ODOUR CONTAINMENT AND VENTILATION AT PERTH'S MAJOR WWTPs

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Abstract

Experience at controlling odours by retrofit of covers and ventilation systems at the three major wastewater treatment plants in Perth has led to recommended design criteria for near complete capture of odours from a high sulphide, high temperature wastewater.

Introduction

Odours from wastewater treatment plants in Perth have caused complaints from nearby residents for many years. Recently the Water Corporation made significant investments at its three largest wastewater treatment plants to achieve a major improvement in odour control at these plants by retrofitting covers, ventilation and scrubbing systems.

These odour control works at the plants were constructed in stages and incorporated different design approaches enabling the effectiveness of different approaches to be compared. As a result, a range of air extraction rates has been examined and it has been established that the effectiveness of covers to contain odours depends on the capture velocity which is a function of the negative pressure developed under the covers. This, in turn, is a function of the ventilation flux rate based on the surface area covered.

Generalising these results, design criteria are recommended to achieve near complete odour capture with the best examples of covering systems used at Perth treatment plants on recent odour control projects.

Odour containment has been successfully achieved at other treatment plants using lower ventilation rates than recommended in this paper. However, based on observation at many other plants, this success commonly reflects either lower ambient temperatures or substantially lower sulphide levels in the influent. Perth has a warm climate and very high sulphide levels in the wastewater; thus a very high level of capture of odours is essential. This is more difficult to achieve where odour control is a retrofit rather than considered as part of the initial design.

Recommended design criteria for near complete capture of odour.

Figure 1. Subiaco Wastewater Treatment Plant.

Details of Covers and Odour Control Facilities

Woodman Point Wastewater Treatment Plant (WWTP)

The Woodman Point WWTP serves Perth's southern suburbs. Wastewater is pumped to the plant and is septic, with hydrogen sulphide levels in the gas space of the inlet channel being typically in the range of 150 to 300 ppm.

The treatment facilities were upgraded in 2001/02 incorporating extensive covering and odour control. The screens and channels were covered with trafficable aluminium covers, while the grit and primary sedimentation tanks were covered with purpose built aluminium covers. All covered areas were ventilated to two, single staged scrubbers employing hypochlorite/caustic and Odorgard™ reactors. After scrubbing, gases were discharged via a common 22 m high stack.

Beenyup WWTP

The Beenyup Point WWTP serves Perth's northern suburbs. About half the wastewater is from large gravity sewers and the other half is pumped. Hydrogen sulphide levels in the gas space of the inlet channel are typically in the range of 100 to 300 ppm.

The odour control facilities at Beenyup WWTP were upgraded in three phases between 2003 and 2005.

In Phase 1, the inlet channels, screens, grit removal and primary sedimentation tanks were covered with fibre reinforced plastic (FRP) covers. Foul air was treated in two sets of two staged scrubbers employing acid and hypochlorite/caustic with Odorgard™ reactors.

In Phase 2, the aeration tanks and dissolved air flotation thickeners (DAFT) were covered. Centrifuges were also installed to dewater digested sludge. Foul air from the centrifuges, conveyors and sludge hopper was collected and ducted to the Phase 2 scrubbers. The ventilation rates from the inlet sewers and screening facilities were

tly increased. Only the secondary
remain uncovered.

:ollected from the Phase 2 works
:d in two staged scrubbers
g hypochlorite/caustic and
l reactors. A 50 m tall stack was
ed to disperse the air from the
nd Phase 2 scrubbers.

3, the Phase 1 and Phase 2 ducts
rconnected and the ventilation
: increased. The first stage of the
crubbers was also modified to
n a caustic solution rather than
ion and pressure sensors were
:o monitor the negative pressures
: covers. The observed variations
'e pressure under the covers
an insight into the complexity of
; air from large covered areas with
:anks and ducts.

WWTP

ıco WWTP serves the central
f Perth. Most of the wastewater
ıe plant by gravity sewers but
ıird is pumped to the plant.
ı sulphide levels in the gas space
:t channel are typically in the
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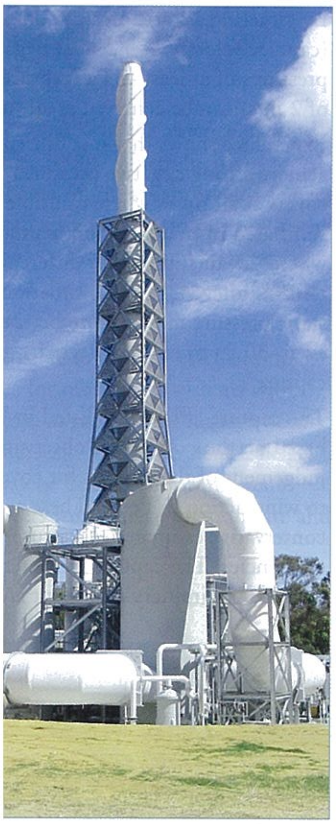
)4, the primary sedimentation
ation tanks and associated
ınd chambers were covered with
rs and ventilated to the odour control facilities. Only the secondary clarifiers remain uncovered (Figure 1).



Scrubbers and Stack at
Vastewater Treatment Plant.

Ventilation rates from the pre-treatment facility were increased, and the building was ventilated to the scrubbers to achieve secondary containment. Foul air from the DAFT, sludge blending tanks, centrifuges, and lime amended sludge process was collected and ventilated to the scrubbers.

Foul air from the inlet sewer, pre-treatment, primary and sludge treatment facilities was combined and treated by two staged scrubbers consisting of acid and caustic to remove ammonia and hydrogen sulphide respectively. These gases were then combined with the gases extracted from the aeration tanks and treated by further two staged scrubbers employing hypochlorite/caustic and Odorgard™ reactors. After scrubbing, all gases were discharged via a 50 m high stack (Figure 2).

Theoretical Considerations for Mechanical Ventilation

Two forces must be negated by mechanical ventilation to achieve a high degree of odour containment. The first is thermal buoyancy caused by the difference between the internal and external temperatures. This is commonly known as the chimney effect.

The pressure difference due to the chimney effect can be expressed as:

$$\Delta P_t = \frac{\rho g h \Delta T}{T_O} \qquad (1)$$

For most odour containment applications, ΔP_t is relatively small, however, the chimney effect can cause a significant circulation through buildings housing large thermal loads.

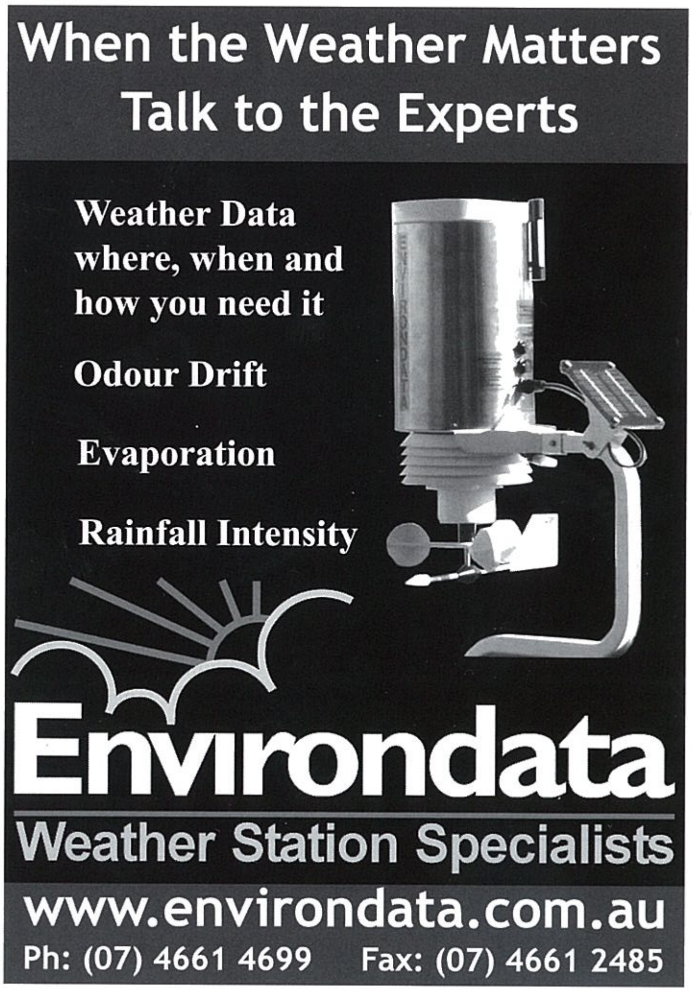
The most important force for odour containment is usually the pressure difference created by air movement over the surface of the cover.

$$\Delta P_w = P_i - P_o \qquad (2)$$

The pressure P_o on the outside surface of the cover may be calculated as:

$$P_o = P_a - \frac{C_P \rho [K_w V_w]^2}{2} \qquad (3)$$

The effect of wind may be represented by the global wind pressure coefficient (C_{wo}), defined as the fraction of the dynamic pressure of the free wind acting on the outside of the structure. Thus:



$$\Delta P_w = \frac{C_{wo}\rho V_w^{\,2}}{2} - \Delta P \qquad (4)$$

The velocity across an opening may be derived from Bernoulli's equation:

$$V = C_d\left[\frac{2\Delta P}{\rho}\right]^{1/2} \qquad (5)$$

Combining equations (4) and (5), the velocity across an opening that will negate the effect of wind action on the cover ($\Delta P_w = 0$) is given by:

$$V_o = C_d C_{wo}^{\;1/2} V_w \qquad (6)$$

The effect of height and topography on the wind velocity acting on the covers may be estimated using information from Table 1, where $K_w = Kz^a$

Where the maximum height of the covers (z) is 1.5 m above ground, and the topography may be characterised as Open Country – Many Windbreaks, and assuming $C_d = 0.6$, and $C_p = 0.9$ (AS/NZ 1170.2, 2002),

$$C_d C_{wo}^{\;1/2} = 0.6\,[0.9(0.52 \times 1.5^{0.2})]^{1/2} = 0.32$$

Capture Velocities

Recommended capture velocities for a range of indoor industrial operations, in the absence of significant wind effects, are listed in Table 2.

USEPA regulations for the control of hazardous volatile organic compounds (CFR 40, Chapter 1, Part 52, Appendix B) assume a capture efficiency of 100 % for a capture velocity of 1m/s. In the field of fire protection, pressures of -25 Pa (capture velocity of 3.9 m/s) under all conditions (NFPA 820) are recommended to contain potentially explosive atmospheres. Pressures of -20 Pa (capture velocity of 3.5 m/s) are recommended to control the spread of smoke in buildings (AS 1668.1:1998).

Degremont (2005) states that pressures of at least -7 Pa (capture velocity of 2 m/s), will generally be adequate to prevent the escape of odours under low wind speeds. Capture velocities of 2 m/s have also been demonstrated to achieve near complete capture of vehicle emissions in road tunnels (CEE, 2001).

Table 1. Topography and Height Factors.

Topography	K	a
Open Country – Few Windbreaks	0.68	0.17
Open Country – Many Windbreaks	0.52	0.20
Rough Country/Outskirts Small Town	0.35	0.25
City Centre	0.21	0.33

Source: CIBSE Guide A2-31, Table A2.11 (1999)

For practical purposes, near complete capture of odour may be assumed where a capture velocity of at least 2 m/s for large odour sources, and 1 m/s for small to moderate odour sources, are maintained at all times. While this is relatively straight forward for small, indoor enclosures, it is more difficult to achieve when covering large process tanks at wastewater treatment plants. At the Subiaco plant, for example, there are 8.8 km of seals between covers. Careful attention to detail is important in the design, installation and operation of cover systems to ensure that the leakage area is as low as possible to minimise the ventilation rates required to achieve adequate capture velocities.

Negative Pressure and Odour Containment

Wind effects have a profound effect on odour release from a liquid surface (Schulz *et al.*, 1996). Even extremely low velocities may have a significant effect on odour release. Passive covering techniques such as adding a layer of straw or tarpaulins can reduce odour emissions by as much as 80 to 90% (Jacobson *et al.*). This was confirmed during the installation of covers in Perth, where significant reductions in odours was noticeable when the covers were in place, but before the ventilation systems were commissioned.

Where the area of openings is known, the pressure required to achieve a particular velocity through the opening may be determined by rearranging equation (5).

$$\Delta P = \frac{\rho V^2}{2C_d^{\;2}} \qquad (7)$$

The recommended capture velocities for odour containment in indoor situations are commonly in the range 0.5 – 1.0 m/s.

Assuming = 1.2 kg/m^3 and C_d = 0.6, it may be calculated from equation (7) that the negative pressure will be 1.7 Pa for a capture velocity of 1.0 m/s. If pressure fluctuations under the covers are greater than this negative pressure, the capture velocity must be increased.

The preceding discussion assumes that wind velocities are constant vectors. Actual winds are highly variable. Examples of this variability are shown in Figure 3, which are based on wind measurements at the Subiaco WWTP. Variations in wind velocities result in fluctuations in pressures underneath the covers.

While low wind speeds are usually associated with most odour complaints, ventilation systems should be designed to contain odours under all but the most extreme wind conditions.

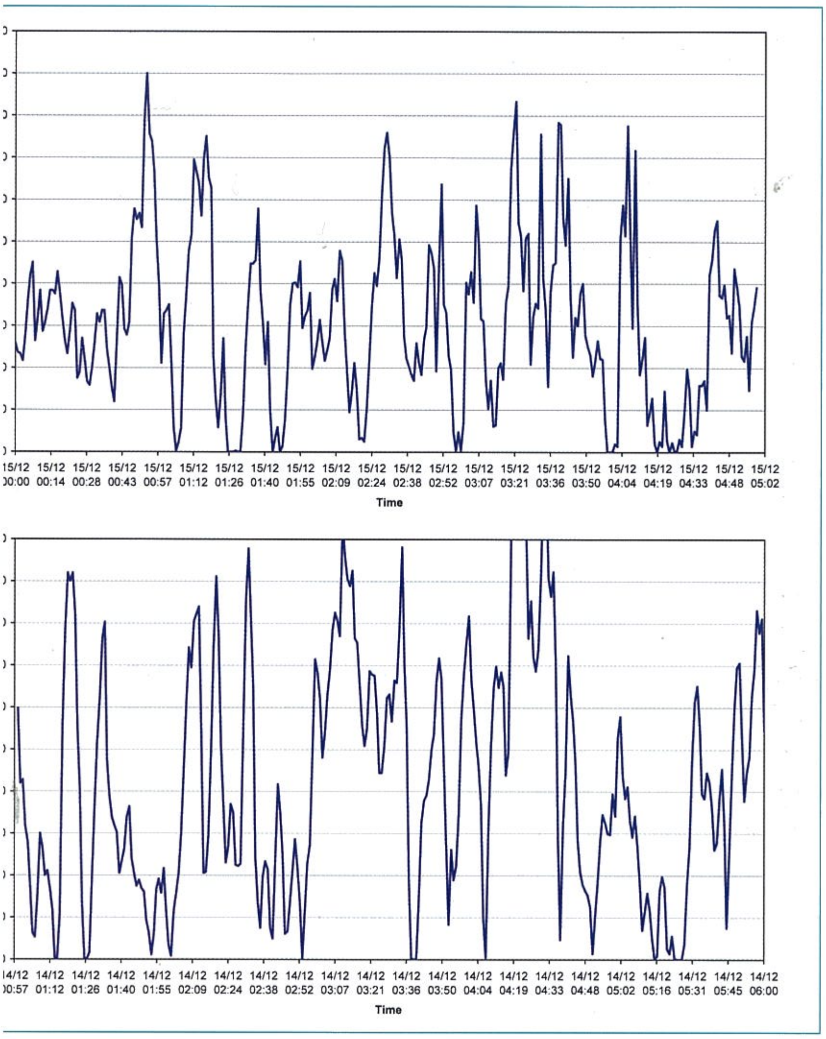
Measurements of the pressures underneath the covers at Subiaco WWTP indicate that pressure fluctuations of up to 10 Pa occur. By targeting a static pressure of -17 Pa (capture velocity of 3.2 m/s) negative pressures of at least -7 Pa (capture velocity of 2 m/s) can be achieved at all times.

Experience shows that it is difficult to achieve strong negative pressures under all covers at all times where multiple tanks are ventilated from a common manifold, and where the air supplied to different aeration tanks is uneven. In these situations, the static pressure may need to be -20 Pa or even -30 Pa to ensure effective odour capture.

The capture efficiencies listed in Table 3 are based on the experience, observation and judgement of the authors for covers subject to wind action in Perth. These are conservative estimates of capture efficiencies. The capture efficiency at Subiaco preliminary treatment area was

Table 2. Recommended Capture Velocities (ACGIH, 2001).

Condition of Containment	Example	Capture Velocity
Release with Practically No Velocity into Quiet Air	Evaporation from Tanks, Degreasers, etc	0.25 – 0.5 m/s
Release at Low Velocity into Moderately Still Air	Paint Spray Booths, Intermittent Container Filling, Low Speed	0.5 – 1.0 m/s
Active Generation into Zone of Rapid Air Motion	Spray Painting in Shallow Booths, Barrel Filling	1.0 – 2.0 m/s
Release at High Initial Velocity into Zone of Rapid Air Motion	Grinding, Abrasive Blasting, Tumbling	2.5 – 10 m/s



3. Variability of Wind Speed Measured at Subiaco WWTP.

d at 99.7% in the absence of wind
CEE, 2006). Where fugitive
ıs based on these capture efficiencies
ıte to a significant proportion of the
npacts, direct measurement or
nt of the actual leakage of fugitive
ıs is recommended.

possible to directly calculate the
area for most cover systems with
ision, as most of the leakage occurs
and seals. The equivalent leakage
may be calculated for different
covers from the ventilation rate and
tial pressure:

$$Q_g = VA = C_d \left[\frac{2\Delta P}{\rho}\right]^{1/2} A \tag{8}$$

Dividing by the total plan area of the covers (A_c) gives the ventilation flux rate (q):

$$\frac{Q_g}{A_c} = q = C_d \left[\frac{2\Delta P}{\rho}\right]^{1/2} \frac{A}{A_c} \tag{9}$$

Rearranging,

$$\Delta P = \frac{\rho}{2C_d^{\,2}}\left[\frac{q}{\alpha}\right]^2 \tag{10}$$

Table 3. Capture Efficiency for Covers Subject to Wind Forces in Perth.

Static Negative Pressure (- Pa)	Capture Efficiency (1) (%)
< 5	95
5 – 10	95 – 99
10 – 15	99 – 99.9
15 – 30	99.9 – 100

It may be seen that the ventilation flux rate q, and the equivalent unit leakage area α, are the two most important factors governing the effectiveness of odour containment systems.

Dilution of Odours and Other Contaminants

The concentration of contaminants underneath covers may be reduced by diluting foul air with clean air. High odour concentrations under covers result in fugitive emissions being of similar high concentrations.

For most wastewater treatment processes, the rate of contaminant released is proportional to the area of the liquid surface and may be characterised by a contaminant flux rate Z. Hence the concentration of contaminant in the air under the cover may be expressed as:

$$C_g = \frac{ZA_l}{Q_g} \tag{11}$$

For most situations, $A_l = A_c$, hence:

$$C_g = \frac{Z}{q} \tag{12}$$

Note that Z is not a constant and may depend on a number of factors including the ventilation rate and turbulence in the liquid phase.

For some locations, such as weirs, drops and other points of high turbulence, the rate of contaminant release may be assumed to be proportional to the wastewater flow rate (assuming that the weir height, temperature, pH and pressure are constant). Hence:

$$C_g = \frac{XQ_l}{Q_g} \qquad (13)$$

Equation (13) may be rewritten in terms of the gas and liquid flow rates as:

$$C_g = \frac{X}{G/L} \qquad (14)$$

The contaminant release factor X is governed by mass transfer laws. It is proportional to the contaminant concentration in the liquid phase, as well as other factors including temperature, pressure, pH and the turbulence in the liquid phase. Where these may be considered constant, the constant of proportionality is the stripping factor ø.

$$X = \phi\, C_l \qquad (15)$$

The stripping factor depends on residence time, turbulence and the degree of mixing or overturning of the contents of tanks.

Air Changes Per Hour

Air changes per hour (AC/h) have been used historically to determine the ventilation requirements in a wide variety of situations to control the concentration of contaminants in the atmosphere.

For odour control at wastewater treatment plants, equations (12) and (14) are more appropriate than AC/h. This is consistent with the Australian Standard for the design of mechanical ventilation (AS1668.2-2002), where the recommended approach is based on the dilution index, with generic requirements based on airflow rates per square metre of floor area rather than AC/h.

Ventilation Rates

The design ventilation rates for the 2002 upgrade at Woodman Point WWTP are summarised in Table 4. These facilities failed to meet the odour control objectives for the plant as they resulted in minimal negative pressures and unacceptably high levels of fugitive emissions. Community complaints and concerns about odour extend to 1.5 km from the plant (CEE, 2005). A future upgrade of the odour control facilities is planned for 2007.

Table 4. Design Ventilation Rates at Woodman Point WWTP [(1)] (2002 Upgrade)

Covered Odour Source	Air Changes Per Hour	Ventilation Flux Rate[(1)] (m^3/m^2 h)	G/L Ratio (m^3/m^3)[(2)]
Screens and Grit Chambers	16.9	12.7	0.7
Primary Sedimentation Tanks	4.4	3.1	1.0

(1) The maximum ventilation rates actually achieved were only 80% of the design values.
(2) Based on an average dry weather flow of 160 ML/d (6667 m^3/h) and a peaking factor of 2.0.

Table 5. Design Ventilation Rates at Beenyup WWTP (2003 Upgrade).

Covered Odour Source	Air Changes Per Hour	Ventilation Flux Rate (m^3/m^2 h)	G/L Ratio (m^3/m^3)[(1)]
Screens and Grit Chambers	5.5	6.5	0.5
Primary Sedimentation Tanks	5.8	4.1	1.3

(1) Based on an average dry weather flow of 120 ML/d (5000 m^3/h) and a peaking factor of 2.0.

Table 6. Design Ventilation Rates at Beenyup WWTP (2005 Upgrade).

Covered Odour Source	Air Changes Per Hour	Ventilation Flux Rate (m^3/m^2 h)	G/L Ratio (m^3/m^3)[(1)]
Inlet Gravity Sewers	n/a	n/a	0.5
Screenings Plant (including channels)	30	40	1.9
Grit Tanks (including inlet channels to PSTs)	30	20	0.45
Primary Sedimentation Tanks (including d/s channels)	10	7	2.3
Aeration Tanks [(2)] and Mixed Liquor Channels	n/a	n/a	9.7
Sludge Treatment (Various Sources)	n/a	n/a	0.45

(1) Based on an average dry weather flow of 120 ML/d (5000 m^3/h) and a peaking factor of 2.0.
(2) Based on 20% air extraction above peak aeration air flow.

Table 7. Design Ventilation Rates at Subiaco WWTP (2003 Upgrade).

Covered Odour Source	Air Changes Per Hour	Ventilation Flux Rate (m^3/m^2 h)	G/L Ratio (m^3/m^3)[(1)]
Inlet Gravity Sewers	n/a	n/a	0.4
Screens and Grit Chambers	30	40	2.3
Screenings and Grit Conveyors and Associated Equipment	60	n/a	0.55
Pre-treatment Building [(3)]	12	60[(2)]	7.0
Channels (u/s of PST)	10	7	0.4
Primary Sedimentation Tanks	12	12	2.6
Channels (d/s of PST)	11	13	0.35
Aeration Tanks [(4)] and Mixed Liquor Channels	n/a	n/a	11.3
Sludge Treatment (Various Sources)	n/a	n/a	1.3

(1) Based on an average dry weather flow of 61.4 ML/d (2558 m^3/h) and a peaking factor of 2.0.
(2) Based on floor area.
(3) Actual operating ventilation rates are less than half of these values.
(4) Based on 20% air extraction above peak aeration air flow.

The design ventilation rates for the 2003 upgrade (Phase 1) at the Beenyup WWTP are summarised in Table 5. At these ventilation rates, only minor negative pressures were developed underneath the covers resulting in unacceptably high levels of fugitive emissions. Community complaints and concerns about odour extended to 1.5 km from the plant (CEE, 2006). As a result of the failure to achieve acceptable levels of odour control, further works were undertaken in 2005 (Phases 2 and 3) to cover additional process units and increase the ventilation rates to the levels shown in Table 6. This resulted in a dramatic improvement in odour control, with increased negative pressures and far lower levels of fugitive emissions from the preliminary and primary treatment areas, which are the major sources of odour emissions at Beenyup. Now, community complaints about odour have been considerably reduced to virtually nil beyond about 750m from the plant (CEE, 2006).

The odour control facilities at Subiaco WWTP were installed in 2003 with the

Table 8. Recommended Design Criteria for Near Complete Odour Containment at Wastewater Treatment Plants in Perth

Covered Odour Source	Recommended Design Criteria for Near Control Odour Capture
Inlet Gravity Sewers	The ventilation rate should be sufficient to negate pressure fluctuations in the sewer and maintain negative pressures at all times. A ventilation rate of 40-50% of the peak wastewater flow rate (m^3/h) may be satisfactory based on experience at Beenyup and Subiaco WWTPs.
Screens and Grit Chambers	The covers on screens generally contain many openings (up to 1% of the total covered area) and it is not practical to achieve strong negative pressures underneath these covers. The ventilation rate (not for personnel entry) should be the greater of 36 m^3/m^2h or 30 AC/h, to ensure > 99% odour capture.
Channels (Unsettled and Settled Wastewater)	For well fitted covers designed to achieve near complete odour capture (> 99 %) the ventilation rate (not for personnel entry) should be 12 m^3/m^2h (1).
	For covers with many openings (not greater than 1 % of total covered area), and not designed to achieve strong negative pressures, the ventilation rate (not for personnel entry) should be the greater of 36 m^3/m^2h or 30 AC/h to ensure > 99% odour capture.
Primary Sedimentation Tanks	For well fitted covers designed to achieve complete near odour capture (> 99%) the ventilation rate (not for personnel entry) should be 12 m^3/m^2h (1).
Aeration Tanks	For well fitted covers, designed to achieve near complete odour capture (> 99%) the ventilation rate (not for personnel entry) should be 20% above the peak aeration air flow rate.
Mixed Liquor Channels	The ventilation rate should be 6 m^3/m^2h, for well fitted covers (not for personnel entry) designed to achieve near complete odour capture (> 98%).
Sludge Handling Facilities	The ventilation rate (not for personnel entry) for covered tanks, silos and major items of process equipment should be up to 30 AC/h (2) based on head space volume under normal operations.
	The ventilation rate for small items of equipment such as conveyors, and other equipment containing sludge or sludge related material should be up to 60 AC/h (2) based on empty volume.
	The ventilation rate for drains and partially filled pipes containing sludge or sludge related material should be > 0.75 m/s calculated on an empty pipe.
Secondary Containment Buildings (Pre-treatment and Primary Treatment)	Where the primary sources of odour and H_2S are covered and contained by appropriate ventilation, the building ventilation rate may be operated at 18 m^3/m^2h (floor area) and achieve > 95% odour capture with all windows and doors closed. Capacity should be provided to increase the ventilation rate to 36 m^3/m^2h (floor area) when covers need to be removed for maintenance. Safe working procedures must address the hazards of H_2S during maintenance activities.
	Where the primary sources of odour and H_2S inside the building are not effectively controlled, specific investigations are required to ensure that the atmosphere inside the building is safe for operators, maintenance personnel and visitors.

Note (1): These ventilation flux rates are recommended for use with well maintained, tightly fitted covers with few openings such as the covers installed at the Subiaco WWTP. Ventilation flux rates in this range should ensure that static pressures of at least -17 Pa are achieved underneath these covers. Higher or lower rates may be necessary to achieve the desired negative pressures with other cover systems.

Note (2): Very tight covers and enclosures with few openings, may achieve the recommended capture velocities of >2m/s at lower ventilation rates.

design ventilation rates summarised in Table 7. These ventilation rates achieve static negative pressures under the primary tank covers of at least -15 Pa and generally up to -20 Pa. Fugitive emissions are very low, and the degree of odour containment is estimated to be better than 99%. There have been no odour complaints in over 2 years and telephone surveys show a high level of community satisfaction with the odour upgrade.

Recommendations

The ultimate test of odour control works is the level of community satisfaction with the outcome. In this respect, the Woodman Point and Beenyup Phase 1 upgrades were not successful and further work was required. The Subiaco upgrade, which was designed to achieve better odour containment and included a reliable scrubber system with an emphasis on achieving 99.9% availability, was a success.

Based on our experience in Perth, the recommended design criteria is to achieve a capture velocity of at least 2m/s under all conditions. This will provide near complete odour capture, which is essential for large treatment plants with high incoming odour levels. The ventilation flux rates are higher than commonly used in North America and European practice. This is believed to be the result of the particularly high odour levels experienced at large plants in Perth and the need to retrofit odour control facilities into plants not specifically designed for odour containment.

The degree of odour nuisance depends on the total odour emissions from the plant. For small plants, or plants with low incoming sulphide levels, a lower level of capture (say 80 to 90%) may be acceptable. For large plants in Perth, it is necessary to aim for 98 to 99% odour capture.

Lower ventilation rates may be used where odour levels are low and thus a lower degree of odour capture is acceptable, or where the design, installation and operation of cover systems enables the recommended negative pressures and capture velocities to be achieved at the lower ventilation rates. This can be achieved only if the equivalent unit leakage area is less than the best examples of covers used in recent odour control projects in Perth. The authors caution against using ventilation rates less than those recommended in Table 8 without the strongest of evidence as to the effectiveness of the proposed cover system and meaningful performance guarantees linked to the achievement of a static negative pressure that will ensure a capture velocity of at least 2m/s is achieved at all times. Because of the high temperatures and high sulphide levels in Perth wastewater, best practice capture (listed in Table 8) must be used to control odour emissions in Perth.

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Definitions

a	Coefficient
A	Total leakage area (m^2)
A_c	Plan area of cover (m^2)
A_l	Plan area of liquid surface (m^2)
C_d	Coefficient of discharge. Generally assumed to be in the range 0.60-0.65 for sharp edged inlets and turbulent flow.
C_g	Concentration of contaminant in air (mass or odour units/m^3)
C_l	Concentration of contaminant in wastewater (mass/m^3)
C_p	External pressure coefficient
C_{wo}	Global wind pressure coefficient
g	Acceleration due to gravity
G/L	Gas/liquid ratio (Q_g/Q_l)
h	Separation height between inlet and outlet (m)
K	Coefficient
K_w	Velocity coefficient relating to topography and the height of the structure
P_a	Atmospheric (Barometric) pressure (Pa)
P_i	Inside pressure (Pa)
P_o	Outside pressure (Pa)
q	Ventilation flux rate (m^3/s per m^2 of plan area of cover)
Q_g	Ventilation rate (m^3/s)
Q_l	Wastewater flow rate (m^3/s)
T_o	Outside temperature (°K)
V	Velocity across opening (m/s)
V_o	Velocity across opening that will negate the effects of wind action
V_w	Free wind speed measured at the standard height of 10 m (m/s)
X	Contaminant release factor (mass or odour units released per m^3 of wastewater)
z	Height of covers above ground level (m)
Z	Contaminant flux rate (mass/s or odour units/s per m^2 of liquid surface area)
α	Equivalent unit leakage area (m^2 per m^2 of plan area of cover)
ΔP	Pressure differential across opening due to ventilation $(P_a\text{-}P_i)$(Pa)
ΔP_t	Pressure differential due to thermal buoyancy (Pa)
ΔP_w	Pressure differential due to wind action (Pa)
ΔT	Temperature differential (°C)
ρ	Air density (kg/m^3)
$ø$	Stripping factor