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Design Requirements for the Treatment of Stormwater Contaminated with Jet Fuel Oil using Corrugated Plate Interceptor

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Abstract

Oil contamination in the stormwater has been generally overlooked even though it causes major environmental pollution and a substantial threat to all species in the ecosystem. Likewise, the treatment of oil-contaminated stormwater in public areas and general industries, especially airports, has also been ignored. Airports are known as one of the most potent contributors to the jet fuel oil contamination of stormwater that pollutes the local waterways. There are many Best Management Practices (BMPs) of stormwater at airports, such as detention ponds, retention ponds, and infiltration basins in which stored water is exfiltrated through permeable soils. However, not many kinds of literature regarding specific actions taken to treat the stormwater contaminated with jet fuel oil within the boundaries of airport facilities. This paper presents the design requirements for the treatment of stormwater in an airport using corrugated plate interceptor (CPI). Specifically, this paper discusses the characteristics and the contaminants of stormwater runoff from certain airports and the design requirements of CPI in treating the wastewater. The design requirements were based on an actual study conducted in an airport using the CPI. The requirements include determining jet fuel concentration at the inlet and outlet of the CPI; selecting the jet fuel density; evaluating the flow rate, oil storage and sludge storage capacity; and determining the oil globule size and surface charge. In addition, the evaluation of the coefficient of surface separation and the design of corrugated plate packs are also elaborated.

Keywords: Stormwater; Jet Fuel; Corrugated plate interceptor (CPI); Airport; Oil-water

1. Introduction

Measures which have been taken by developed and developing countries to treat the oil-contaminated stormwater are mostly confined to high-end industries, such as refineries; petrochemical plants; power plants; mills. Whereas the treatment of oil-contaminated stormwater in public areas, such as theme parks; vehicle washing shops; and maintenance parking bays and general industries such as fabrication yards; workshops; manufacturing mills; and airports, has been ignored. The airports stormwater treatment management is primarily exercised in most developed countries not only due to the huge catchment area of airports but also due to the fact that airports release possibly one of the most contaminated runoff waters.[1] Airports are one of the key important areas for the stormwater surface runoff to be treated before being discharged into the watercourse. The key elements of contamination in airports surface runoff include slitter, sand, dirt, grease, and oil (especially jet fuel) [2]. Two major factors contribute to the contamination level of the stormwater flow in airports. First, the airports, in general, have a huge catchment area, for instance, hardstand area that includes runways, taxiways, parking, and aprons. Therefore, the volume of the stormwater from these areas is

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expected to be quite huge. Second, the stormwater flow rate considerably depends on climatic conditions of the location of a certain airport [3].

In addition to the issues noted above, further research needs to be conducted on designing treatment systems to ensure that backflow does not happen at the time of high stormwater levels so that flooding event can be avoided in the airports. This point leads to the next problem as these treatment systems need to be located underground to ensure the stormwater flow is smooth enough through the designed treatment system. The static and dynamic loading of big aircrafts and possibilities for accidental jet fuel discharge are two crucial considerations when designing and locating the underground stormwater treatment plants.

The corrugated plate interceptor (CPI), which has combs of plates arranged in packs, creates the surface area for reactions between the incoming contaminated stormwater (suspended solids and jet fuel) and the plates to remove the jet fuel and the suspended solids [4]. Although numerous studies have been conducted and many stormwater management projects have been carried out or completed, only a little attention has been paid to the treatment of stormwater to achieve water of higher quality. The value of 800 m^2 of parking apron can easily be surpassed; thus, airports are quite important and significant areas to have the CPI installed. This further leads to the necessity of installing CPI in the airports, where the areas are easily contaminated with jet fuel, as part of the stormwater treatment system. In airports, jet fuel hydrants are placed all over the parking aprons where minor maintenance activities are also typically carried out for the purpose of fuelling the aircrafts. Therefore, CPI can be an effective way to treat surface runoffs and stormwater in airports. This study aims to provide some basic understanding of the design requirements for the treatment of stormwater contaminated with jet fuel oil using CPI in an airport. Specifically, the objective of this study is to highlight some design considerations such as jet fuel density, flow rate, oil storage and sludge storage capacity, oil globules size, coefficient of surface separation, the material of construction for the corrugated plate packs and some other design considerations.

2. Characteristics and Contaminants of Stormwater Runoff from The Airports

The efficiency of CPI depends on the pollution by fuel or hydrocarbons, but only if fuel or hydrocarbons are free and in abundance [5, 6]. The separators are adapted to intercept massive pollutions from fuel distribution areas, car wash utilities, airports, and accidental discharges. On the contrary, their usage seems less relevant for car parks and roads, where traces can be seen, but the concentration traps remain low. It is also not clear that fuel hydrocarbons coming from motor vehicles and soaking into the concrete will be washed by water. CPIs are, therefore, more adaptable for an industrial treatment than for treatment of runoff waters. There is also a mix up due to the presence of the settling tank upstream of the separator. However, it is not designed to intercept the type of particles where hydrocarbons can fix. In fact, the liquid-liquid separation of hydrocarbons requires an ascending velocity of about 8 m/h, while purification by sedimentation requires descending velocities between 1 and 3 m/h [7]. A different approach would be necessary for urban runoff because of its nature and characteristics; thus, the lamellar sedimentation seems to be the most adaptable alternative. A sedimentation followed by separation of oil would be ideal [8].

Moreover, even if sometimes the cleaning of CPI does not improve the purifying efficiency, most of the time, poor maintenance results in dysfunctions. Municipalities should organise not only maintenance and control programs of the separators' performances but also an inventory of the quantities of hydrocarbons extracted [9]. Rusticity and robustness are qualities for this type of work since in most cases, maintenance will be rare and carried out by someone not qualified or particularly motivated. Insulation is also recommended to limit acts of vandalism. The settling of measuring equipment and alarms (for example, captors detecting the level of sludge and probe detecting the level of hydrocarbons) is necessary for better reliability and optimisation of operating costs. For better management, these alarms can be connected to remote monitoring [10]. Important differences in the behaviour of the separators also exist due to their settling on different types of watersheds. Several parameters, such as discharge, effluents, length of rain events and their frequency of occurrence, and pollution, are important considerations in choosing the installation and design of the pre-treatment work [11]. The quality of the CPI is not the only parameter. It needs to be adapted to give precise conditions of use. A preliminary study into the treatment trials for each water purifier seems necessary to quantify and qualify the runoff waters, and the results are used as a basis for the choice and design of separators. For this end, the purifying efficiency should be assessed in terms of suspended solids [12]. According to the above-mentioned findings, the major contaminants found in airports stormwater runoff are fuel/hydrocarbon and sediments/suspended solids when the climatic condition is tropical, which means no de-icing or anti-icing agents are present or used [13]. In cold climate airport, the characteristics were different slightly due to anti-icing fluids or de-icing fluids, which includes ethylene fluids containing potassium acetate, sodium acetate, calcium magnesium acetate, or mixtures of urea and water. Besides treating the two main contaminants, for instance, fuel/hydrocarbon and sediments/suspended solids, the development of the stormwater treatment system shall guarantee the draining of runoff from the pavement as soon as possible, collecting it in an adequate drainage system, where accidental fuel spills of leakage may exist [14]. CPIs must be installed as close as possible to the source of the to-be-treated effluent. Therefore, they are frequently found along motorways. Airports are also equipped with separators in waterproofed areas, treating runoff from car parks as well as from planes runways and landing areas [15].

3. Design Requirements Of CPI

The design of CPI needs to be produced based on the standards prescribed in BS EN 858-1 [16] and BS EN 858-2 [17] which is widely implemented in Europe. In addition, it should also follow the API 421 standards [9]. Specific design requirements of CPI are as follows:

a) The efficiency of CPI (jet fuel concentration at inlet and outlet)
b) The flow rate shall be based on the rainfall intensity and the catchment area.
c) The stormwater runoff shall be drained from the pavement as soon as possible and collected in an adequate drainage system through CPI.
d) The velocity of the stormwater flow through CPI shall be laminar and without turbulence to avoid any physical emulsification of the oil.
e) The globule micron size of the hydrocarbon, the density of the hydrocarbon, the concentration of hydrocarbon in the influent shall be determined Based on the influent and effluent criteria and conditions which are set by the codes and standards.
f) The treated water shall meet the requirement set by the local authorities.
g) The volume of the sludge and separated oil storage capacity shall be either in upstream sedimentation pit or within the CPIs.
h) The static and dynamic loading from the heaviest aircraft model, surface, and burial depth shall be incorporated as CPI is required to be located underground.
i) The shut off or oil stop valves shall be able to handle accidental discharges
j) The density of jet fuel
k) Plate packs
l) Inlet screen
m) Inlet flow regulators
n) Back flow prevention
o) Water level in the oil separators
p) Corrosion control

Concerning jet fuel oil and suspended solids, the contamination of surface stormwater at the airports is influenced by two main factors, namely the specific gravity (SG) of the oil and the water temperature. Table 1 shows that different oil SGs at different temperatures affect the size of oil droplets, which are separated under specific operating conditions. The smaller the oil droplets separated, the greater the separation and the removal of oil from the water phase. The higher the temperature, the faster the oil droplets separate; and the larger the oil droplets, the faster the oil droplets separate from the water phase.

Table 1. Correlation of temperature, specific gravity, and oil droplet size separated

Temperature (^{o} C)	Specific gravity of oil				
	0.7	0.75	0.8	0.85	0.9
	Oil droplet size separated (micron)				
20	80	100	120	135	150
30	72	90	110	125	140
40	65	80	95	112	130

3.1. Determining jet fuel concentration at inlet and outlet of the CPI

The maximum contents of oil treatable in the stormwater have to be predetermined in order to optimise the design criteria of the CPI. Hence, several regulations, namely the international standards BS EN 858 [16, 17], API 421 [9] and Environmental Protection Act (EPA), Department of Environmental Regulations and the Malaysian Environmental Quality Act 1971, Environmental Quality (Industrial Effluent) Regulations 2009, were used as the basis for the design. The optimum chosen allowable outlet oil content should be less than 5 ppm or 5 mg/l, which is in accordance with BS EN 858 standard [16, 17]. The performance of the CPI can be measured in many ways. Typical examples of performance measures are jet fuel separation efficiency, suspended solids separation efficiency, flow rate capacity, reliability, operator training/attention required and the ability to operate without service or maintenance. Under given conditions, the primary criterion for judging CPI performance or effectiveness is the jet fuel separation efficiency. It is often the main criterion in determining final discharge water quality [18]. The jet fuel separation efficiency of CPI can be calculated as the concentration of jet fuel in the influent minus concentration of jet fuel in the effluent divided by the concentration of oil in the influent. The oil separation efficiency can be expressed as [19]:

E = $(Ci - Co)$ /Ci x 100
E = Oil Separation efficiency
Ci = feed inlet concentration (mg/l)
Co = discharge outlet concentration (mg/l)

For example, if the CPI is designed to be very highly efficient and has the ability to remove 99.9% of the influent jet fuel oil, the following equation is used to calculate the inlet oil concentration:

Co = $(Ci - Co)$ x Ci x E /100
Co = Ci – (Ci x (E/100))
Ci = Co / (1- (1 x E /100))
Ci = 5 / (1- (1 x 99.9 /100))
Ci = 5000 mg/l

The value 5000 mg/l as the feed inlet concentration gives exactly 5 mg/l as the value of discharge outlet concentration when the CPI efficiency level is 99.9%. A lower value of 4250 mg/l is proposed as the feed inlet concentration to achieve a value lower than 5 mg/l with the same efficiency level. Accordingly, when tabulated, the discharge outlet concentration would be: Co = 4250 – (4250 x (99.9/100)) = 4.25 mg/l. This value is lower than the allowable limit set by BS EN 858 of 5 mg/l. Therefore, the selected inlet jet fuel concentration shall be not more than 4250 mg/l.

3.2. Selecting the jet fuel density

The density of jet fuel generally ranges from 0.775 g/cm3 to 0.84 g/cm3 at 15 ºC [20]; the higher the temperature, the lower the density. The jet fuel density cannot be higher than 0.84 g/cm3 at 15 ºCelsius. When the temperature is at 20 ºCelsius, the jet fuel density is expected to be 0.83 g/cm3 or lower. The performance of the CPI is highly dependent on the differences between the density of the water and the jet fuel oil, respectively. The closer the density of the jet fuel is to that of the water, the slower the separation process, i.e. the rate of jet fuel oil globules will rise in water. Hence selecting 0.85 g/cm3 at 20 ºC instead of 0.83 g/cm3 at 20 ºC would be an optimistic value because the water density is 1.00 g/cm^3 at 20 ºC. The performance of the plate interceptor would be even more efficient when the jet fuel density is at its actual density of 0.83 g/cm^3 at 20 ºC.

3.3. Flow rate, oil storage and sludge storage capacity

The required design volumes that are to be decided shall be as minimum as possibly allowed. This is due to the space constraints factor that is expected in the designated area in the airports. An actual study was carried out in an airport, which is divided into 10 areas (Section 1 and 2, Table 2). The area coverage was calculated together with the 3-month Average Recurrence Interval (ARI) to derive with the corresponding flow rate.

Table 2. Flow rates on the proposed locations

	Area	Ref.	m^3/s	m^3/h	l/s
Section 1	1A	R6	1.63	5,868	1630
	1B	T7	1.53	5,508	1530
	1C	V7	2.73	9,828	2730
	1D	Y6	2.15	7,740	2150
Section 2	2A	A6	1.80	6,480	1800
	2B	RR2	0.84	3,024	840
	2C	D9	2.05	7,380	2050
	2D	F7	2.75	9,900	2750
	2E	I8	2.20	7,920	2200
	2F	I11	0.38	1,368	380

Typically, it is within the first 20 minutes of the storm, the jet fuel or oil is carried over to the CPI for the separation process. This process in stormwater management is referred to as First Flush. Hence, the flow rate is taken based on the 3 months ARI, as a design flow rate is more than sufficient and can be classified as the peak flow rate. In this design, reference was made to BS EN 858, the flow regulation diversion chamber with a mechanical regulator, sized to accommodate the designed flow rate of the novel CPI unit and divert any excess flow to by-pass the novel CPI unit.

Since it is planned to have the flow equalisation bypass system, and the design of the sludge storage capacity in a flow incoming concrete chamber is separated and segregated from the CPI, the oil storage volume shall be minimally allowable. The proposed flow rates for each of the 10 areas vary widely from one to another. The flow rates needed to be as close as possible to ensure a standardise design and to avoid multiple sizes of CPI. Table 3 and Table 4 show the actual study of the flow rates, which was carried out in an airport. It is preferred to have the CPI with less variance in terms of the flow rates, and thus, a single standard design of having a flow rate of 2000 m^3/hr equivalent to 555.6 l/s for all the 35 numbers of CPI can be used in all the 10 areas allocated. However, due to space constraints, the allocated area for construction only allows for a maximum of 2 numbers of CPI per area. Hence, a total of 18 numbers of CPI, having multiple standards with customised tank dimensions, incorporating the relevant required surface area within the corrugated plate packs were designed in accordance with Table 4 to accommodate the flow rate variances.

The oil storage volume in the study is summarised in Figure 1 and Figure 2. From these graphs, we can see that the value of the oil storage volume of the standard manufacturers' products from all types of oil-water separators is either based on the certain volume (i.e. litres) for every specified flow rate (i.e. litres per second) l/l/s or based on the percentage of the oil storage volume versus the total storage volume. For the analysis that was based on certain volume for the specified flow rate, the results varied from 1.5 litres to 1028 litres for every litre per second flow rate (from 1.5 l/l/s to 1028 l/l/s) depending on the type of the oil-water separator. For prefabricated separator systems, the separated light liquid storage capacity shall be at least ten times the nominal size in litres where automatic closure devices are fitted, and at least fifteen times the nominal size in litres where automatic closure devices are not fitted. These capacities shall be based on a light liquid density of 0.85g/cm^3. When using an automatic closure device and separating bypass line, where the nominal/design flow rate is the expected peak rate, a value of 10 l/l/s should be used in accordance with BS EN 858.

Table 3. Flow rates with a maximum of 5 CPI per area

No	Area	Ref.	Drain pipe dia. (mm)	Flow rate (m^3/s)	Flow rate (m^3/h)	Flow rate (l/s)	No of CPI	Flow rate @ each CPI (m^3/s)	Flow rate @ each CPI (m^3/h)	Flow rate @ each CPI (l/s)
1	**1 A**	R6	1800	1.63	5,868	1630	**3**	**0.543**	**1,956**	543
2	**1 B**	T7	1800	1.53	5,508	1530	**3**	**0.51**	**1,836**	510
3	**1 C**	V7	2100	2.73	9,828	2730	**5**	**0.546**	**1,965.6**	546
4	**1 D**	Y6	2100	2.15	7,740	2150	**4**	**0.5375**	**1,935**	537.5
5	**2 A**	A6	1800	1.80	6,480	1800	**4**	**0.45**	**1,620**	450
6	**2 B**	RR2	900	0.84	3.024	840	**2**	**0.42**	**1,512**	420
7	**2 C**	D9	1800	2.05	7,380	2050	**4**	**0.5125**	**1,845**	512.5
8	**2 D**	F7	2100	2.75	9,900	2750	**5**	**0.55**	**1,980**	550
9	**2 E**	I8	1800	2.20	7,920	2200	**4**	**0.55**	**1,980**	550
10	**2 F**	I11	1200	0.38	1,368	380	**1**	**0.38**	**1,368**	380

Table 4. Flow rates with a maximum of 2 CPI per area

No	Area	Ref.	Drain pipe dia. (mm)	Flow rate (m^3/s)	Flow rate (m^3/h)	Flow rate (l/s)	No of CPI	Flow rate @ each CPI (m^3/s)	Flow rate @ each CPI (m^3/h)	Flow rate @ each CPI (l/s)
1	**1 A**	R6	1800	1.63	5,868	1630	**2**	**0.815**	**2,934**	815
2	**1 B**	T7	1800	1.53	5,508	1530	**2**	**0.765**	**2,754**	765
3	**1 C**	V7	2100	2.73	9,828	2730	**2**	**1.365**	**4,914**	1,365
4	**1 D**	Y6	2100	2.15	7,740	2150	**2**	**1.075**	**3,870**	1,075
5	**2 A**	A6	1800	1.80	6,480	1800	**2**	**0.9**	**3,240**	900
6	**2 B**	RR2	900	0.84	3.024	840	**1**	**0.84**	**3,024**	840
7	**2 C**	D9	1800	2.05	7,380	2050	**2**	**1.025**	**3,690**	1,025
8	**2 D**	F7	2100	2.75	9,900	2750	**2**	**1.375**	**4,950**	1,375
9	**2 E**	I8	1800	2.20	7,920	2200	**2**	**1.1**	**3,960**	1,100
10	**2 F**	I11	1200	0.38	1,368	380	**1**	**0.38**	**1,368**	380

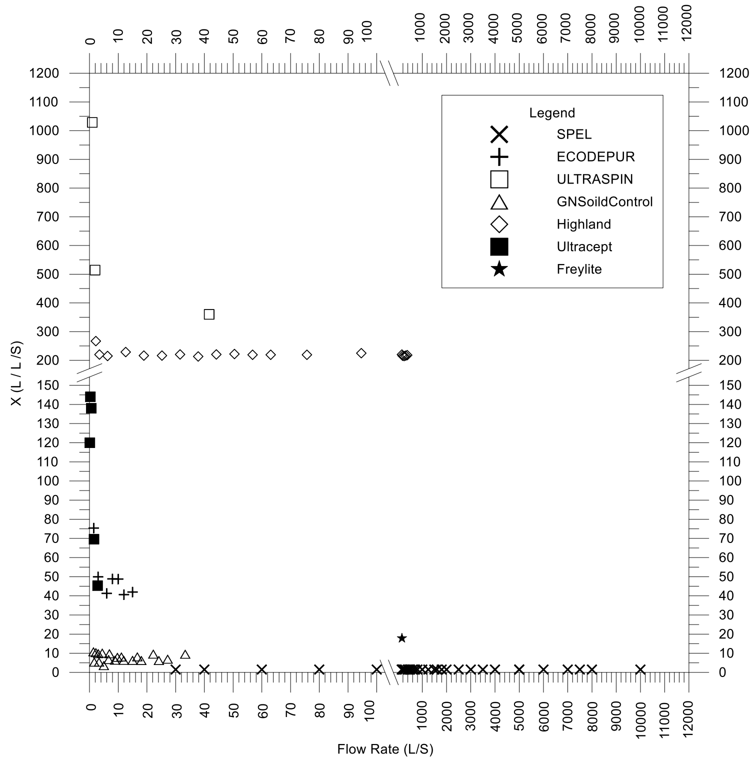

Figure 1 Various standard manufacturer's oil storage volume versus flow rate

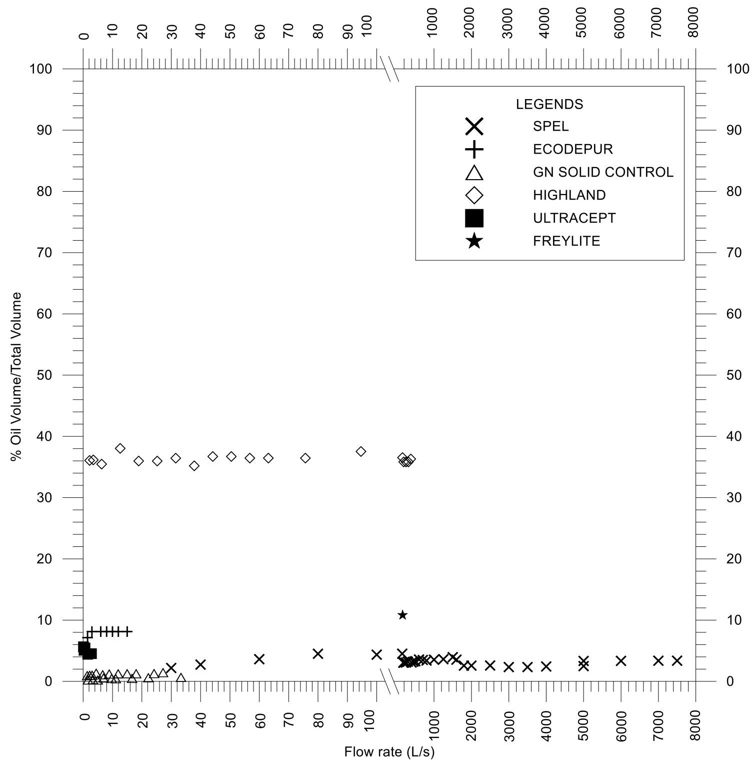

Figure 2 Various standard manufacturer's percentage (%) oil storage volume versus flow rate

For the analysis based on the percentage of oil storage volume versus total tank volume, the results vary from 0.24% until 38%. Most manufacturers are having the oil storage volume about 10% or less; however, the guide specification calls for 10% as a minimum, as mentioned below. In summary, 10 l/l/s oil storage volume shall be the design value required to be used for this design of the noel corrugated interceptor. In the event that space constraints occur at the allocated area, where these novel CPIs are meant to be located to treat the contaminated stormwater, and the value 10l/l/s is too big to be used as the design value, then the value of 10% volume of the total CPI volume shall be used as the design value.

Concerning the sludge storage volume, no specific correlation has been found in the literature, and no data has been found in the manufacturer standard oil-water separators products. The requirements or the actual physical wastewater may have been determined mainly based on different suspended solids pollution levels depending on the area, location or site. However, it is recommended to have the same 10% volume allocated for sludge within the total volume of the corrugated oil-water separator as a minimum. The sludge storage volume can be determined with a series of formula specified in BS EN 585-2 [17]. For an airport that has a road tarmac and parking apron, the amount of sludge expected to flow in the stormwater is very small, which is less than 50mg/l.

$V_s = 100 \times NS / f_d$

V_s = Volume of sludge storage

NS= Flow rate in l/s

f_d = Density factor which is equivalent to 1 for liquid/fuel which has the density 0.85 or below.

Therefore

V_s = 100 litres for every litre per second

= 100 l/l/s

A solids collections sump should be designed preceding to the CPI. The total volume of both the solids collections sump and the sludge collection chamber within the CPI should be not less than 100 l/l/s. The requirement for the oil storage volume and the sludge storage volume is summarised in Table 5.

3.4. Determining the oil globules size and surface charge

Determining the oil globules sizes is one of the key factors in the application of CPI. If the oil globules size is less than 60 µm, then cyclone separators, centrifuge or other more suitable devices for finer droplets should be used. However, if the oil globules size is more than 60 µm but less than 150 µm, then CPI or other suitable oil/water separators with coalescers are recommended. If the oil globules size is more than 150 µm, then it is only recommended to use the conventional baffle type gravity oil separators.

Oil globules with a diameter greater than or equal to 150 µm can be expected to be removed effectively in a gravity separation chamber without plates [9]. Therefore, the range of the oil globules size recommended as a design criterion for CPI is from 60 µm to 150 µm. The ideal globules size shall be a mid-value between 10 to 300 µm. On the other hand, it shall neither be lower than 60 µm nor above 150 µm (but it is recommended to be above 100 and below 150 µm). Hence, the size of the ideal globules chosen as a design criterion shall be 130 µm.

Table 5. Oil and sludge volume for each area of CPI

	Area	**Flow rate (m^3/h)**	**Flow rate (l/s)**	**Oil storage required in 10 l/l/s (m^3)**	**Sludge storage required in 100 l/l/s (m^3)**	**No of CPI no.s**	**Flow rate @ each CPI (m^3/h)**	**Flow rate @ each CPI (l/s)**	**Oil storage required in 10 l/l/s @ each CPI m^3**	**Sludge storage required in 100 l/l/s @ each CPI m^3**
1	1 A	5,868	1630	16.3	163	2	2,934	815	8.15	81.50
2	1 B	5,508	1530	15.3	153	2	2,754	765	7.65	76.50
3	1 C	9,828	2730	27.3	273	2	4,914	1365	13.65	136.50
4	1 D	7,740	2150	21.5	215	2	3,870	1075	10.75	107.50
5	2 A	6,480	1800	18	180	2	3,240	900	9.00	90.00
6	2 B	3.024	840	8.4	84	1	3,024	840	8.40	84.00
7	2 C	7,380	2050	20.5	205	2	3,690	1025	10.25	102.50
8	2 D	9,900	2750	27.5	275	2	4,950	1375	13.75	137.50
9	2 E	7,920	2200	22	220	2	3,960	1100	11.00	110.00
10	2 F	1,368	380	3.8	38	1	1,368	380	3.80	38.00

Using the equation derived from Stokes Law [9]:

$$V_o = \frac{2}{36}\, g \left[\frac{\rho_w - \rho_o}{\mu_w}\right] \delta^2$$

Where,
V_o = rising velocity of the design oil droplet, cm/sec
g = acceleration due to gravity, (981 cm/s^2)
μ_w = dynamic viscosity of the wastewater at design temperature, dyne.s/cm^2 or Poise, (1cP)
ρ_w = density of wastewater at design temperature, (1 g/cm^3)
ρ_o = density of oil at design temperature, (0.85 g/cm^3)
δ = diameter of the oil globule, cm (0.013 cm)

$$V_o = \frac{2}{36}\left[\frac{981\ cm}{s^2}\right]\left[\frac{1 - 0.85\ g}{cm^3}\right]\left[\frac{}{1cP}\right]\left[\frac{1cP}{0.01\ g/cm.s}\right] 0.013^2\, cm^2$$

V_o = 0.1382 cm/s
V_o = 4.97 m/hr or which can be rounded up to 5 m/hr

Therefore, the design value for the surface charge of the CPI should not be more than 5m/hr.

3.5. Coefficient of Surface Separation

Based on the above-mentioned results on oil globule size of 130 μm and the surface charge of 5m/hr, the minimum surface area and the corresponding surface separation coefficient shall be determined using the equation derived from Stokes Law [9]:

$$\frac{Q_w}{A_h} = V_o \text{ Therefore } \qquad C_s = A_h / Q_w$$

Where,
Q_w = design flow rate of the water (m^3/hr)
A_h = horizontal surface area (m^2)
V_o = rising velocity of the design oil droplet, m/hr
C_s = coefficient of the surface separation m^2 for every m^3/h or l/s
A_h = 2934 m^3/hr / 5m/hr = 586.8m^2
C_s = 0.2 m^2/ m^3/hr or 0.72 m^2/ l/s

Table 6 illustrates the area of the surface and the coefficient of the surface separation.

3.6. Design of corrugated plate packs

Many minute but crucial factors are involved and need to be considered when deciding and before finalising the design of the corrugated plate pack. These factors are as follows but not limited to:

a) the material of the construction,
b) the inclination or the tilting angle of the plate pack,
c) the spacing of the plates or the perpendicular distance between plates/sheets within the plate pack
d) the arrangement of the plate pack and the stormwater flow direction

All the above are essential factors to be thoroughly analysed when designing the corrugated plate pack to achieve proper durability, maintainability, operability, efficiency, standardisation, exchangeability and etc. The plate packs shall be designed in modules to be retrofitted into the Interceptors' tanks when the maintenance of the tanks is necessary or when the replacement of the part, with minimum or without major structural modification, is required in the future. The separation efficiency of different structures and space configurations of the corrugated plates was analysed. It was found that the structures of the corrugated plates, such as the plate aperture ratio; the inclination angle; and the plate spacing and length, had significantly influenced the oil-water separation efficiency. The structures of the corrugated plates are shown in Figure 3.

Table 6. The surface area and coefficient of surface separation

No	Area	Ref.	Flow rate (m^3/h)	Flow rate (l/s)	No of CPI	Flow rate @ each CPI (m^3/h)	Flow rate @ each CPI (l/s)	Surface area required (m^2)	C_s (m^2/m^3/hr)	C_s (m^2/l/s)
1	1 A	R6	5,868	1630	2	2,934	815	586.8	0.2	0.72
2	1 B	T7	5,508	1530	2	2,754	765	550.8	0.2	0.72
3	1 C	V7	9,828	2730	2	4,914	1,365	982.8	0.2	0.72
4	1 D	Y6	7,740	2150	2	3,870	1,075	774	0.2	0.72
5	2 A	A6	6,480	1800	2	3,240	900	648	0.2	0.72
6	2 B	RR2	3.024	840	1	3,024	840	604.8	0.2	0.72
7	2 C	D9	7,380	2050	2	3,690	1,025	738	0.2	0.72
8	2 D	F7	9,900	2750	2	4,950	1,375	990	0.2	0.72
9	2 E	I8	7,920	2200	2	3,960	1,100	792	0.2	0.72
10	2 F	I11	1,368	380	1	1,368	380	273.6	0.2	0.72

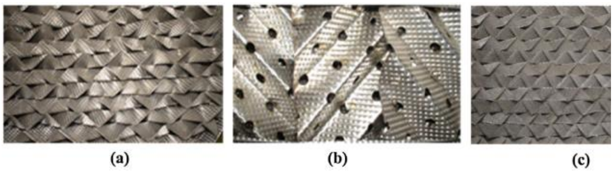

Figure 3. Corrugated plate filler with different configurations, including (a) stainless steel corrugated sheet structured packing, (b) stainless steel corrugated orifice plate structured packing and (c) stainless steel corrugated wire mesh structured packing.

3.6.1. Material of construction for the corrugated plate packs

Since the design of CPI is meant for only treating the jet fuel and or lube oil that could have been leaked during the fuelling and or maintenance works of the aeroplanes, these leakages are considered to be free oil or stratified oil. These leakages are then gravitationally flown into the CPI without any pumping mechanism. Unlike the leakages that can happen in any kind of process plants, such as refineries or petrochemical plants which may contain chemicals and/or mechanical emulsion possibilities. It is considered that there are neither chemical nor mechanical emulsifications that can happen in stormwater flow distribution process from the parking apron to the CPI. This is in line with the size of the globules, which has been concluded as 130 μm in the consideration of the design [15]. Hence, it is also another reason for deciding to direct the treatment process only on the free oil or stratified oil. Correspondingly, the material of construction selection shall only be related to free oil or stratified oil. The superhydrophilic or underwater superoleophobic surfaces have better efficiency up to 99.9% compared to superhydrophobic / superoleophilic surfaces of only 99% efficiency for free or stratified oil/water separation. The stainless-steel material is the substrate that has been used most commonly, and the 2nd highest efficiency level of 99.8% is recorded as superhydrophilic or underwater superoleophobic surfaces. Although the highest efficiency level that has been recorded is using fabric which is 99.9%, due to the longevity and design lifetime of the CPI is expected to be at least 25 years or more, stainless steel material is more suitable than fabrics due to its robust nature, easy for maintenance and its natural characteristic of high resistance to the temperature. The stainless-steel material can easily withstand even boiling water equivalent up to 100 o C. Thin and hard materials are recommended to reduce the occupancy rate of coalescence packing on the separation equipment.

3.6.2. Plate pack inclination or the tilting angle of the corrugated plate packs

The angle should be between 45° to 60° [9]. The angle 60° is chosen when the wastewater or the stormwater is typically high in suspended solids but low in jet fuel/oil content. This 60° angle is required when we need to treat suspended solids/sludge parameters prominently whereby it allows suspended solids to slide easily downwards because of the steeper inclination. However, when both the suspended solids and jet fuel/oil are present in the wastewater or the stormwater, the angle recommended is 45°.

3.6.3. Plate spacing or the perpendicular distance between plates within the plate pack

The plate spacing within the plate pack also plays a vital role in the efficiency of the CPI. The plate spacing should be from 0.75 inches (19 mm) to 1.5 inches (38 mm), as described in the American Petroleum Institute [9]. However, there are also some cases which indicated that the lowest allowable plate spacing with low fouling impact is 3/8” (10 mm) for both Metal (Hydrophilic) or Plastic (Oleophilic) Corrugated plates [21].

3.6.4. *The arrangement of the corrugated plate pack and the stormwater flow direction*

The arrangement of the corrugated plate pack is very much dependent on the stormwater flow direction. The CPI design depends on three types of stormwater flow directions: downflow, upflow and crossflow. Although an inlet chamber exists in most types of oil water separators where the first level suspended solid or sludge is usually captured, the characteristics of incoming wastewater need to be checked before deciding the flow direction of the next separation chamber. Typically, the downflow direction of the next separation chamber is more effective when the stormwater contains high suspended solids or sludge, which is heavier than water and oil, making it easier to fall and be separated from the liquids. Contrarily, if the oil content in the stormwater is very high, then it works the flow direction in the second separation chamber, which is the opposite direction. The upflow easily enhances the separation of the oil due to the water flow direction and the lower density of the oil and the suspended solids or sludge. Hence, since oil is lighter than water and the suspended solids or sludge, the oil floats and gets separated more easily from water and the suspended solids or sludge. If the contents of both the oil and the suspended solids or sludge in the wastewater are equally high, then the crossflow arrangement is recommended. This is because the separation of both the oil and the suspended solids or sludge is enhanced alongside the plates. Thus, the oil floats to the top, and the suspended solids drop and fall to the bottom of the plates.

4. Conclusion

Airports are one of the most notable areas containing stormwater surface runoff which need to be treated before being discharged into the watercourse. Much consideration shall be given to designing the treatment systems to ensure that water backflow and flooding does not occur in the airports during severe storming conditions. Satisfactory maintenance of oil-water separators may not be sufficiently effective in achieving oil removal to the required levels. Pre-treatment should be considered if the level of total suspended solids in the inlet flow would cause clogging, which may impair the long-term efficiency of the separator. Installing CPI to stormwater treatment systems in airports is essential since airports are known for their large, paved areas that may contain oil, grease, or jet fuel. Moreover, interceptors are innovative tools to address different problems, for instance, to treat huge voluminous flow rates, to avoid backflow, to take static and dynamic loadings of the latest biggest aircraft, and to take any accidental discharge. Utilising the CPI provides a cost-effective method of ensuring an operative effluent system from oil-water separators in airport facilities. Proper design of the CPI ensures an operative effluent system that meets or exceeds the requirements of regulations.

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