

# Atmospheric Dispersions of Tomago Aluminium Refinery Effluents

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## ABSTRACT

The prediction of dispersion, especially in nearer field areas, of fluoride effluents from a mixture of low level line sources and medium level stack sources does not seem readily amenable to mathematical modelling, and wind tunnel model testing is likely to be a more effective method. This paper describes the procedures and results of on-site measurements at Tomago Refinery near Newcastle, N.S.W., which will provide data for checking the efficacy of wind tunnel modelling.

## INTRODUCTION

It is unlikely that anyone can confidently predict pollution levels caused by line sources close to ground level. Of particular interest are modern aluminium smelters which typically use roof vent exhausts running the full lengths of very long building.

Fluorides are potentially pollutant wastes whose dispersion in the atmosphere is of concern to operators such as those of Tomago Aluminium Co., near Newcastle, N.S.W., which produces 220 000 tonne of aluminium a year, but at the same time emits about 150 tonne of fluoride. About one-quarter is exhausted through four tall chimneys, while the remainder enters the environment through four 800 m long rooftop vents. These line sources emit fluoride at low velocity fairly close to the ground, namely at about 20 m height, conditions which reduce the atmosphere's ability to mix and dilute the pollutant before it reaches ground level.

The efficacy of wind tunnel model testing for effluent dispersion in the vicinity of such a refinery is being investigated in the Civil and Mining Engineering School at Sydney University. The reference data for that study are being provided by onsite measurements at Tomago.

## SITE FEATURES

The smelter is located in estuarine swamplands at the end of the Hunter River Valley, and is 12 km NNW of the city of Newcastle. Its proximity to this large population centre, and to the vineyards and cattle regions of the Hunter make pollution control especially important.

Weather conditions are dominated by S-SE sea breezes during Summer and NW land breezes draining out of the Hunter Valley during Winter. A comprehensive meteorological weather station is run continuously by Tomago Company.

Apart from a few small villages, the main surface roughness is low swamp vegetation. It is a terrain of Category 2 accordingly to the Australian Wind Loading Code (1983).

The plant itself is dominated by four 800 m long pot-room buildings oriented east-west. Each building is 21 m high (including 3.3 m high roofvent structures and 3 m recess below general ground level) and 23 m wide (see Fig. 1).

## FLUORIDE COLLECTING STATIONS

Seven different test stations were set up within the plant, as shown in Fig. 1. They are identified as:

- (a) SE and SW Scrubber Stacks
- (b) Four eastern Crushed Bath Silos
- (c) Eastern Silo Walkway

Whereas groups (a) and (b) are for measurement of concentrations at various heights, at (c) the collectors sample fluoride at one height but variable downwind distances, as shown in Table 1.

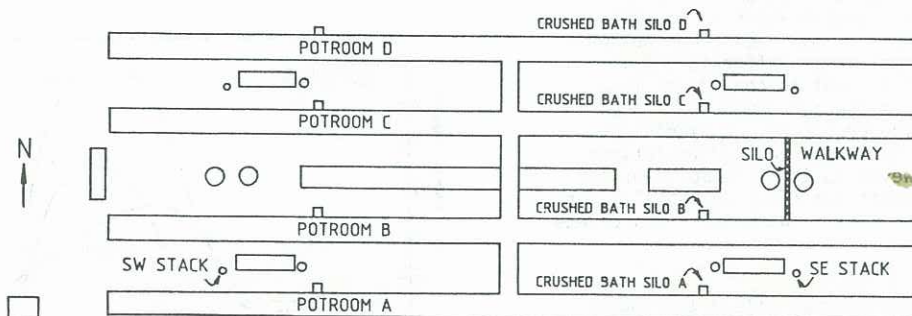


Fig. 1 Tomago Smelter showing test station locations.

TABLE 1: TEST STATION INFORMATION

Test Station	(1)	(2)	(3)
Scrubber Stacks	5 50	35 either way	110
Crushed Bath Silos	0 26	A and C 22 and 48 B 22 and 78 D 22 only	200
Silo Walkway	13	0 - 100	115

- (1) Sampling Height Range (m)  
 (2) Lateral Distance to Roofvents (m)  
 (3) Longitudinal Distance to Potroom Ends (m)

## SAMPLING EQUIPMENT AND TESTING PROCEDURES

Fluoride samples are collected using a modified version of the device described in the Australian Standard for determination of gaseous and particulate fluorides (1984). Air is drawn through two treated filters, the first of which traps particulate and the other gaseous fluoride compounds. The exposed filters are later chemically analysed using a fluoride specific ion electrode to determine fluoride content. These data, combined with the volume of air passing across the filters, enable atmospheric fluoride concentration to be determined.

Each test station has a single vacuum pump linked to five separate filter holders and airflow meters. Household vacuum cleaners are used for cheapness. Each pump has a total flow of about 350 L/min or 70 L/min on average through each filter holder. To ensure adequate airflow, large diameter filters and holders are used. A 150 mm diameter Whatman No.5 collects the particulate fluorides (mainly  $AlF_3$ ) and a 150 mm diameter Whatman No.4 collects the gaseous fluoride (mainly HF).

Testing procedure begins by inserting two unexposed filters into each holder. Tests last between 3 and 12 hours, corresponding to morning, afternoon or night sessions. The flow rates through each holder are recorded at the beginning of the test; the accuracy of sample volume is better than 10%.

For chemical analyses, a Fluoride Specific Ion Electrode (Orion model 9409) is employed, as specified in the previously mentioned Australian Standard; the overall analysis is estimated to be accurate to  $\pm 5\%$ .

## RESULTS

Figs. 2, 3 and 4 show examples of 'typical' fluoride profiles determined from the onsite tests. Figs. 2 and 3, for the scrubber stack and crushed bath silo test stations, indicate the changes in fluoride concentration with height, whilst for the walkway test station (Fig. 4) fluoride concentration is graphed against downwind distance. It must be noted that profiles from other individual tests differ in detail from the 'typical' profiles, but is considered most likely that the latter are the consequences of the main fluoride distributing processes, and individual profile differences are due to unrecorded variations of those processes. However to indicate how profiles may differ, Fig. 5 contrasts the fluoride profiles for two tests which generally similar wind speed and direction conditions prevailed.

One factor which may significantly affect the individual profile is the roofvent emission concentration (REC). REC is highly variable, depending on the type of activity within the potroom. However although data on REC are available it is not possible to account for it in individual tests and it can be considered in over all averaging only.

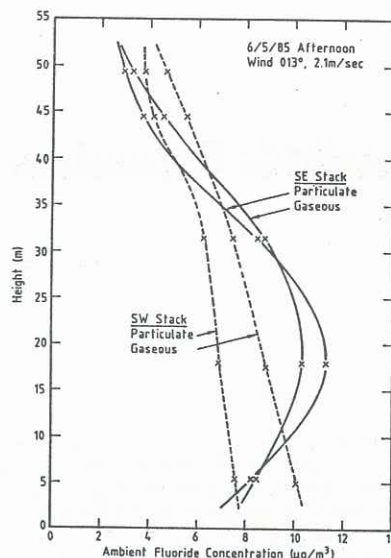


Fig. 2 Typical fluoride concentration profiles at the scrubber stacks.

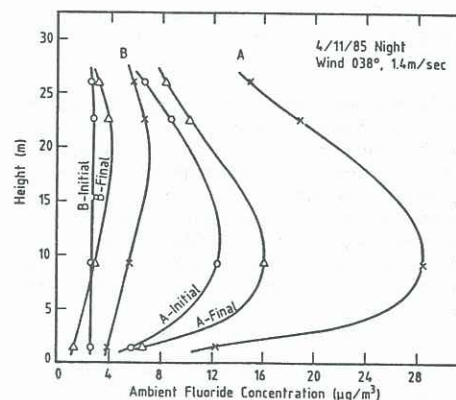


Fig. 3 Typical fluoride concentration profiles at two crushed bath silos.

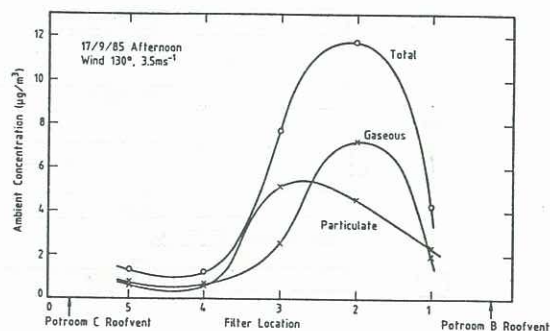


Fig. 4 Typical fluoride concentration profiles along the silo walkway.

TABLE 2: SCRUBBER STACK PROFILES - PLUME RISE

Windspeed Range (m/s)	Number of Profiles	(1)		(2)	
		Number	%	Number	%
0 to 1.5	19	1	5	1	5
1.5 to 2.5	49	1	2	18	37
2.5 to 3.5	38	2	5	16	42
> 3.5	38	1	3	18	47

(1) Profiles with Max. Conc. above 32 m

(2) Profiles with Max. Conc. below roofvent

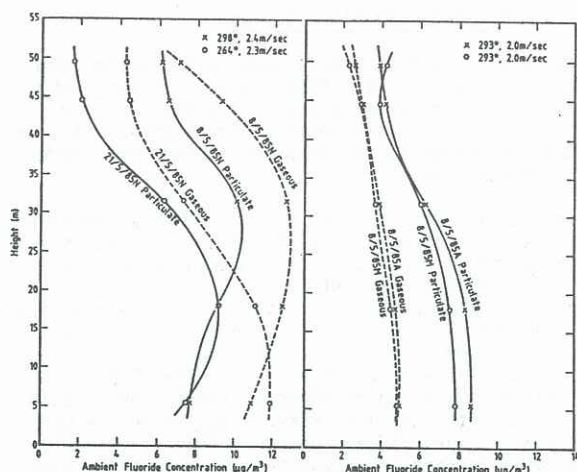


Fig. 5 Fluoride concentration profiles at the SE scrubber stack with differing details.

## Results: Scrubber Stack Test Station

Two types of vertical fluoride concentration profiles emerge from measurements at the SE and SW scrubber stack test stations. A typical example of the most common type where the fluoride concentration peak occurs approximately at roofvent level, is shown by the SE stack results in Fig. 2. The other less common profile is where fluoride concentration increases as height decreases, as indicated by the SW stack results in the same figure. Of 150 profiles measured, 107 are similar to the first type, 24 to the second. The remaining 19 do not fit either pattern.

A major feature is that in 97% of the scrubber stack tests, the maximum concentration occurs below 32 m, with a general rapid decrease in concentration above that level: Fig. 6 shows the height at which the maximum fluoride level occurs for all particulate and gaseous profiles; the emissions come from the roofvents at 18 m so most maxima do occur at around this height. Also from the scatter of results in Fig. 6 there appears to be no strong correlation between wind speed and plume rise. However it appears that plume downwash behind the potrooms is more likely to occur as wind strength increases: of 19 fluoride profiles measured when winds were below 1.5 m/s, it is deduced from 18 that the plume is rising as it travels downstream from the roof-vent; Table 2 shows how the percentage being downwashed increases as windspeed increases.

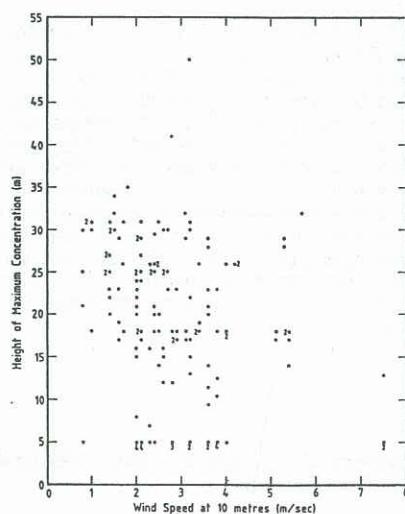


Fig. 6 For plume rise versus wind speed at scrubber stacks.

Other weather conditions than wind may affect the height of maximum plume concentration, but further data is necessary to define any significant trends. But it appears that the atmospheric temperature gradient may be a significant factor. During September 1985 temperature gradients were  $-0.08^{\circ}\text{C}/\text{m}$  on average at night and  $0.009^{\circ}\text{C}/\text{m}$  during the day. Corresponding to this, of 50 nighttime tests, just 2 had their maximum fluoride concentration at ground level, whereas of 97 daytime tests, 24% had maximum concentrations at ground level.

To investigate the effects of wind direction on the fluoride profiles, results were split into one of the eight major compass sectors according to prevailing conditions. Sufficient data was available to calculate average profiles for all but N and NE sectors. For westerly (or easterly) winds the local velocity patterns are dominated by flow channelling between each potroom. For northerly or southerly winds, blowing transversely to the buildings, large recirculating wakes will be behind each potroom. For skew winds, there will be a combination of these two types of flow pattern. The average fluoride profiles in Fig. 7 reflect the effect of the different flow patterns. Also in Fig. 7, from the SE stack test station, each profile shows low levels above 45 m, a peak between 10 m and 30 m, and a tapering off towards ground level; westerly winds produce higher concentrations but perhaps at a lower height than for winds from east. From the SW stack station there are similar patterns, but easterly winds produce higher concentrations.

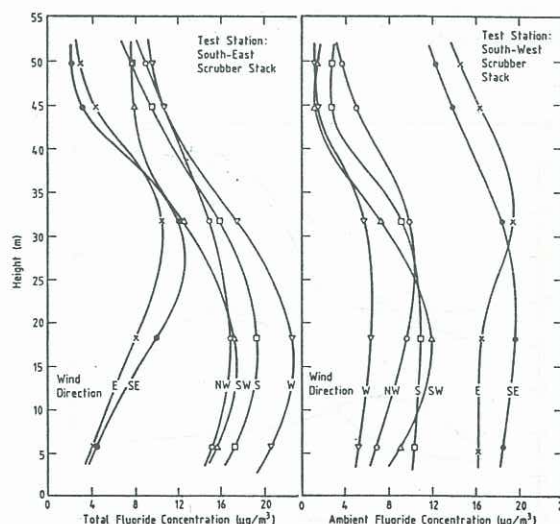


Fig. 7 Average fluoride concentration profiles at scrubber stacks - various wind directions.

The dilution rate of fluoride between roofvent and samplers (that is the ratio between fluoride concentration and REC) is of interest. The average mean total fluoride concentration (for 71 profiles measured at SE and SW stacks) was  $11 \mu\text{g}/\text{m}^3$ . The ratio between this and the average REC of  $310 \mu\text{g}/\text{m}^3$  is 3.5%, a significant reduction ratio over a downwind distance of as little as 35 m. Using the same 71 profiles, the average maximum total fluoride concentration at the stacks is  $17 \mu\text{g}/\text{m}^3$ , still less than 6% of the roofvent concentration. When the total fluoride readings are divided into particulate and gaseous components, distinctly different dilution rates appear. Average mean particulate and gaseous fluoride levels at the stack are  $4.8$  and  $6.1 \mu\text{g}/\text{m}^3$  respectively. From refinery data average particulate REC is  $180 \mu\text{g}/\text{m}^3$  while average gaseous REC is  $130 \mu\text{g}/\text{m}^3$ . Thus the particulate fluorides appear to disperse almost twice as rapidly as the gaseous fluorides: a question yet to be answered is whether the apparent rapid dispersal of particulates is due to the rapid fall soon after discharge of heavier particles.

#### Results: Silo Walkway Test Station

Typical fluoride profiles for measurements along the elevated walkway are shown in Fig. 4; for those tests most walkway sampling has been conducted during southerly wind period, and most results show fluoride concentrations highest towards the southern end of the walkway.

So far eighteen complete fluoride profiles have been determined, providing sufficient data to draw average profiles for four wind directions - SW, S, SE and E. These are shown in Fig. 8. For easterly winds, when the walkway lies transversely in the airflow which is channelled along the potrooms, fluoride levels are low and the profile fairly constant. For the other profile with southerly components of wind, emissions from potroom B roofvent are dominant and the profiles show a maximum at that end of the walkway. The SE and SW profiles peak at around 26 m downwind of roofvent B whereas the S profile peaks right up next to potroom B. This suggests maximum downwashing occurs for winds perpendicular to the potrooms, whereas some air velocity component parallel to the potrooms reduces the high concentration in the region directly downwind of the potroom.

From the results, it seems unlikely that the maximum fluoride concentration would occur at the northern end of the walkway in southerly wind conditions, and at the southern end in northerly wind conditions, but further data are required to demonstrate the latter more conclusively.

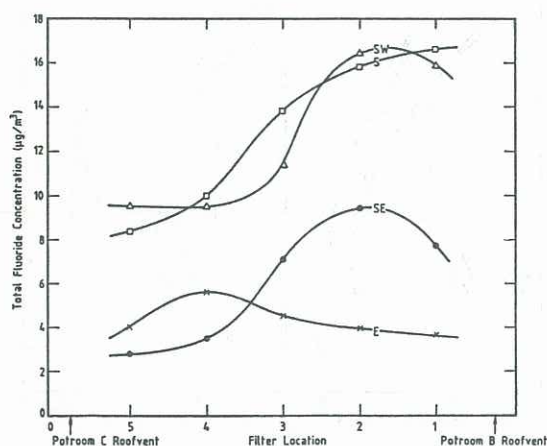


Fig. 8 Average fluoride concentration at silo walkway various wind directions.

#### Results: Crushed Bath Silo Stations

As yet insufficient data have been collected to form specific conclusions for these tests. In fact, the data available are even more variable than for the other test stations, perhaps suggesting these stations are just too close to the emission sources for representative sampling.

Typical results for stations A and B, the two southern test sites, are shown in Fig. 3. Almost all tests have been carried out during NW, N or NE wind conditions. Fig. 9 shows the estimated average total fluoride profiles for NE wind conditions. Some interesting points emerge. First, silo station D, upwind of all the potrooms, only picked up trace fluoride concentrations and this was verified by all other D-silo profiles for NW, N and NE winds. Clearly very little fluoride is entrained into airflow eddies on the upstream side of the windward potroom. Second, fluoride levels at silo station A (the test site furthest downwind) were always higher than those at D, C and B. Again this was the case for all tests under NW, N or NE wind conditions. This suggests that either the airflow is becoming more turbulent as it passes over each successive potroom and so entraining more fluoride emitted from roofvent B directly upwind, or that fluoride is accumulating from all three upwind roofvents.

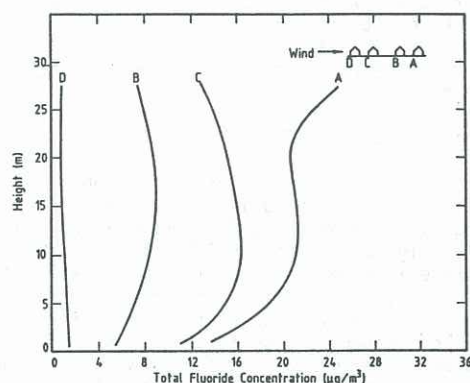


Fig. 9 Average fluoride concentration profiles at crushed bath silos - NE winds.

#### CONCLUSIONS

For this particular aluminium refinery, fluoride concentration levels reduce by a factor of 30 on average between roofvents and positions 35 m downwind. Vertical concentration profiles measured between the smelter potrooms show most pollutant remains below  $1\frac{1}{2}$  times the roofvent emission height. Fluoride profiles do not show a constant shape and differ even for the same wind speed and direction. However the patterns are fairly distinctive for different wind directions: maximum concentrations occur near roofvent level for winds parallel to the line sources; whilst for transverse winds the high concentrations occur close to ground level, and close to the leeward edge of each potroom.

#### REFERENCES

- Australian Standard 1170, Part 2 - 1983: SAA Loading Code, Part 2 - Wind Forces.
- Australian Standard 2618 - 1984: Ambient Air - Determination of Gaseous and Particulate Fluorides - Selective Ion Electrode Method. Part 2 - Gaseous Fluorides and Acid-Soluble Particulate Fluorides ( $0.1 \mu\text{g}/\text{m}^3$  or greater) - Manual, Double Filter Paper Sampling.