# Design and Efficiency Comparison of Various Belt Type Oil Skimmers

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Abstract: During the recent decade, World has witnessed big oil spillage accidents into ocean and made huge impact to the environment. Apart this, sometimes Oil is getting spillage through being the results of chronic and careless habits in the use of oil industries and oil products. It is estimated that approximately 706 million gallons of waste oil enters the ocean every year; whereas more than half of that sourced from land drainage and waste disposal. Offshore drilling & production operations and spills or leaks from ships or tankers are typically contributing less than 8% of the total whereas routine maintenance of ships (nearly 20%), onshore air pollution & hydrocarbon particles (about 13%) and natural seepage from the sea floor (over 8%). This has caused ever lasting damage to aquatic life. To separate the mixed oil from the water, industries wide various type of oil skimmers are getting used. Herewith, the objective of this project is to design and conduct efficiency studies of belt type oil skimmer by using various materialed belts. The belts absorb the oil from water which can be scooped out and collect into a vessel by providing piping arrangements. The collected oil can be reused for many purposes.

Keywords: Belt type oil skimmer, Function of oil skimmer, Material of oil skimmer, Design of oil skimmer

#### 1. Introduction

Oil is one of the precious crude and being used in many routine application of human life. Since most of the oils are toxic so quite dangerous for alive when it comes to direct contact with them. During the years of recent decades, world has witnessed many oil spillage tragedies and subsequent damage to alive and environments.

Many countries has made stringent safety norms for waste water disposal contained with oils mainly typically from petrochemical and process industries so that such industries are equipped with such kind of oil skimmers to separate the oils from disposal water.

The continuous removal of oil from process fluids; increases the life of the fluid; resulting of:a) Reduce the machine fluid refilling cost.b) Improves the disposal water quality.(Note : In this paper, All units are in MKS)

## 2. Design Calculation

#### 2.1 Length of the Flat Belt

First of all, length of the belt is derived and calculated from the Figure 1 so the total efficiency of the belt can be found out. Let 'L' be denoted as the length of the belt. 'X<sub>1</sub>', 'X<sub>2</sub>', and 'X3' are the distances of the portion of the belt as denoted in the sketch above. Now the above distances have been measured from the set up and are as follows;

Distance,  $X_1 = 0.845 \text{ m}$ Distance,  $X_2 = 0.43 \text{ m}$ Distance,  $X_3 = 0.730 \text{ m}$ 



Figure 1: Design calculations for the length of the belt

If we derive the formula for the length of the belt from the Figure 1, then we write,

Belt Length, 
$$L = X1 + X2 + X3 + S1 + S2 + S3$$
 (1)

The arc lengths ' $S_1$ ', ' $S_2$ ' and ' $S_3$ ' are unknown and cannot be calculated through measurement. So these lengths need to be calculated first. In order to do this the 'Angle of Lap' and 'Angle of Contact' must be found out.

#### 2.1.1 Angle of Lap

The Angle of Lap is calculated by the equation,

$$\phi = \sin^{-1} (r1 - r2) / X \tag{2}$$

Where,

 $r_1 = Radius of shaft '1'$ 

 $r_2 = Radius of shaft '2'$ 

X = Distance between the shaft centers

Using Eq.(2), calculate ' $\phi_1$ ', ' $\phi_2$ ' and ' $\phi_3$ ' as follows,

$$\phi 1 = \sin^{-1} (13 - 13) / 0.46 = 0^{0}$$
(3)

Since  $r_1 = r_2$ , Similar to Eq.(3)  $\phi_2 = \phi_3 = 0^\circ$ 

#### 2.1.2 Angle of Contact

The Angle of Contact is calculated by the equation,

$$\theta = (180^{O} - 2\phi) \tag{4}$$

Where,

 $\phi$  = Angle of Lap

Using Eq.(4), calculate ' $\theta_1$ ', ' $\theta_2$ ' and ' $\theta_3$ ' as follows,

$$\theta_1 = (180^o - 2x0.06227) \approx 180^o$$
 (5)

Since,  $\phi_2 = 0.1177$ ,  $\phi_3 = 0.06639$ ; Similar to Eq.(3)  $\theta_2 = \theta_3 \sim 180^{\circ}$  (6)

From the above solutions we can find that  $\theta_1 = 180^0$  is the maximum angle of contact.

Therefore, Using Eq.(1); Length of Belt,

$$\mathbf{L} = 0.845 + 0.43 + 0.730 + 3(0.013 \times 3.14) = \mathbf{2.127}$$
(7)

#### 2.2 Linear Velocity of Belt

The individual linear velocities of the driver (motor shaft) and driven (bottom shaft).

#### For Driver:

$$V_1 = \pi d_1 N_1 / 60 = \pi * 0.026 * 72 / 60 = 0.098 m / s$$
 (8)

#### For Driven:

$$V_2 = \pi d_2 N_2 / 60 = \pi * 0.026 * 72 / 60 = 0.098 m / s$$
 (9)

From Eq. (8) & (9),

**Velocity Ratio** = 
$$V_1/V_2 = 0.098/0.098 = 1$$
 (10)

#### 2.3 Torque & Tension in Belt

Power is calculating through,

$$P = 2\pi NT / 60(watt) \tag{11}$$

Where, N = Motor Speed T = Torque transmitted by Motor

The 0.5hp (Horse Power) (=0.3728 kW) motor is used in experiment so using Eq.(11),

$$372.8 = 2 \pi x 72 x T \implies \mathbf{T} = 49.44$$
(12)

Whereas, Force is calculated by,

$$T = F * r \tag{13}$$

Using Eq.(13), Force 
$$\mathbf{F} = 49.44/(13e-3) = 3803.1$$
 (14)

Tension in the tight and slack sides to be calculated by,

$$T = (T_1 + T_2) * r$$
(15)

$$T_1 / T_2 = e^{\mu\theta} = 4.684$$
 (16)

Substituting the values of T, T1 and r into Eq.(15),  $49.44 = (4.684T_2+T_2) \times 13e-3$ **T2 = 669.1 & T1 = 3134.0** (17)

#### 2.4 Effective Pull in Belt

Effective Pull is calculating through,

$$Pe = T_1 - T_2 = 3134.0 - 669.1 = 2464.9$$
(18)

#### 2.5 Power Transmitted by Belt

Transmitted Power by belt is calculating through,

$$P = Pe * V_{1/2} = 2464.9 \ge 0.098 = 241.5$$
(18)

#### 2.6 Bearing Calculation

#### 2.6.1 Allowable Pressure

It is calculating through, $P_{Allow} = W / (LxD)$	(19)
Where, W = Vertical load acting on bearing	
Using Eq.(19),	
$\mathbf{P}_{\text{Allow}} = (2464.9 \text{ x } 4) / (3.8\text{e}-2 \text{ x } 3\text{e}-2) = 8.64\text{e}6$	(20)

#### 2.6.2 Bearing Life

Using Design data book,  $L_n = (C/P)^3$  (21)

Where, C = 12260 for 6304 bearing from Design data book) Using Eq.(21), Bearing Life  $L_n = (12260 / 3803.1)^3 = 33$  millions of Rev.

#### 3. Components Design

#### 3.1 Tank Frame

The frame is placed inside the tank dipped in a mixture of oil and water with length measuring 0.99m, breadth measuring 0.695m and height 0.400m.



Figure 2: Tank Frame Sketch

#### 3.2 Motor Supporting Plate

The plate is placed above the Tank Frame on which the wire

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motor is placed. The thick iron plate was needed to withstand the bending of the motor shaft. It has 0.375m length, 0.255 m breadth and 0.008m thickness. Figure 3, shows the detailed view.



Figure 3: Motor Supporting Plate Sketch

## 3.3 Induction Motor

Figure 4, shows the views of the motor along with shaft. Further groove is made on the motor shaft to prevent the belt slippage.



Figure 4: Sketch demonstrating Motor

## 3.4 Pulleys Supported By Pillow Block Bearings

The shafts are mounted between the Pillow block bearings. Further grooves are cut on the shaft (circular cut out) to accommodate the belt and knurling is made on the circular cut out to prevent the slipping of the belt. The distance between the belt and the length of the belt between the shafts is as shown in figure.



Figure 5: Sketch demonstrating Distance between the Pulleys

## 3.5 Pulleys Supported By Pillow Block Bearings

The distance between the Pillow Block Bearing and the length of the shaft is as shown in figure 6.



Figure 5: Sketch demonstrating Distance between the Bearings

#### 3.6 Selection of Belt Material

The belt should be made of such a material which can easily lift/carry the oil above head and pour it over the blade.

The oil lifts through belt by having the its materials following inherent properties:

- Belt material is selected according to its polar & non-polar properties. Water consists of polar molecules as H+ and OH- whereas oil doesn't have any polar molecules hence it reacts as non-polar element. Polar & non-polar molecules attract towards their respective elements and bond with it. Moreover to these, Oil is lighter in density as compare to water so always oil floats on it. Hence water and oil form a separate layer in the reservoir. Belt material has been selected in such a manner so it can react as a non-polar element and oil gets attract toward it and get stick on it which permit us to easily lift the oil through belt. Here we are selecting the belt materials of polymers (non-polar). like., Cotton, Steel, Rubber, Polyurethane, Oleophilic.
- 2) Adhesive property of oil is greater than water so we select such a material for the belt having adhesive property greater than water and having close to oil, hence it can easily absorbs oil over the belt which ultimately gets separate from water. Since water having poor adhesive property, it doesn't stick much to belt and remains in the reservoir.



Figure 6: Polar-Nonpolar properties of oil & water

3) During operation, belt is getting wear due to friction and subsequently reduction of its life. Oleophilic material offers less wearing property as compare to polyurethane so ultimately Oleophilic belt is choose to use in Oil skimmer.

## 4. Manufacturing & Assembling Components

Manufacturing of various components has been done by following best of the industry standards and get assembled to function properly. Following are some of photographs of oil skimmers.



Figure 7: 3D CAD model of oil skimmer conceptual model



Figure 8: Actual snap of oil skimmer model

# 5. Commissioning & Testing of Oil skimmer

After assembling all the oil skimmer parts, it was time to do commissioning properly. As a part of preparation, SAE40 oil is filled into the tank. The motor is connected to the 'Speed Regulator' through power supply board. The motor starting speed is adjusted to 20 rpm then gradually speed increases. All the set-up was functioning smooth as per expectation.

After having successful commissioning of oil skimmer, we conducted multiple testing & note the oil recovery rate per hour using various types oils & belt materials as following. Here we have taken three oil samples of different viscosity. 1) Garage waste oil

2) SAE40 oil

3) Mixture of Garage oil and SAE40 oil

## 6. Result Discussion

A set of experiments has been conducted by using the various oil and different materials of belt to understand the oil recovery performance and viscosity deviation of oils before & after separation.

## 6.1 Oil recovery performance

Figure 9, Shows the experimental results of oil recovery of oil skimmer by using the various type of oil and material of belt.



Figure 9: Performance Graph of Oil Skimmer by using various types of belts & oils

Figure 9, indicated that Steel belt offers the best performance followed by Nylone & Fibre belts.

## 6.2 Oil Viscosity & Efficiency Measurement

By using Oswald viscometer, we have measured the resultant oil viscosity of before & after separation.

Oil viscosity can be determined through Poiseuille's Law. The expression which governs the flow of liquid the capillary is given as:

$$\eta = \frac{P\pi r^4 t}{8LV} \tag{22}$$

Where,

V = Liquid volume flowing through capillary in time 't'

- P = Pressure head
- r = radius of the tube
- L = Length of pipe
- t = time taken by liquid to flow

Since having same experimental set-up and procedure, oil viscosity is determined using the relative viscosity through Poiseuille's Law. Let assume  $t_1$  and  $t_2$  be the time of the flow of a fixed volume (V) of the tube liquid thrown the same capillary and viscosity of liquid can be determined from Eq. (22) as following:

$$\frac{\eta_{oil}}{\eta_{water}} = \frac{\frac{P}{o} t}{\frac{P}{v} t} \frac{t}{\frac{P}{w} w}$$

Since the pressure head is proportional to density by liquid:

$$\frac{\eta_{oil}}{\eta_{water}} = \frac{\frac{d}{o} t}{\frac{d}{d} t}_{ww}$$
(23)

1001

#### 6.2.1 Procedure

- 1) Weight accurately of empty pyknometer.
- 2) Add 10ml water in pyknometer.
- 3) Calculate the density of water.
- 4) Calculate the density of separated oil.
- 5) Calculate the density of pure oil.
- 6) Determine the time of flow for different oil with the help of Oswald viscometer.

7) Calculate the viscosity of oils.

## 6.2.2 Oil Viscosity and Efficiency Calculations:

By following the above mentioned experimental set of procedure and Eq. (23), Oils viscosity and subsequently its efficiency is also measured with reference to water as following,

Table 1: Oil Viscosity and Efficiency

Sr.	Type of	Oil Viscosity	Efficiency	
	Oil	Before Separation	After Separation	Efficiency
1	Garage Oil	50.0	45.2	86%
2	SAE40	161.1	155.8	92%
3	Mixed Oil	114.3	103.6	88%

# 7. Conclusion

In this project, we enforced to highlight the function of oil skimmer, its various design aspects and performance. All the results of experimental studies indicate that slight design improvement of typical oil skimmers towards to include additional belt shaft and use of belt with steel material instead of rope; significantly improve the oil recovery efficiency and also its structure became simpler. As practical overview of different oil spillage cleanup method, this paper has illustrated several limitations of these methods and current oil spill technology. Further extensive research & testing can improve the existing techniques and equipment to have better control for oil recovery exercise.

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# **Author Profile**



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