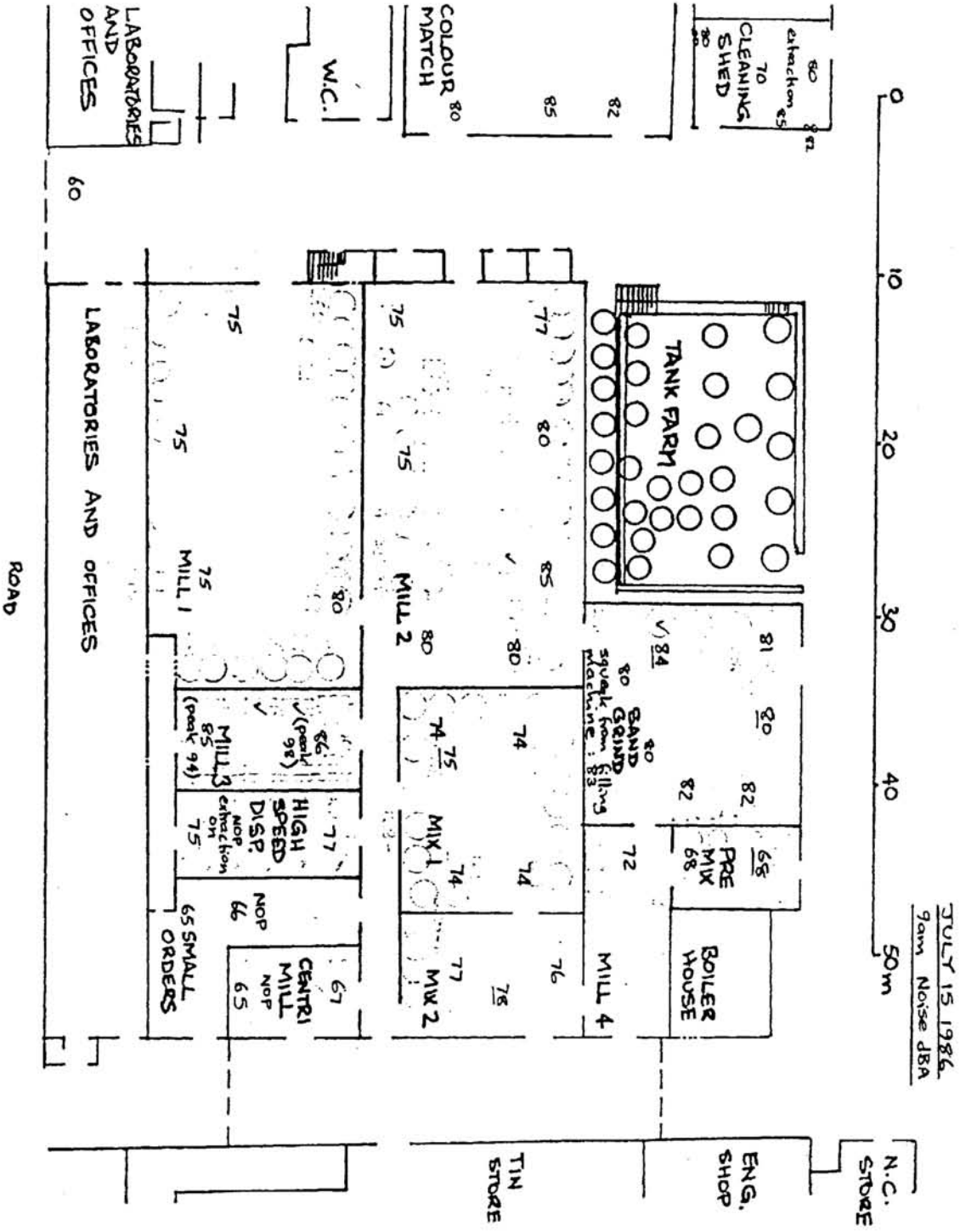
The filling machines and hoists are all pneumatically operated and their exhausts have no diffusers, so add several dB to the noise. Diffusers cost pence and should be considered.

MILL 3 was the noisiest room measured but their operation is intermittent. Ear muffs could be provided for the operator during these times.

A noise dose over 80dBA would not be expected on the basis of this survey and subjective observations.

An exception was two contractors who were seen cleaning a mixer with a chipping hammer. The noise inside the mixers was intense. They were using cotton wool as an ear plug for hearing protection, which would give a false impression of protection.

NOISE



FACTORY DETAIL

NOTATION

○ ○ : mixers or tanks of 2500 to 11000 litre capacity

▢ : ball mill

* : 500 litre mixer on wheels

⊠ : bead mill or sand grinding mill

○ — □ : can filling machines

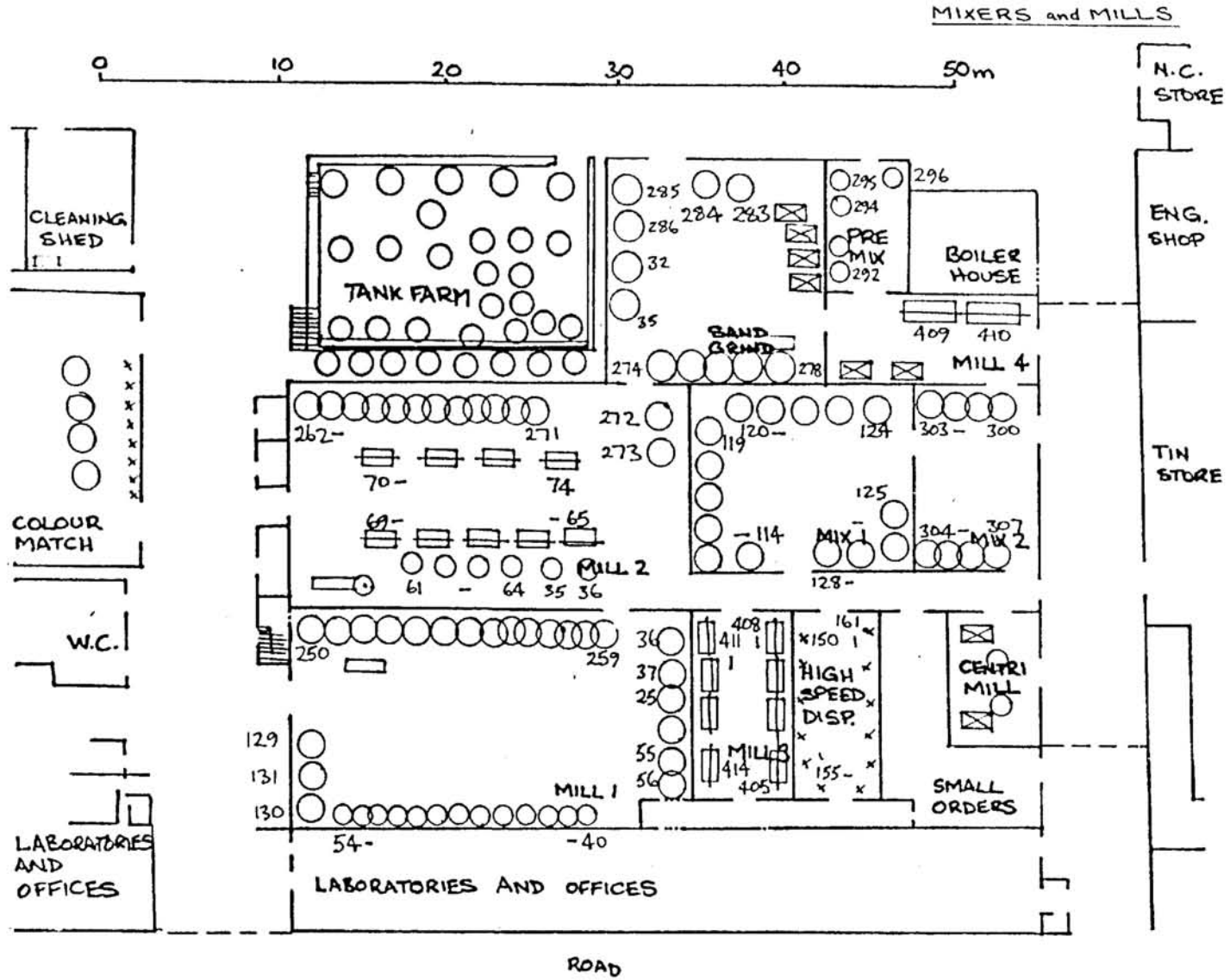
□ : trough in cleaning shed

xxx : number of mixer or ball mill

— : fire door - spring loaded

ND : no door in doorway

NC : door normally closed



SOLVENTS	CODE	Kg
PURE GUM TURPENTINE	1S-S102	11
TETRALINE	1S-S107	2377
PINE OIL	1S-S108	90
XYLENE	1S-S11	453090
DI-ACETONE ALCOHOL	1S-S111	46913
REGULAR KEROSENE	1S-S114	600
ETHYL ACETATE	1S-S12	19615
PHOSPHORIC ACID	1S-S126	1964
S.B.P. NO.2	1S-S130	94476
ISO-BUTYL ACETATE	1S-S135	73812
METHYL OXITOL ACETATE	1S-S139	920
ETHYLENE GLYCOL DI-ACETATE	1S-S141	?
SHELLSOL 'R'	1S-S142	8256
PENTOXONE	1S-S148	13
SHELLSOL 'A'	1S-S149	69497
METHYL AMYL ACETATE	1S-S150	?
RECOVERED SOLVENT	1S-S151	243350
SOLVESSO	1S-S154	5706
ISO-PROPYL ALCOHOL	1S-S155	90350
S.B.P.NO.3	1S-S17	61380
SHELLSOL T	1S-S170	2898
BENZYL ALCOHOL	1S-S176	?
HEXYL CELLOSOLVE	1S-S178	?
OCTANOL 2 ETHYL HEXONAL	1S-S186	88
D.I.B.K.	1S-S203	732
BUTYL GLYCOL ACETATE	1S-S207	172
ACETONE	1S-S21	701872
CARBITOL	1S-S215	?

<u>SOLVENTS</u>	<u>CODE</u>	<u>Kg</u>
IMSOL 'R'	1S-S228	3420
SOLVENT AW 240	1S-S230	15649
SOLVENT NLS 270	1S-S231	399640
N METHYL PYRROLIDONE	1S-S234	?
IMSOL PMA	1S-S239	2336
CYCLOHEXANONE	1S-S24	1490
SOLVENT NLS 128	1S-S240	685226
BUTYL ACETATE	1S-S3	200269
M.E.K.	1S-S31	301921
M.I.B.K.	1S-S38	509447
WHITE SPIRIT	1S-S40	11933
N BUTANOL	1S-S5	33835
ISOBUTYL ALCOHOL	1S-S58	158279
BUTYL OXITOL	1S-S59	63729
OXITOL	1S-S6	104320
TOLUENE	1S-S60	1542406
INDUSTRIAL METHYLATED SPIRIT	1S-S68	16218
OXITOL ACETATE	1S-S7	55307
S.B.P.NO.6	1S-S75	78488

In figure 38 the first peak is paint and covers most solvents. The second peak is thinners and gun wash on top of common paint solvents like toluene, xylene and acetone.

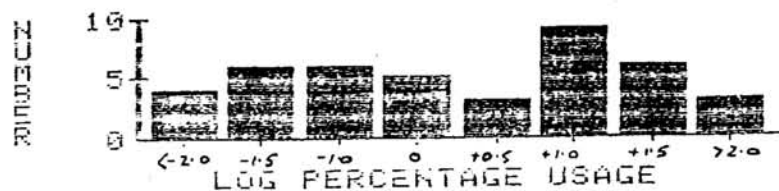


Figure 38 solvent usage

PRESSURE MONITORING POINTS

A static measuring point which could not catch on operators was needed. One based on rubber tubing and sheeting was developed, both materials being available in the factory. Approximately 40, 5cm squares of 3mm rubber gasket material were cut from a sheet using a metal guillotine. Holes were bored with a slightly undersize cork borer in the centres to take a 4cm length of 9mm laboratory rubber tubing.

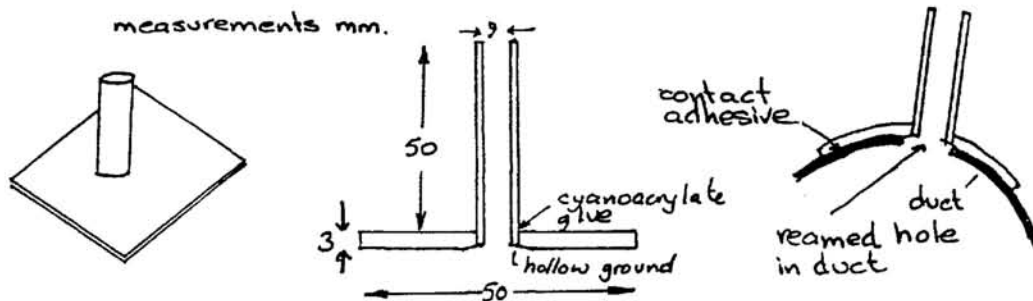


figure 39 static pressure measuring point

A cyanoacrylate glue was used to join the pieces once they had been cleaned with solvent. A destructive test on the unit failed in the rubber, proving the strength of the join.

A different type of bond was needed for the rubber to the extraction ducting. A contact adhesive was chosen, and batches of six affixed to a given system once the hole and glueing had been prepared.

For each point a 10mm hole was drilled with an airdrill in the duct, usually in a vertical face where internal debris would be expected to be least. Initial attempts to produce a smooth hole were unsatisfactory and subsequent holes were

drilled undersize and enlarged to 10mm with a tapered reamer. This produced a smooth hole almost free of burrs on the inside of the duct.

The surface of the duct was cleared back to a firm base, usually the galvanised metal, with a penknife and sandpaper and cleaned with solvent before the contact adhesive was applied.

To centre the unit over the hole when contact adhesive was ready on both surfaces a close fitting metal rod was inserted through the rubber tubing to serve as a locating pin, and the surfaces pushed together. The bond was left overnight to gain full strength.

It was possible to insert a 30cm pitot tube down the tube without damage. This allowed only two holes to be drilled at each monitoring point for horizontal and vertical pitot traverses, which would also double as the static monitoring point.

PITOT TRAVERSES

1) Attritor extraction

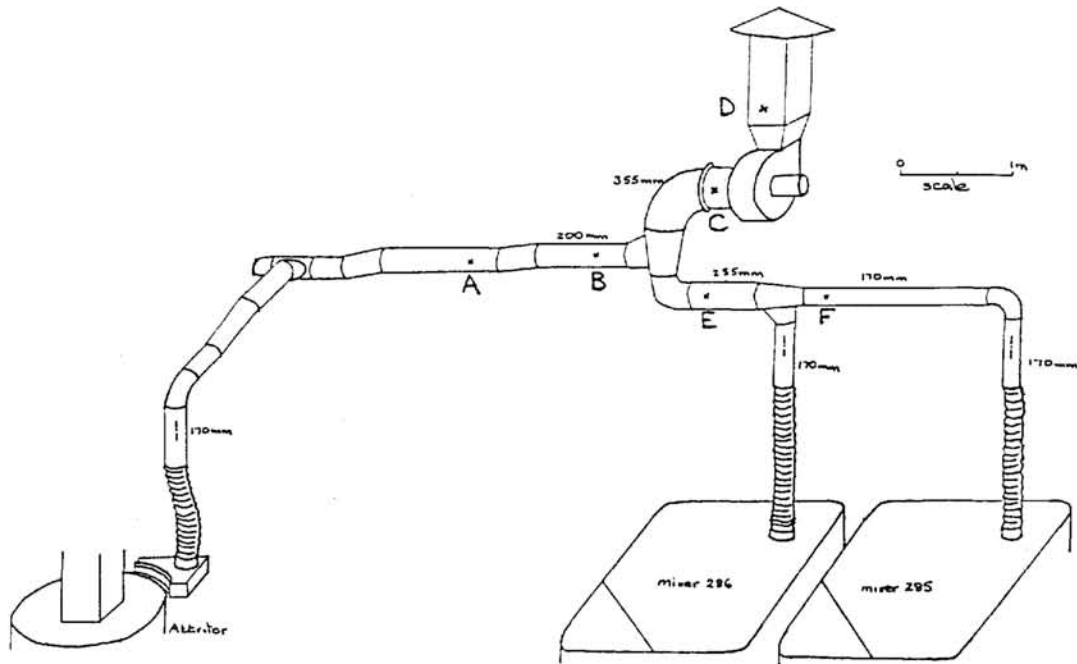
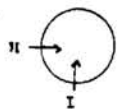


figure 40 Attritor extraction

In the tables below, imperial units are used except for the velocity calculation, since the pitot tubes were marked in inches and manometric in inches of water. All dampers were open unless otherwise indicated.

A:



	.25	.63	1.13	1.75	2.75	5.25	6.25	6.88	7.38	7.75	: 4
I	.20	.22	.26	.26	.26	.26	.26	.26	.26	.24	.26
II	.22	.26	.28	.29	.28	.29	.28	.26	.26	.22	.26

The traverses gave a mean velocity of 10.32 m/s

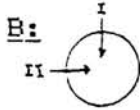
The centreline (4") gave a velocity of 10.41 m/s

A: Dampers E, F closed for this measurement only.

	.25	.63	1.13	1.75	2.75	5.25	6.25	6.88	7.38	7.75	: 4
I	.22	.24	.26	.27	.28	.26	.26	.25	.22	.20	.26
II	.17	.20	.20	.24	.24	.24	.26	.26	.26	.26	.25

The traverses gave a mean velocity of 10.02 m/s

The centreline (4") gave a velocity of 10.31 m/s

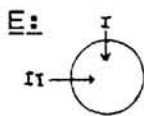


	.25	.63	1.13	1.75	2.75	5.25	6.25	6.88	7.38	7.75	: 4
I	.18	.25	.27	.28	.30	.30	.30	.30	.28	.24	.30
II	.20	.24	.26	.26	.30	.31	.31	.29	.27	.26	-

The traverses gave a mean velocity of 10.59 m/s

The centreline (4") gave a velocity of 11.18 m/s

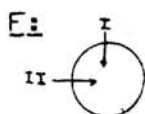
Compare these with A above 10.32 m/s



	.25	.68	1.50	2.25	3.38	6.68	7.75	8.50	9.13	9.75	: 5
I	.75	.85	.80	.65	.50	.50	.75	.85	.85	.60	.50
II	.50	.82	.96	.88	.60	.40	.48	.46	.46	.55	.40

The traverses gave a mean velocity of 16.34 m/s

The centreline (5") gave a velocity of 13.67 m/s



	.13	.68	1.00	1.68	2.38	4.68	5.38	6.00	6.38	6.88	: 3.5
I	.50	.60	.67	.68	.68	.75	.80	.77	.65	.60	-
II	.60	.74	.74	.71	.69	.69	.65	.67	.62	.58	-

The traverses gave a mean velocity of 16.68 m/s

No centreline velocity was recorded.

2) Premix extraction

The two tables below show the effect on flow of cleaning and upgrading a hood on this system.

- Old hood to B with grille cleaned

	Area(m ²)	Pv(Pa)	\bar{v} (m/s)	$Q=\bar{v}.A$ (m ³ /s)	Ps(Pa)
A	0.114	5.3	2.98	0.339	90
B	0.090	4.3	2.67	<u>0.240</u>	88
C	0.090				93
D	0.090	1.2	1.44	0.130	93
E	0.114	2.9	2.2	0.250	112.5

The flow through the fan is 0.589m³/s

- Hood to B removed

B	0.090	14.9	4.99	<u>0.450</u>	45
---	-------	------	------	--------------	----

- Old hood to B cleaned out

B	0.090	8.9	3.86	<u>0.347</u>	53
---	-------	-----	------	--------------	----

- New hood

B	0.121	12.36	4.54	<u>0.549</u>	50.0
---	-------	-------	------	--------------	------

table 24 PREMIX hood flow measurements

In summary:

hood	Ps(Pa)	face velocity(m/s)	flow(m ³ /s)
dirty grille	(est)112	(est)0.83	(est)0.026
cleaned grille	88	2.67	0.240
cleaned out	53	3.86	0.347
new hood	50	4.54	0.549

table 25 summary of PREMIX hood flow

INTERIM REPORT JUNE 1986

DAVID BROMWICH LSH&TM.

Work to date has been:

1. Reading of LSH&TM November 1985 report. (2)
2. Dissemination of draft project proposal:
 - assessment of work practices
 - ventilation studies
3. Surveys on two days:
 - solvent levels using OVA Organic Vapour Analyser (intrinsically safe) to determine:
 - a)solvent concentration pattern
 - around factory at two levels
 - vertically from ground to carousels
 - b)changes in levels during various work practices
 - c)gradients near mixers
 - air movements using vane anemometer and smoke tubes
 - a)between rooms
 - b)into ventilation systems
 - temperature measurements
 - a)around factory
 - b)vertically.
4. Trial survey with diffusive samplers using TENAX and thermal desorption. (qualitative)
 - a)couple with OVA results on that day (quantitative)
 - b)demonstrate that this technique could be used.
5. Photography of some work practices and ventilation systems. (Mechanical camera, 400ASA film)

6. Collecting of data:

- materials used-solvents and paint additives-incomplete
- Safety Policy
- plant layout
- ventilation drawings - nil.

My work to date have been directed at establishing a framework and background for the body of my project.

As indicated in my project proposal this will take place between July 14 and August 1 when I will move to Perivale from Worthing.

In that time I intend to:

- 1) Further study work practices.
- 2) Consider four representative ventilation systems.

Tentatively:

- a)Design a hood for filling machine in Number 2 mill
- b)Design a hood for a ball mill in Number 3 ball mill room
- c)Test alternative hood for a large mixer and establish a static pressure monitoring system
- d)Test modification to fume hood in small orders canning area.

Any modifications will be temporary and made of hardboard.

3)Set down ventilation requirements for other areas where exposure to solvents is significant.

In August I will write up the project detailing the work done. In the report I intend to:

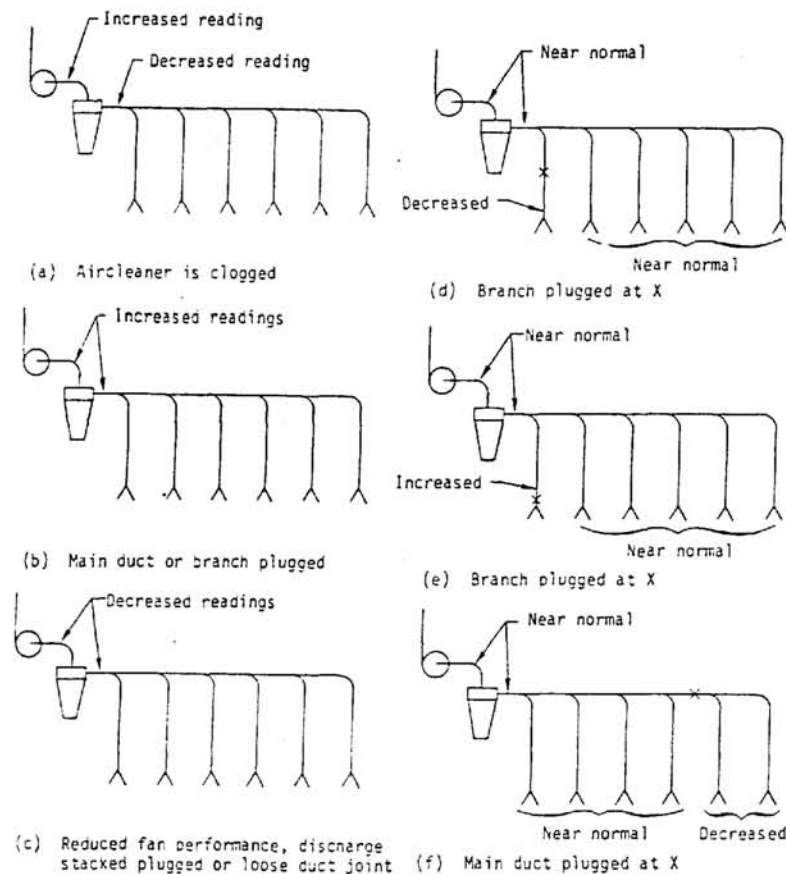
- 1)Demonstrate the extent of the work required to control solvent exposure in the factory, giving various options.

- 2) Estimate hot air losses and power costs in running the existing ventilation systems.
- 3) Demonstrate the solvent monitoring options.
- 4) Devise a programme for performance monitoring of the existing system.

TESTING OF VENTILATION SYSTEMS

1) Performance Testing

Once a baseline has been established for flows in a ventilation system, then any changes will be reflected in changes in the static pressure P_s . Pressure measurements may be made with a water manometer, which at its simplest is a plastic U tube filled with water but a commercial manometer is recommended. A smooth hole in a long section of duct is essential. For repeatable measurements a fixed monitoring point (Appendix K) is recommended.



Ventilation system problems diagnosed by comparing static pressure readings with earlier tests.

figure 41 P_s fault finding

The figure above from McDermott (9) illustrates the use of static pressure measurements in diagnosing faults in a

ventilation system.

A difference of 10% is significant and should be investigated.

A six monthly schedule of static pressure monitoring of all systems is recommended once optimum operation is obtained, and baseline flow and static pressure measurements made.

2) Smoke Tubes

Smoke tubes are cheap and show whether an extraction system is working from the direction and speed of the flow of air. If the smoke is extracted from near the likely source of solvent vapour and away from the breathing zone of the operator, then it is likely that the extraction is working. If it also extracts a lot of smoke from behind or to the side of the inlet, then the hood cannot be working efficiently, and a change of inlet or hood design is warranted.

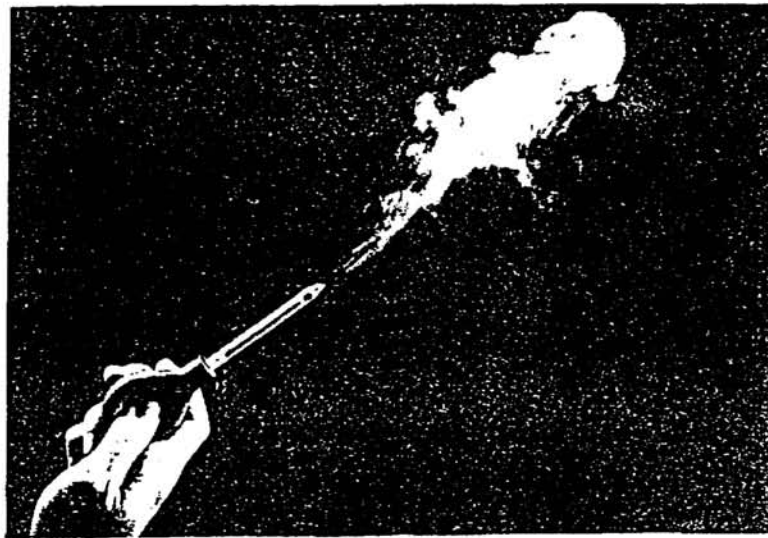
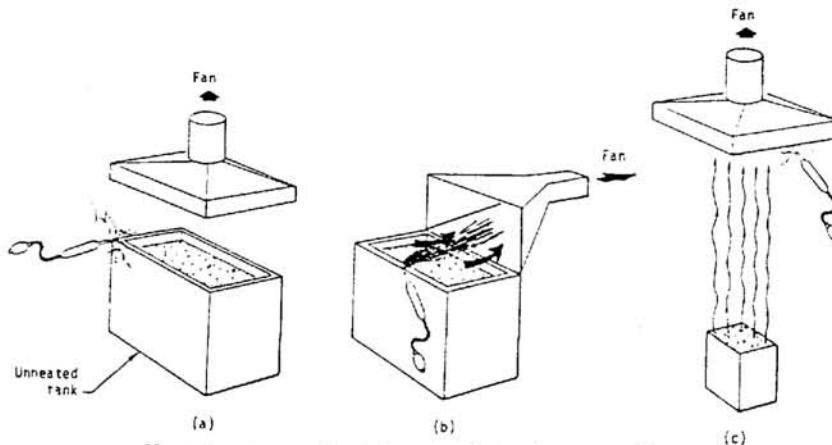
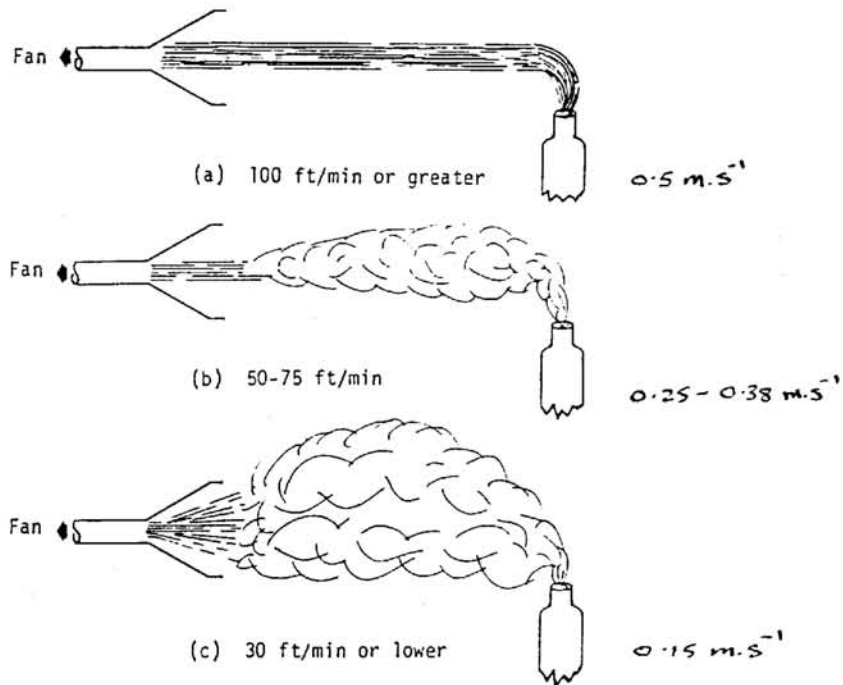


figure 42 a smoke tube



How to use smoke tubes to determine: (a) dispersion of contaminants; (b) range of capture velocity; (c) spillage from canopy hoods or enclosures.

figure 43 use of smoke tubes

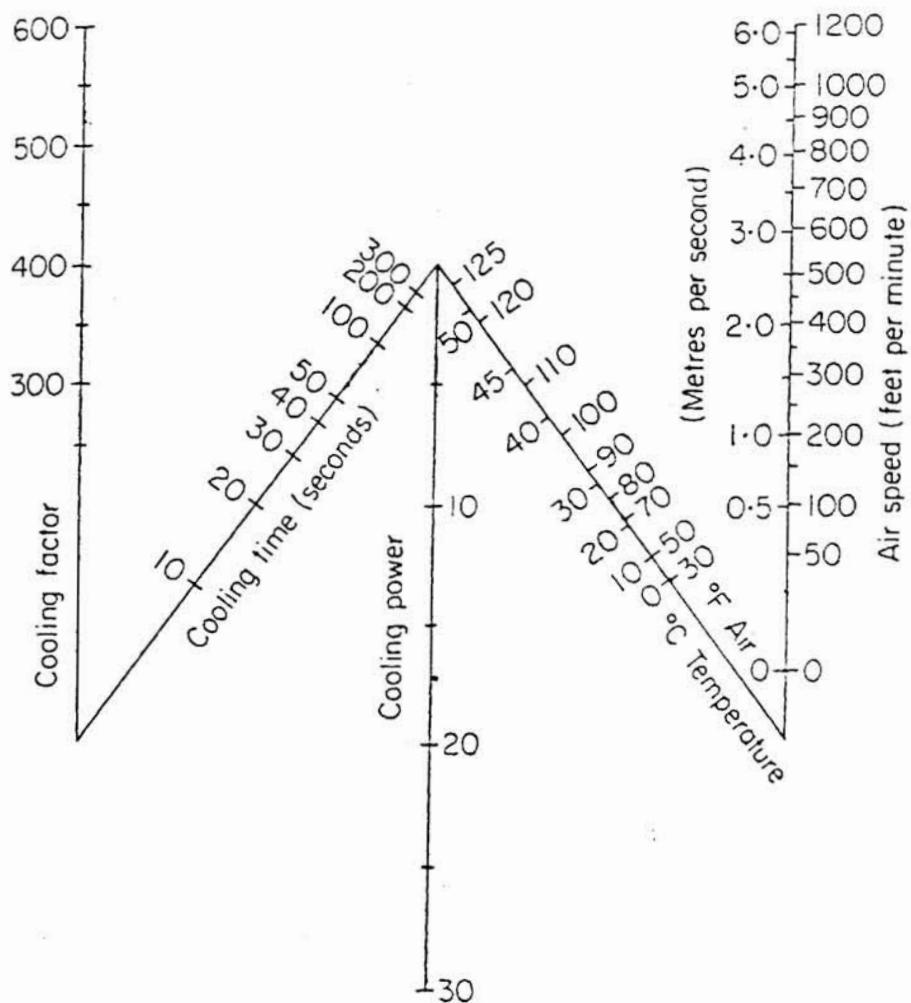


Approximate behavior of a smoke jet in different velocity airstreams.

figure 44 quantitative use of smoke tubes

3) Kata Thermometer

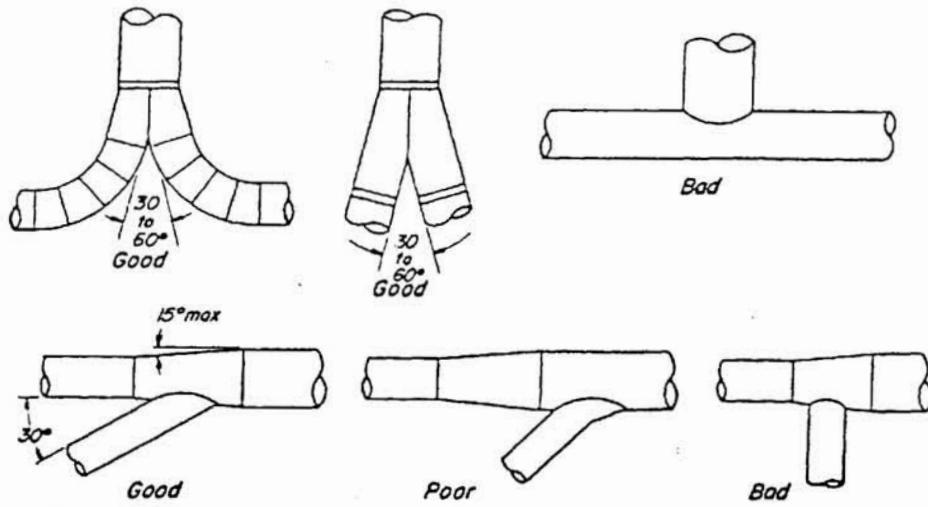
The nomogram attached was used for calculating air flow. A range of kata thermometers is available for different air speeds. Their use is tedious and requires hot water and a stop watch, but they are safe.



Kata thermometer chart for temperature range 54.5–51.5°C (After a withdrawn British Standard BS3276, 1960)

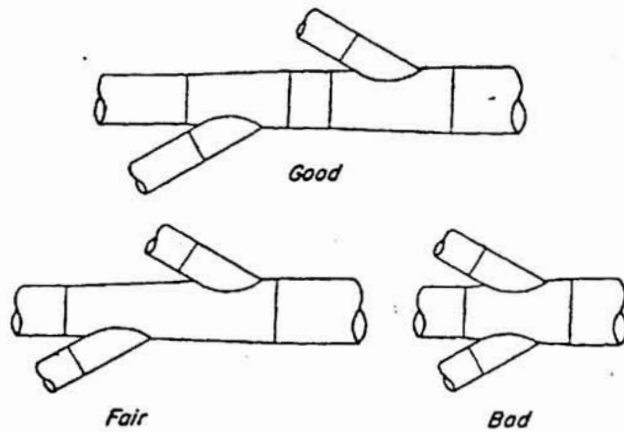
DUCT DESIGN

The attached sheets are from 'Industrial Ventilation' (8) and will be useful in assessing good practice in the present ventilation systems.



BRANCH ENTRY

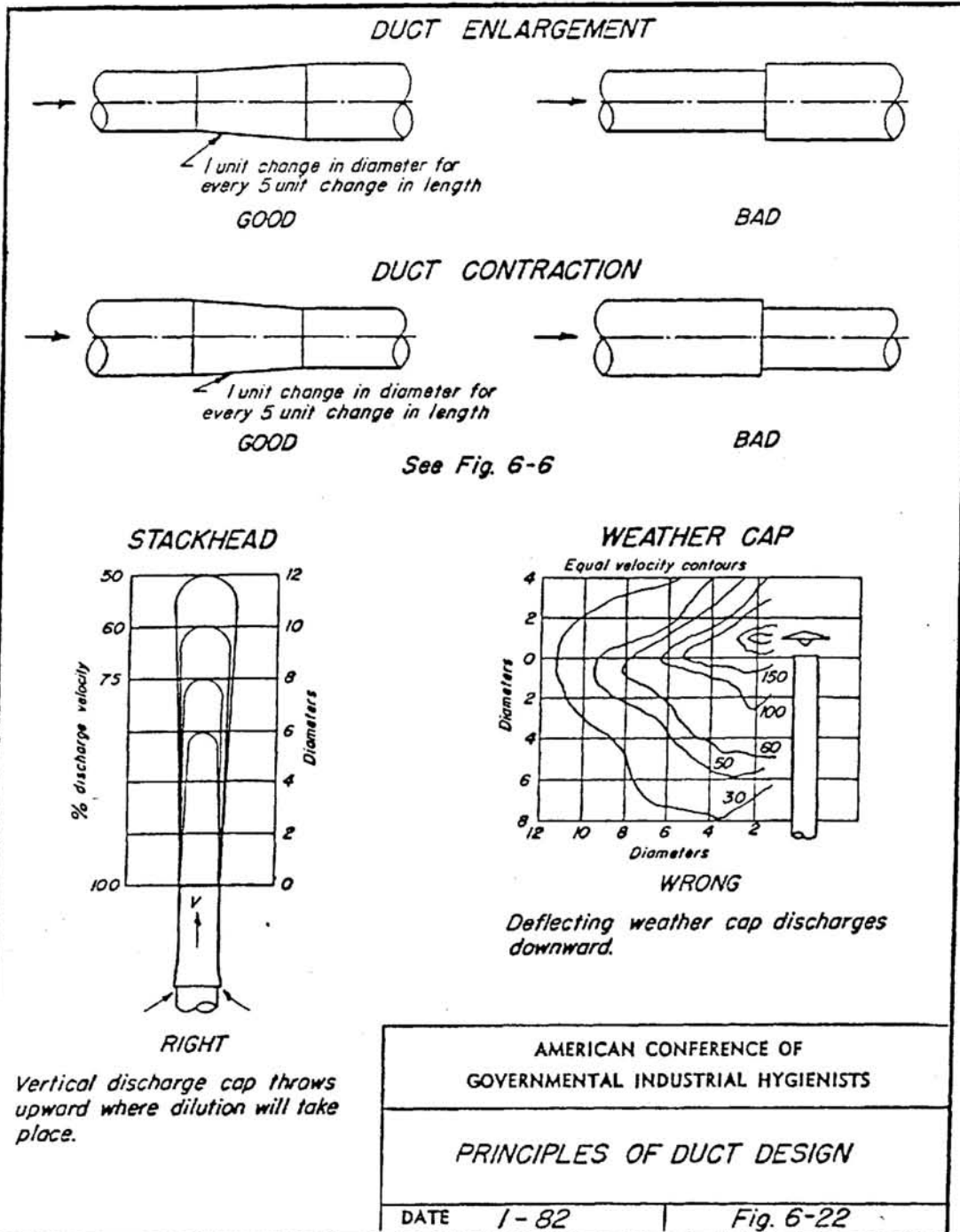
Branches should enter at gradual expansions and at an angle of 30° or less (preferred) to 45° if necessary.

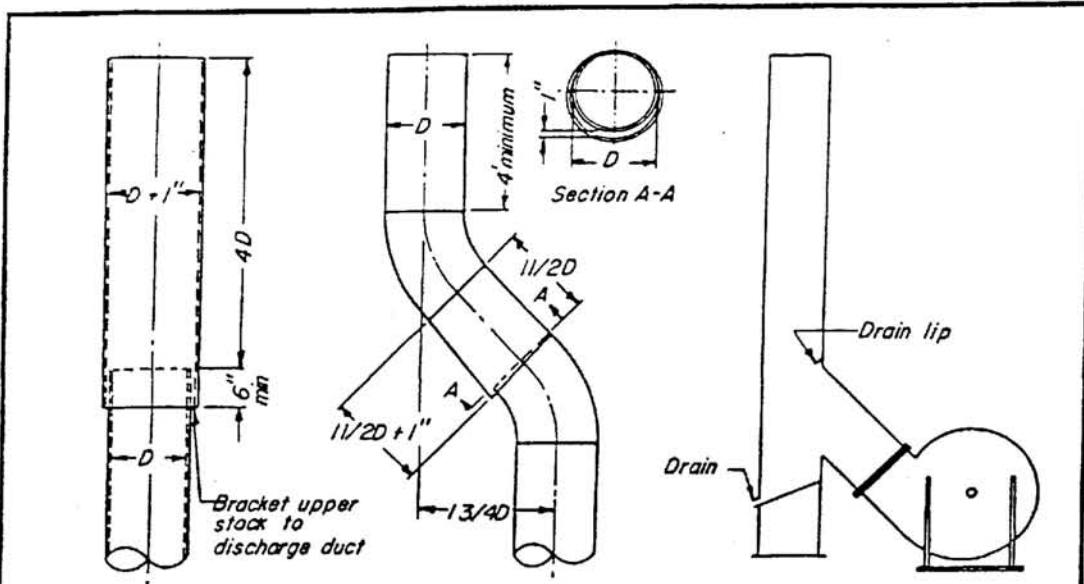


BRANCH ENTRY

Branches should not enter directly opposite each other.

AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS	
PRINCIPLES OF DUCT DESIGN	
DATE 1-76	Fig. 6-20





VERTICAL DISCHARGE⁽⁸⁷⁾⁽¹¹⁶⁾

No loss

OFFSET ELBOWS⁽¹⁰⁶⁾

Calculate losses due to elbows

OFFSET STACK⁽¹⁰⁶⁾

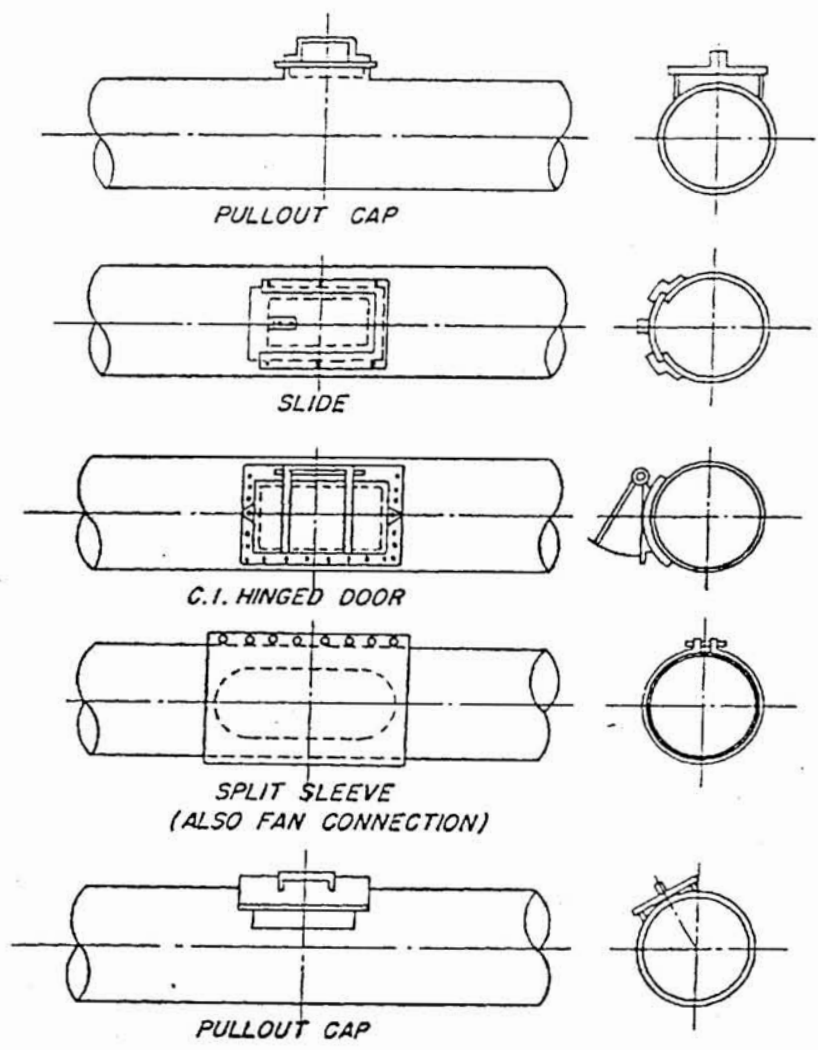
1. Rain protection characteristics of these caps are superior to a deflecting cap located $0.75D$ from top of stack.
2. The length of upper stack is related to rain protection. Excessive additional distance may cause "Blowout" of effluent at the gap between upper and lower sections.⁽⁸⁶⁾

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GOVERNMENTAL INDUSTRIAL HYGIENISTS

STACKHEAD DESIGNS

DATE 1-76

Fig. 6-24



AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS	
CLEANOUT OPENINGS	
DATE 1-56	Fig. 8-1