
33 OIL SEPARATORS

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33.1 INTRODUCTION

33.1.1 Application and Purpose

Oil separation devices are applicable for stormwater runoff from areas where hydrocarbon products are handled or where small spills routinely fall on paved surfaces exposed to rain.

The objective of the oil separators is to treat most of the flow (90 to 95%) from a potentially contaminated catchment to an acceptable degree (10 – 20 mg/l oil and grease) and to remove free floating oil. In addition to collecting oil, which rises to the surface, separators collect sediment, which falls to the bottom of the devices. In fact, the sediment is likely to contain petroleum products, which are attached to fine sediments. Oil separation devices sized in accordance with the guidelines in this Chapter will achieve a sufficient degree of sedimentation so further sedimentation devices would not be required.

Oil in general urban stormwater runoff is likely to be in the form of an emulsion, which is intimately mixed with the water. Such oil will not readily float out, so oil separators are not used for treatment of general urban runoff.

Oil separators need to treat only the stormwater runoff from oily areas or areas which may become oily. General stormwater runoff from other areas should be routed away from the separator and treated for sediment removal in the usual fashion. Treatment should be as close to the source of the oil-generating activities as possible.

High rates of runoff and practical limitations on the treatment process mean that oil separators can only be used for small catchment areas. For Malaysian conditions the practical maximum catchment area that can be treated is in the order of 1000 m² (0.1 hectare).

More relevant applications are for :

- service stations,
- yards where petroleum products are stored or handled, or vehicles are serviced, and
- heavily used highway parking lots.

The potential also exists to use separators (and in particular, the balancing storage) for containment of accidental oil spills, in addition to their primary function of treatment. Spills will enter the separator via the site drainage system and mix with the water in the separator, then the oil in the spill will rise to the surface. If the separator is to be used for spill containment, it should be ensured that the separator can hold the anticipated spill volume. Additional storage may be required.

33.1.2 Types of Separator

API tanks (see Figure 33.1) and plate separators are the more efficient oil separators. API tanks were originally designed by the American Petroleum Institute (API) for use in refinery applications, but modifications of the design can be used for stormwater treatment.

Plate separators (see Figure 33.2) contain packs of plates, typically spaced at 10 mm to 20 mm centres. The plates increase the effective surface of the device. Viewed another way, the close spacing of the plates reduces the height that an oil droplet must rise before it reaches a collecting surface. Therefore, to achieve the same degree of treatment as an API tank, a much smaller device can be used. This will result in less land area being taken up and less excavation, which will more often than not compensate for the higher cost of the plate packs. Plate separators are often supplied by manufacturers as proprietary devices.

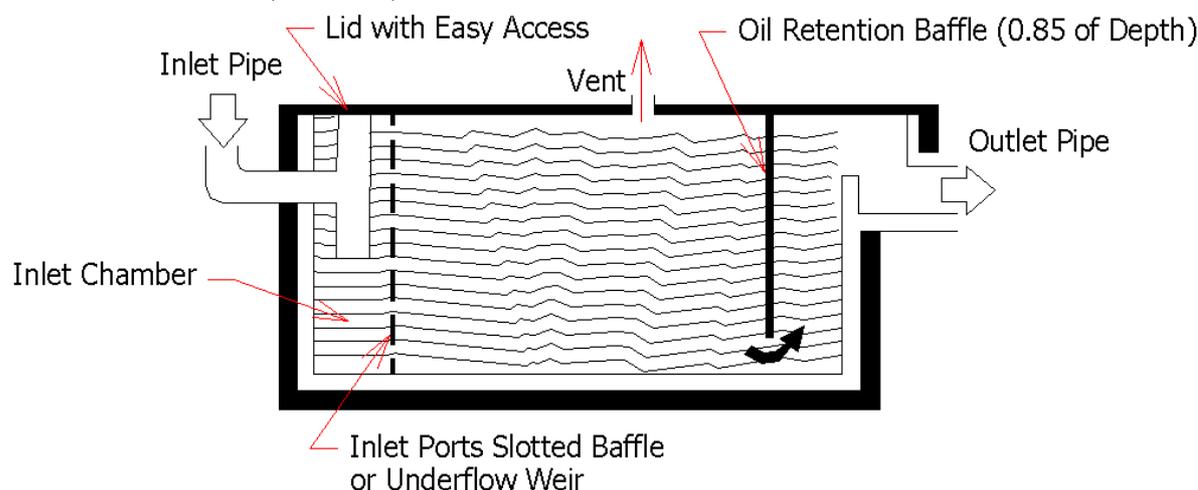


Figure 33.1 Schematic of API Separator

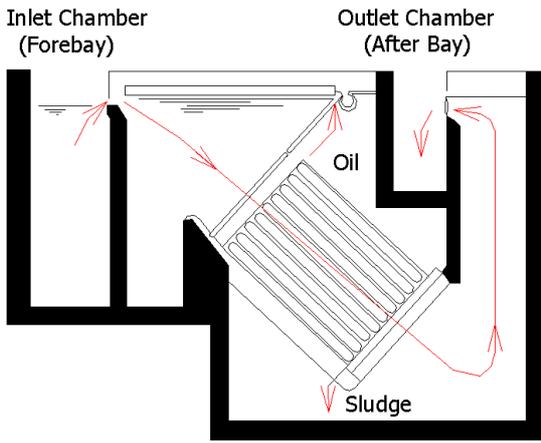


Figure 33.2 Schematic of Plate Separator (Meyers, 1980)

33.1.3 Flow Configuration

Oil separators, which receive stormwater runoff, should be installed with a high flow bypass and flow balancing, unless special circumstances make it impractical. The high flow bypass diverts excess flows away from the separator, ensuring that it is not overloaded. Flow balancing uses storage to reduce the peak inflow rate and increase the efficiency of the separator. The

recommended configuration is shown schematically in Figure 33.3.

(a) *Flow balancing*

A storage tank is provided upstream of the separator to reduce the peak inflow rate to that which the separator can handle. The stored runoff is treated slowly through the separator in the period between storms. The flow rate through the separator is then more even or 'balanced'.

In large storms, the storage area may fill completely, in which case some flow is bypassed without treatment. The storage area may consist of a tank or banded area. The potential also exists to use the storage area for containment of fuel spills.

(b) *High-flow Bypass*

The bypass configuration is also shown in Figure 33.3. The bypass begins to operate when the balancing storage becomes full. At this stage the water level in the bypass is at the bypass weir level and the flow through the separator is controlled hydraulically to Q_d (the separator design flow). Careful hydraulic design is necessary to achieve this condition.

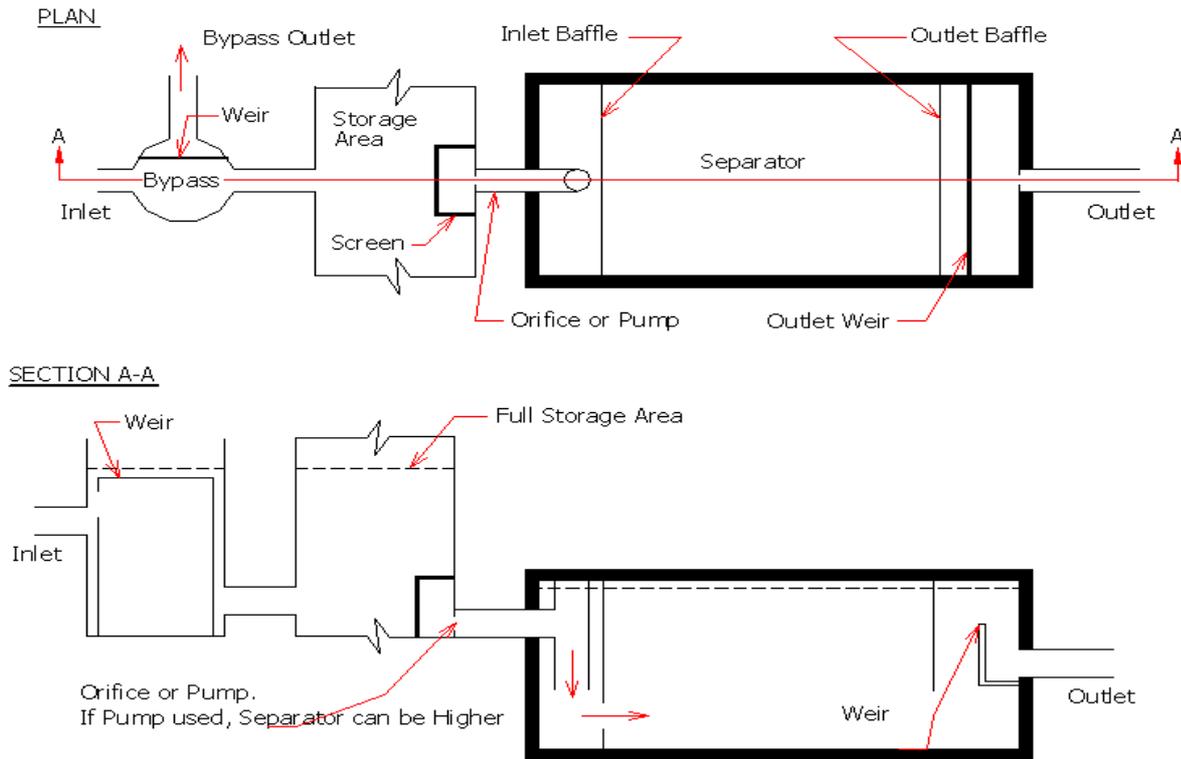


Figure 33.3 Oil Separator with Bypass and Flow Balancing

Usually flow throttling will be at the outlet of the tank because if the flow constriction orifice were at the inlet, the oil may become emulsified. Furthermore, an orifice at the outlet is less likely to clog. A non-emulsifying (e.g. diaphragm) pump may be used instead of flow throttling to control the flow rate to the separator. The bypass weir should be long enough to pass the maximum design flow in the incoming pipe while keeping the flow to the separator small enough to ensure that oil re-entrainment does not occur.

33.2 DESIGN AND SIZING

33.2.1 Design

Oil separators shall be divided into three compartments by baffles or berms: a forebay (inlet chamber), an oil separator cell, and an afterbay (outlet chamber). The forebay is primarily to trap and collect sediments, encourage plug flow and reduce turbulence. The oil separator cell is to trap and hold oil. The afterbay provides a relatively oil-free exit cell from the outlet.

The length of the forebay shall be approximately 1/3 of the total length of the three cells (see Figure 33.1). The oil-retaining baffle shall be located approximately 1/4 of the total length of the three cells from the outlet wall.

33.2.2 Degree of Treatment

The degree of treatment achieved by the separator system depends on two factors:

- What level of treatment is achieved for flow, which is passed through the separator? In other words, what is the design level of treatment at the design flow rate?
- What fraction of the runoff from the catchment is passed through the separator? A higher flow capacity of the separator or a larger flow balancing area will result in more flow being treated.

(a) Design Level of Treatment at Design Flow Rate

Grease and oil, which is not emulsified, dissolved or attached to sediment, will be present as oil droplets or as a surface slick. If only large droplets can be removed, then small droplets will pass through the device and into the receiving water body. If small droplets can be removed, then effluent quality will be improved (at the expense of requiring a slower passage of stormwater through the device, because smaller droplets rise more slowly).

No data are available on the size distribution of oil droplets in stormwater from commercial or industrial areas, but some overseas data are available for petroleum product storage terminals. These data indicate that about 80% of droplets (by volume) are greater than 90 µm and 30% are

greater than 150 µm in diameter (Washington State Department of Ecology, 1990).

Traditionally, 150 µm separation has been used overseas, which typically results in an effluent oil and grease concentration of 50 – 100 mg/l (Meyers, 1980). Typically standards for industrial discharges in Australia are 10-20 mg/l, which generally corresponds to the removal of droplets larger than 60 µm (Meyers, 1980). Separation of the 60 µm droplet was adopted as the basis for design for devices in Australia and New Zealand; this figure corresponds to the lower tail of the droplet size distribution and should result in an effluent quality of 10 - 20 mg/l at the design flow.

The rise velocity for a 60 µm droplet can be calculated, given the water temperature (which affects the viscosity of the water) and the density of the oil. This rise velocity is then used in the sizing calculations for the device. The rise velocity may be calculated according to:

$$V_r = \frac{g D^2 (1 - s)}{18\nu} \quad (33.1)$$

where s = specific gravity of the oil,

D = the droplet diameter (m),

ν = kinematic viscosity of water, and

g = gravitational acceleration (9.8 m/s²).

At 15°C and for an oil specific gravity of 0.9, the rise velocity of a 60 µm droplet using Equation 33.1 is 0.62 m/hr and this is the recommended design value for most situations.

(b) Fraction of Runoff Treated

The objective is to treat 90% to 95% of the runoff from the catchment on a long term basis (not for each and every rain event). The choice of the degree of treatment is based on rainfall analysis, as discussed in Chapter 13. This degree of treatment leads to a required separator flow capacity, and possibly a requirement for flow balancing storage.

33.2.3 Design Flow Rate

The required design flow rate is that from the water quality design storm (see Chapter 4). This 3 month ARI flow (and smaller flows) should be passed through the flow balancing storage and the device, and flows in excess of this amount are bypassed. This means that only 5% - 10% of the flow is bypassed (on a long term basis, not for each flow event).

The peak design inflow rate can be computed using the Rational Method or hydrograph methods, as described in Chapter 14.

For service stations, the catchment area should include an allowance for rain, which manages to get under the canopy. In some cases washout water from under the canopy areas in service stations, or spill-down water from open paved areas, will be passed to the separator. It is unlikely that wash-down and heavy rain will occur at the same time, so it is not necessary to add the wash-down flow to the stormwater runoff flow. Rather, the maximum of the stormwater runoff flow and the wash-down flow can be used to size the separator. That is, if the wash-down flow is larger than the calculated peak inflow, then use the wash-down flow as the design flow.

33.2.4 Flow Balancing Storage Volume

The required volume of the flow-balancing compartment depends on the design storm runoff rate and volume and the treatment rate of a separator. The calculation of the balancing volume is done by storage routing, as described in Chapter 14. A worked example is given in Appendix 33.A (ii).

33.2.5 API (American Petroleum Institute) Tank Sizing

The horizontal velocity U in the tank is calculated as:

$$U = \frac{Q_d}{d \times W} \quad (33.2)$$

where d = tank depth and
 W = tank width

The plan area (A_d) for the separator cell is based on the rise velocity (V_r) and design flow rate (Q_d), according to the formula:

$$A_d = \frac{F Q_d}{V_r} \quad (33.3)$$

Based on plug flow, the above relationship ensures that a droplet with rise velocity V_r will rise to the surface during its passage through the tank. The required rise velocity is the rise velocity of a 60 μm oil droplet (see Section 33.2.2(a)), which for a temperature of 15°C and an oil specific gravity of 0.9, is 0.62 m/hr. The dimensionless factor F accounts for short-circuiting and turbulence effects, which degrade the performance of the tank. This factor depends on the ratio of horizontal velocity (U) to rise velocity (V_r), as shown in Table 33.1.

The volume and area determined from this tank sizing refer to the dimensions of the main compartment of the tank. Additional volume should be allowed for inlet and outlet sections in the tank.

Table 33.1 F Factor for API Separators

U/V_r	F Factor
15	1.64
10	1.52
6	1.37
3	1.28

Other dimensional requirements (from American Petroleum Institute, 1969) are:

- $\frac{U}{V_r} \leq 15$
- $0.3 W \leq d \leq 0.5 W$
- $2 \text{ m} < W < 5 \text{ m}$
- $1 \text{ m} < d < 2.5 \text{ m}$

where d is the depth and W is the width of the tank.

Some of these dimensions will not be appropriate for smaller catchments and may need to be relaxed.

To avoid re-entrainment and degradation of performance, it is required that the maximum horizontal flow velocity in the main part of the tank be less than 25 m/hr (when the bypass is operating at the maximum flow).

33.2.6 Plate Separator Sizing

A flowchart for the sizing of an API plate separator is given in Figure 33.4.

Plate separators are available from several suppliers. The suppliers will be able to provide an appropriate size of device to achieve 60 μm droplet separation at the chosen design flow rate (Q_d). The required effective area can be calculated from:

$$A_E = \frac{Q_d}{V_r} \quad (33.4)$$

where A_E = effective area

Some increase in the calculated size should be allowed, to account for short-circuiting.

33.2.7 Flow Control Device

(a) Orifice Sizing (Inlet pipe to separator)

For a round orifice plate flowing full, with head (h), the area of the orifice is estimated from:

$$A_o = \frac{Q_d}{0.6\sqrt{2gh}} \quad (33.5)$$

where Q_d = the design flow (m^3/s),

A_o = area of the orifice (m^2),

g = gravitational acceleration (m/s^2), and

h = head (m).

Other means of throttling the inlet may be used, with design based on the appropriate head loss formula. As an alternative to hydraulic flow control a non-emulsifying pump may be used to control the flow rate.

The recommended orifice sizing procedure is as follows:

1. Choose an orifice diameter and calculate the orifice area. Consideration should be given to the risk of blockage.
2. Calculate the water level in the bypass when the design flow, Q_d is being passed through the separator. Set the bypass weir at this level.
3. Calculate the head over the bypass weir (h_w) (using an assumed weir length) when the weir is passing Q_w , the maximum flood flow to go over the bypass. A standard weir equation may be used to calculate this head.
4. Calculate the flow through the separator when the bypass weir is passing Q_w . If this flow is larger than the maximum allowed flow through the separator, then either increase the bypass weir length and return to Step 3, or reduce the orifice area and return to Step 1. The maximum allowed flow for a plate separator is 2 times Q_d while the maximum allowed flow for an API tank is the flow corresponding to a horizontal velocity of 25 m/hr.

In some situations it may be desirable to use flow throttling at the inlet to the tank rather than at the outlet. In this situation there would be less variation of water level in the tank (which is beneficial for oil skimming) but there would be larger velocities at the inlet (which may cause oil emulsification). To avoid emulsification, it is recommended that flow velocities through an inlet flow control orifice be limited to less than 0.5 m/s.

33.3 OTHER DESIGN CONSIDERATIONS

33.3.1 Oil Retention Baffles

An inlet baffle is required so that oil collected in the tank does not pass back into the bypass and over the bypass weir. The baffle may consist of a wall extending down from the surface. Alternatively, an inverted elbow, or preferably a tee (to make cleaning easier), may be attached to the inlet pipe as shown in Figure 33.1. The tee extends down below the oil level so oil will not pass back into the bypass.

An outlet baffle extending from the surface down is required to stop trapped oil from passing over the outlet weir.

33.3.2 Flow Spreading Baffles

To achieve even flow distribution across tanks at the inlet, baffled inlet ports or other devices are used. API (1969) recommended slotted inlet baffles, while other devices such as those used in settling tanks in wastewater treatment plants may be used.

The sizing of the inlet ports or baffles should be such that some head loss is provided (to spread flow), but it is recommended that velocities should be less than 0.5 m/s, at the maximum separator flow to avoid oil emulsification.

33.4 MAINTENANCE

With any oil separation device maintenance is essential. Oil and solids build up to such a degree that gross re-entrainment of captured pollutants occurs. The devices are then ineffective. For this reason, maintenance schedules must be submitted with the permit application.

Oil Removal – The separator should be inspected periodically and frequently to determine the amount of oil collected. Oil should be removed if necessary (by pumping or decanting). For automatic oil skimming systems, checks can be less frequent, since, if the oil outlet device is working properly, oil should not collect to a great depth.

Oil will usually be decanted or pumped to a storage tank or barrel, which should be checked periodically. If the tank or barrel is full, the oil should be removed for re-refining or disposal.

Oil Absorbing Pads – Pads (if used) should be checked and replaced if they are saturated. The used pads should be disposed of in an appropriate manner.

Oil Skimmer Operation – The bypass should be checked to determine whether oil is collecting in the bypass. If so, the oil should be removed and modifications to the pipe between the bypass and separator should be considered.

Removal of Sediment – The slurry at the bottom of the tank should be removed periodically and disposed of. Sediment removal from the bypass may be required as well. Sediment should also be removed from the flow balancing compartment (if used).

Cleaning of Screens – Screens, which remove debris or protect the flow control orifice (if used) should be cleaned regularly.

Clearing of Orifices – Orifices and inlet pipes should be checked regularly for clogging and should be unplugged if

necessary. If clogging is a persistent problem, then further screening should be used.

separator is not operating. It should be compared with the design value and the weirs adjusted if necessary.

Weir Levels – A check should be made of the elevation of the bypass weir with respect to the water level when the

Access – Easily removed covers and easily accessed screens and orifices should be used. This will ensure ease of maintenance.

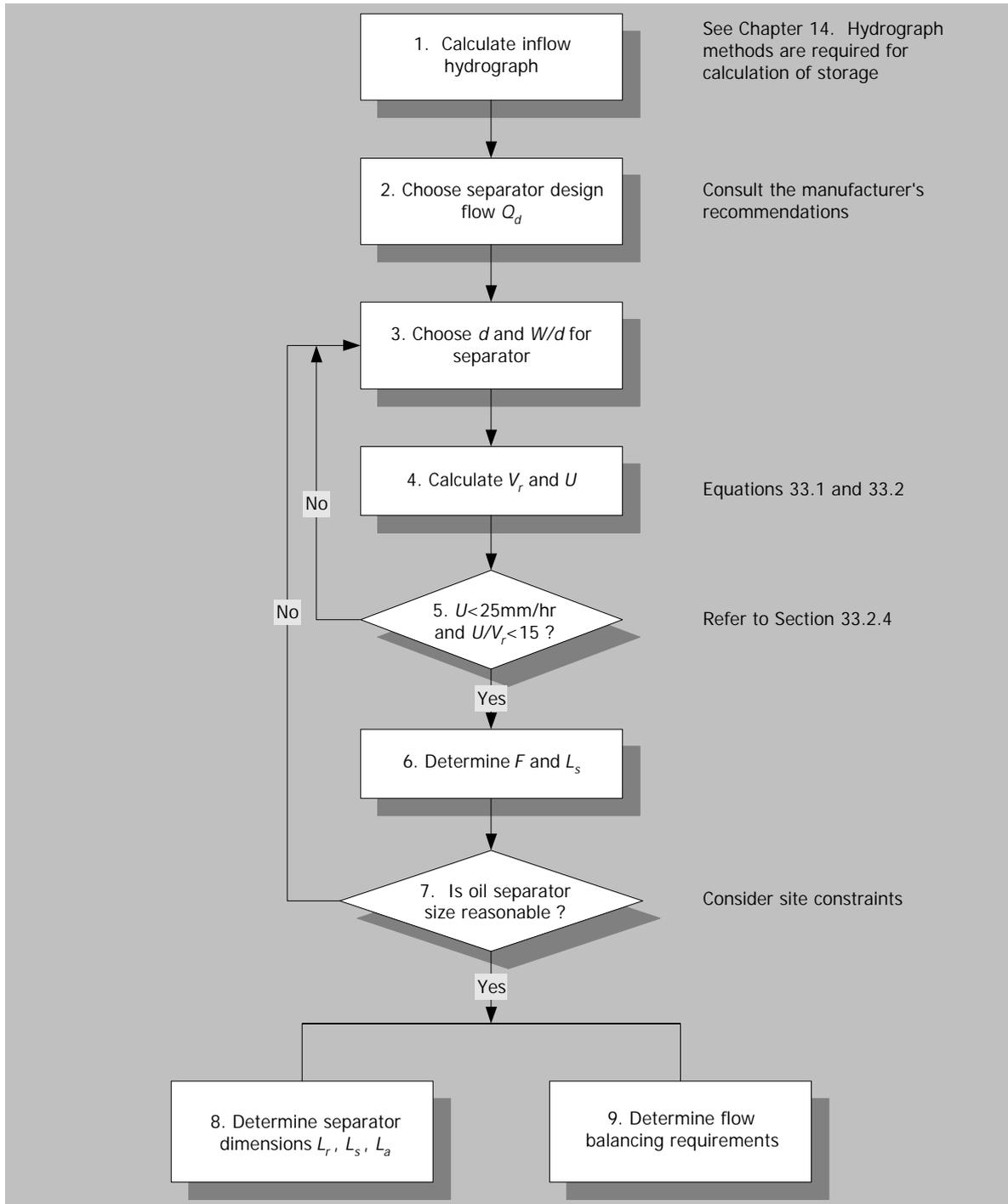


Figure 33.4 Flow Chart for Sizing of API Oil Separator

APPENDIX 33.A WORKED EXAMPLE

A service station is fitted with an oil separator. The layout is shown in Figure 33.A1. Runoff from unpaved areas, the covered forecourt, and areas unlikely to be contaminated with oil is routed away from the separator. This leaves a paved oily surface of 300m² draining to the oil separator. The wash-down water from the carwash is routed to the sanitary sewer.

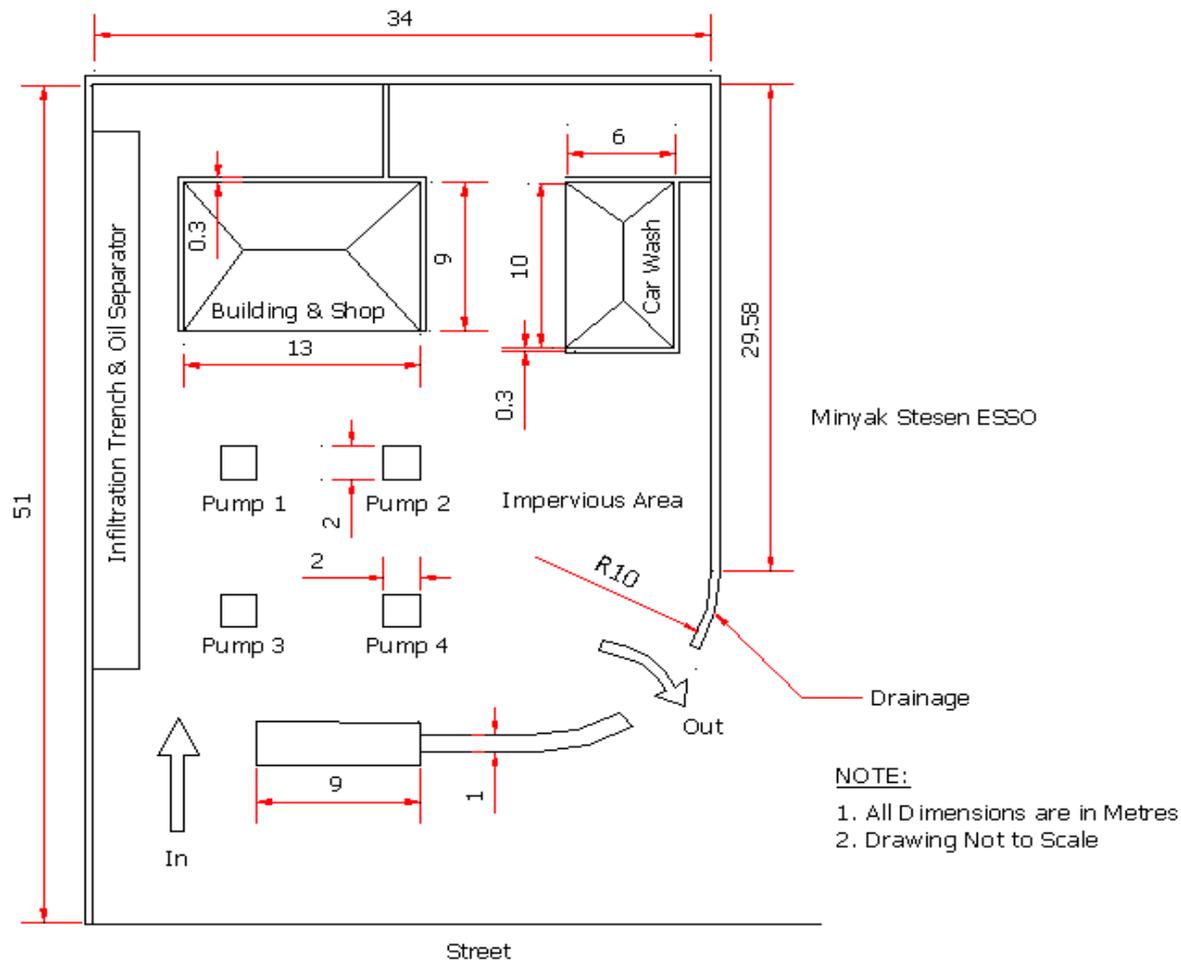


Figure 33.A1 API Tank Design for Example Service Station

Step 1. Design Flow

$C = 0.9$ for impervious area

$A = 300 \text{ m}^2$

$t_c = 5 \text{ min}$ (assumed)

I_5 for 3 month ARI and t_c of 5 min = 120mm/hr

$$Q_{\text{peak}} = \frac{CIA}{360} \quad (\text{Equation 14.7, see Chapter 14}).$$

$$= \frac{(0.9 \times 120 \times 0.03)}{360} = 0.009 \text{ m}^3/\text{s} = 32.4 \text{ m}^3/\text{hr}$$

Step 2

From the manufacturer's advice, the design flowrate $Q_d = 5 \text{ m}^3/\text{hr}$

Step 3. Trial sizing of oil separator

Try $d = 1.0 \text{ m}$ and $W = 2.5 \text{ m}$

Step 4

For design flowrate $Q_d = 5 \text{ m}^3/\text{hr}$

$$U = Q/(d.W) = 5/(1.0 \times 2.5) = 2 \text{ m/hr} \quad (\text{Equation 33.2})$$

For a design particle size of $60 \mu\text{m}$ or larger oil droplets, $V_r = 0.62 \text{ m/hr}$ (Equation 33.1)

$$U/V_r = \frac{2}{0.62} = 3.23$$

Step 5

The trial design complies with velocity limits, so it is accepted.

Step 6

From Table 33.1, $F = 1.28$

Plan area of API separator cell A_d

$$= \frac{5 \times 1.28}{0.62} = 10.3 \text{ m}^2 \text{ hr} \quad (\text{Equation 33.3})$$

Length of separator cell $L_s = A_d/W$

$$L_s = 10.3/2.5 = 4.12 \text{ m}$$

Step 7

The trial design is considered to be acceptable as it meets site constraints.

Step 8

Total length of separator L (refer Figure 33.1):

$$L = L_f + L_s + L_a$$

$$L = L/3 + 4.12 + L/4$$

$$(1 - 0.33 - 0.25) \times L = 4.12$$

$$L = 9.8 \text{ m, say } 10 \text{ m overall}$$

Step 9. Calculation for Flow Balancing

(i) The critical design storm for storage will be longer than the calculated t_c . Try a series of different durations.

Trial $t = 20 \text{ min}$ (assumed)

I_5 for 3 month ARI and t_c of 20 min = 94.13 mm/hr

$$Q_{peak} = \frac{CIA}{360} \quad (\text{Equation 14.7, see Chapter 14}).$$

$$= \frac{(0.9 \times 94.13 \times 0.03)}{360} = 0.0071 \text{ m}^3/\text{s}$$

(ii) The storage routing calculation for flow balancing is shown in the following table.

Table 33.A1 Routing Calculation for Flow Balancing Storage

Cumulative Time (min)	Inflow (m ³ /s)	Inflow Volume (m ³)	Outflow (m ³ /hr)	Outflow Volume (m ³)	Cumulative Storage (m ³)
0	0				
2.5	0.0035	0.263	5	0.104	0.159
5	0.0071	0.795	5	0.208	0.746
7.5	0.0071	1.065	5	0.208	1.603
10	0.0071	1.065	5	0.208	2.460
12.5	0.0071	1.065	5	0.208	3.317
15	0.0071	1.065	5	0.208	4.174
17.5	0.0071	1.065	5	0.208	5.031
20	0.0071	1.065	5	0.208	5.888
22.5	0.0035	0.795	5	0.208	6.475
25	0	0.263	5	0.208	6.530

- (iii) Repeat the calculation for storm durations of 30 min, 45 min, 60 min, etc.

These calculations give the following results:

Storm Duration (min)	Cumulative Storage (m ³)
20	6.53
30	6.69
45	6.99
60	6.67
90	5.41
120	3.71

The critical storm duration (that which gives the largest storage requirement) for the balancing storage is 45 minutes and the volume required for flow balancing = 7 m³