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Full Length Research Paper

Empirical correlations for the performance of belt skimmer operating under environmental dynamic conditions

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The present study is predicting, by deducing empirical correlations, the effect of varying the operating and the environmental parameters on the performance of belt skimmer. The belt linear speed, belt inclination angle and oil film thickness are the operating parameters. The current speed and the wave height are the environmental parameters. The oil recovery rate, ORR and the oil recovery efficiency, ORE, the two most important parameters displayed the performance of the belt skimmer, are predicted by empirical correlations as function of these operating and environment parameters. Sets of published experimental data in the open literature were used to obtain these empirical correlations. Five different cases are studied. In each case two equations are deduced, one for ORR and the other for ORE. These cases covered the static and dynamic belt skimmer working conditions. The empirical correlations are obtained by using the least squares method (Regression analysis). Comparisons are performed between the results obtained, for ORR and ORE, using the deduced empirical correlations and the used experimental data. Finally, general empirical correlations, cover practical operating belt skimmer ranges, are obtained and show reasonable agreement with the experimental data.

Key words: Empirical correlations, belt skimmer, performance.

INTRODUCTION

Oil pollution of the sea has steadily grown with the increasing use of oil and become a worldwide problem in recent years. Oil spills endanger public health, imperil drinking water, devastate natural resources and disrupt the economy. Every effort must be made to prevent oil spills and to clean them once they occur. The best approach for containing and controlling the spill is to respond quickly and in a well-organized manner. This will happen if response measures have been planned ahead of time. Just an oil spill occurs; two major steps involved in controlling oil spills should be immediately established. They include, in order, the containment and then the recovery processes. A key feature to effectively combating spilled oil is the careful selection and proper use of the equipment and materials most suited to the type of oil and the conditions at the spill site. The effectiveness of the response using modern equipment varies with sea and weather conditions. Local data and weather fore-casts will assist in determining oil spill response strategies. Sea conditions influence the behaviour of spilled oil and determine the effectiveness of response techniques.

Mechanical devices for the removal of oil from the surface of water are known as 'skimmers'. Skimmers may be static or dynamic. A static skimmer is a recovery device, which is not being moved through the water, and no water and oil is moving past it. A dynamic skimmer is a unit, which is moved though the water or it may be fixed and the water and oil is moving by. Most skimmers are meant to be dynamic. The scientific work concerned with the different types of skimmers is limited in the literature.

This reflects the need for additional efforts both experimental and theoretical related to the skimmer's characteristics and performance. Borst (1986) found that there was little or no variation in the skimmer oil recovery rate

Abbreviations: ORR, Oil recovery rate; **ORE,** oil recovery efficiency.

introduced by altering test conditions. In calm water, recovery efficiency was minimally 85 - 95%. Under wave conditions, the recovery efficiency was 65 - 75%.

Schulze (1998) reviewed many studies for skimmers and stated that; “Unfortunately, all available reviewed data are old and may not be a good indicator of the performance of the current version of skimmers”. Shoier (1998) analyzed experimentally and theoretically the performance of belt skimmer. His results showed that the oil recovery rate increases by increasing the belt speed and/or increasing oil film thickness. In addition, the oil recovery efficiency has a maximum value at a certain speed. Hammoud and Khalil (2000) studied experimentally the ability of belt skimmer in oil spill recovery under different operating parameters. Their results showed that the oil recovery rate increases by the increase of spilled oil film thickness and submergence depth. As the inclination angle decreases the oil recovery rate increases. Furthermore, the maximum oil recovery rate was obtained at the lowest belt angle of inclination used. Afify (2004) investigated theoretically the effect of the working parameters on the performance of belt skimmer. She studied the flow over the belt surface as well as the flow patterns of oil over the water surface. The results showed that the amount of oil skimmed by the belt increases by increasing of belt speed, oil film thickness over water surface, oil viscosity, belt width and by decreasing of belt inclination angle. In addition, the effect of surface tension gradient on the flow patterns on the belt surface is minor and can be neglected.

Kassab et al. (2007) studied the effect of varying the operating parameters on the performance of belt skimmer. The belt linear speed, belt inclination angle and oil film thickness are the operating parameters considered in their study. Kassab et al. (2007) found that the oil recovery rate increases with the increase of the oil film thickness and the decrease of belt inclination angle. The effect of varying the belt linear speed on the oil recovery rate depends on the range of this speed. Meanwhile, the oil recovery efficiency increases by increasing the belt inclination angle and/or oil film thickness and/or decreasing belt linear speed. In addition, it is important to point out that Kassab et al. (2007) compared their experimental data with both the theoretical results of Shoier (1998) and the empirical results obtained using static skimmer data, Hammoud and Khalil (2000). This comparison revealed that the three sets of results have the same trend and there was good agreement, on average, between the experimental and the empirical results.

Kassab et al. (2006) studied the effect of varying the environmental parameters on the performance of belt skimmer. The current speed and the wave height were the environmental parameters considered in their study.

The results are presented for the oil recovery rate, ORR, as well as the oil recovery efficiency, ORE. Within the operating range of the considered parameters, their results show that the oil recovery rate decreases by increasing the current speed. As the wave height increases the oil recovery rate decreases. The oil recovery efficiency decreases by increasing the current speed and wave height. Kassab et al. (2006) pointed that the use of booms surrounding the spilled oil region, can add benefits to the oil recovery that is, decreasing the current speed and the wave height. Consequently, the oil recovery rate and efficiency are increased.

On the other hand, Kassab et al. (2006) concluded that "The comparison between the results obtained using static belt skimmer (zero current speed and wave height) and the results obtained using dynamic belt skimmer reveals that their trends are different with the increase of belt linear speed." This fact initiated the effort towards modifying the existing empirical correlations or finding new ones taking into consideration the effects of the dynamic parameters, such as current speed and wave height. For the best knowledge of the present author, there is no empirical formulas existed in the open literature taking into consideration these dynamic effects. Consequently, one aim of the present study is to achieve this goal.

The present study is considered the third stage of a research program dealing with the influence of various parameters on the performance of different types of mechanical skimmers. The first stage (static stage) dealt with the influence of the operating parameters on the performance of static skimmer (that is, both the current speed, V_c, and the wave height, H_w, are equal zero). A thorough review for this stage is covered by Kassab et al. (2007). The second stage (dynamic stage), Kassab et al. (2006), dealt with the influence of the environmental conditions (that is, the current speed, $V_c > 0$, and the wave height, $H_w > 0$) on the performance of belt skimmer. It represented the performance of the dynamic skimmer. The present study (third stage) attempts to fill the gap between the theoretical and experimental results of the belt skimmer. It is a step further towards making the things easier by putting the outcomes from the experiments, performed in the previously mentioned two stages, into suitable as well as useable empirical formulas. These formulas, after validation, can be used directly, with confidence, to obtain the performance of belt skimmers working in real environmental conditions. The importance of the present study comes from the implementation of the effects of the environmental parameters in the determination of the obtained empirical correlations. This makes these correlations more useful and practical than previously obtained empirical correlations. Therefore, the experimental data obtained in the previous two stages, which includes the effect of both operational, Kassab et al. (2007), and environmental, Kassab et al. (2006), conditions on the belt skimmer performance will be used in the present study to obtain the empirical correlations.

SPECIFICATIONS OF THE USED DATA

Kassab et al. (2006, 2007) experimental data are used in the present study to deduce the empirical correlations. Therefore, it is important to specify these data, first, in order to determine the validity rages in which these correlations can work effectively. Kassab et al. (2007) experimental data covered the following ranges:

a) The oil film thickness was varied from 6 - 14 mm,
b) The inclination of the skimmer was varied in a 5 deg. steps from 35 to 65 deg,
c) The belt linear speed varied from 0.6 - 1.2 m/s.

Meanwhile, Kassab et al. (2006) data covered the following ranges:

a) Current speed, V_c, in the range: 0 - 1.8 knot,
b) Wave height, H_w, in the range: 0 - 39 mm.

The oil used in the experimental studies by Kassab et al. (2006); (2007) was: used oil from local market. Its properties, at the working temperature, were as follows.

a) The oil density was 870 kg/m^{3},
b) The oil viscosity was 0.67 Pa.s.

The belt has the following specifications:

The material is leather; belt effective length is 1 m, and belt width is 0.2 m. The oil recovery rate, ORR, and oil recovery efficiency, ORE, were calculated as follows:

ORR = V_o / time
ORE = V_o / V_t
V_o = ($_w$*V_t - M_t)/ ($_w$ - $_o$)
M_t = ($_o$ *V_o) + ($_w$*V_w)

Where:
M_t = Total oil/water mass collection
V_o = Oil recovery volume
V_w = Water recovery volume
V_t = Total oil/water volume collection

Kassab et al. (2006); (2007) reported that the uncertainty of the oil recovery rate is ± 5.6 % and the uncertainty of oil recovery efficiency is ± 7.9%. Details about the uncertainty as well as the experimental procedure of Kassab et al. (2006); (2007) are given by Ahmed (2004).

The empirical correlations

Kassab et al. (2006); (2007) experimental data, the data used in the present study to obtain the empirical correlations, show that the oil recovery rate, ORR, increases with the increase of the oil film thickness, T and the decrease of belt inclination angle, θ. The effect of varying the belt linear speed, V, on the oil recovery rate depends on the range of this speed. Meanwhile, the oil recovery efficiency, ORE, increases by increasing the belt inclination angle, θ and/or oil film thickness, T and/or decreasing belt linear speed, V. Furthermore, the oil recovery rate, ORR, decreases by increasing the current speed, V_c. As the wave height, H_w, increases the oil recovery rate decreases. The oil recovery efficiency decreases by increasing the current speed and wave height. To find the empirical correlations for oil recovery rate, ORR, and oil recovery efficiency, ORE, the procedure will be as follows:

a) The empirical formula for the oil recovery rate, ORR (L/s), is assumed in the form of power function for the operating conditions, taking into consideration the same parameters considered by Kassab et al. (2007). These parameters are, the belt linear speed, V (m/s), the oil film thickness, T (mm), and the belt inclination angle, θ (degree). This means that in this stage the effect of the environmental parameters are neglected (current speed, V_c = 0 and wave height, H_w = 0).

$$ORR = aV^{b}T^{c}(sin\theta)^{d} \qquad (V_c = 0 \text{ and } H_w = 0) \quad (1)$$

Similarly, the oil recovery efficiency, ORE (%), is assumed as

$$ORE = eV^{f}T^{g}(sin\theta)^{h} \qquad (V_c = 0 \text{ and } H_w = 0) \quad (2)$$

b) The empirical formula for the oil recovery rate, ORR (L/s), is assumed in the form of power function for the operating parameters V (m/s), θ (degree) and one of the environmental parameters, current speed, V_c (m/s). These are at T = 10 mm and H_w = 0.

$$ORR = kV^{i}V_c^{j}(sin\theta)^{L} \qquad (T = 10 \text{ mm and } H_w = 0) \quad (3)$$

Similarly, the oil recovery efficiency ORE (%) is assumed as

$$ORE = mV^{n}V_c^{q}(sin\theta)^{p} \qquad (T = 10 \text{ mm and } H_w = 0) \quad (4)$$

c) The empirical formula for the oil recovery rate, ORR (L/s), is assumed in the form of power function for the operating parameters V (m/s), θ (degree) and one of the environmental parameters, wave height, H_w (mm). These are at T = 10 mm and V_c = 0.

$$ORR = rV^{s}(sin\theta)^{w}H_w^{u} \qquad (T = 10 \text{ mm and } V_c = 0) \quad (5)$$

Similarly, the oil recovery efficiency ORE (%) is assumed as

$$ORE = xV^{y}(sin\theta)^{z}H_w^{z1} \qquad (T = 10 \text{ mm and } V_c = 0) \quad (6)$$

d) Taking into consideration all the operating parameters, V, T, and θ, as well as the environmental parameters, V_c and H_w, a general empirical formula for the oil recovery rate ,ORR (L/s), can be written in the form:

$$ORR = aV^{b}T^{c}\left|\left(1-\frac{V_c}{V}\right)\right|^{d}(sin\theta)^{e}\left|\left(1-\frac{H_w}{T}\right)\right|^{f} \quad (7)$$

Similarly, the oil recovery efficiency ORE (%) is assumed as

$$ORE = aV^{b}T^{c}\left|\left(1-\frac{V_c}{V}\right)\right|^{d}(sin\theta)^{e}\left|\left(1-\frac{H_w}{T}\right)\right|^{f} \quad (8)$$

e) For more practical consideration, one can start the validity of the general empirical formula for the oil recovery rate, ORR (L/s), from 0.07. In this case ORR (L/s), can be written in the form:

$$ORR = aV^{b}T^{c}\left|\left(1-\frac{V_c}{V}\right)\right|^{d}(sin\theta)^{e}\left|\left(1-\frac{H_w}{T}\right)\right|^{f} \quad ORR \;\; 0.07 \text{ L/s} \quad (9)$$

Similarly, the oil recovery efficiency ORE (%) can star from 50%

instead of zero. In this case ORR (L/s), can be written in the form:

$$ORE = aV^{b}T^{c}\left|\left(1-\frac{V_c}{V}\right)\right|^{d}(sin\theta)^{e}\left|\left(1-\frac{H_w}{T}\right)\right|^{f}$$

ORE 50% (10)

Equations 1 - 10 are transformed to the form of a linear function by taking the (ln) function to each side. For example, Equation (1) is written as:

$$ln(ORR) = \ln a + b\ ln\, V + c\ ln\, T + d\ ln(sin\theta)$$

Applying the regression to the above Equation using the least squares method, the constants a, b, c and d are obtained, Table 1. The values of the constants presented in the other equations can be similarly obtained. Summary of the empirical correlations and their constants and constrains are shown in Table 1. The average difference between calculated, ORR_{calc}, and measured, ORR_{Exp}, oil recovery rate, ORR, results is obtained as follows:

$$= \frac{\sum_{n=1}^{n=N}\left|\frac{ORR_{calc}-ORR_{Exp}}{ORR_{Exp}} * 100\right|}{N} \qquad (11)$$

Similarly, The average difference between calculated, ORE_{calc}, and measured, ORE_{Exp}, oil recovery efficiency, ORE, results is obtained as follows:

$$= \frac{\sum_{n=1}^{n=N}\left|\frac{ORE_{calc}-ORE_{Exp}}{ORE_{Exp}} * 100\right|}{N} \qquad (12)$$

Where, N is the total number of data.

RESULTS AND DISCUSSIONS

Figure 1 shows the variation of the calculated oil recovery rate, ORR, Equation 1 with the corresponding measurements, obtained by Kassab et al. (2007), under various operating conditions. These results are for the case of static recovery conditions, (that is, the current speed, V_c = 0, and the wave height, H_W = 0). The straight line shown in Figure 1 and the other coming Figures (Figures 2 - 10), represents the equality of the calculated and the measured ORR results. Consequently, the scatter of the presented points around this line is an indication of the deviation between the two sets of ORR or ORE results. The average difference between the calculated and the measured ORR results shown in Figure 1 is 11.68%. It is important to point out that Kassab et al. (2007) compared their experimental data, the same results used in Figure 1, with the theoretical results of Shoier (1998) and the empirical results of Hammoud and Khalil (2000). This comparison revealed that the three sets of results have the same trend and there was good agreement, on average, between the experimental and the empirical results. Figure 2 shows the variation of the calculated oil recovery efficiency, ORE, using the obtained correlation, Equation 2, with the corresponding measurements, obtained by Kassab et al. (2007), under various operating conditions. These results are for the case of static recovery conditions, (that is, the current speed, V_c = 0, and the wave height, H_W = 0) . The average difference between the calculated and the measured ORE results is 2.63%. Figure 3 shows the variation of the calculated oil recovery rate, ORR, using Equation 3, with the corresponding measurements obtained by Kassab et al. (2006). The differences between this case and the results presented in Figure 1 are that: the current speed, V_c, is no longer equals zero but can be varied, and the oil film thickness, T, is held constant, T = 10 mm. Note that H_W = 0. The average differrence between the calculated and the measured ORR results is 14.44%.

Figure 4 shows the variation of the calculated oil recovery efficiency, ORE, using Equation 4, with the corresponding measurements, obtained by Kassab et al. (2006). The differences between this case and the results presented in Figure 2 are that: V_c 0, and T= 10 mm. Note that H_W = 0. The average difference between the calculated and the measured results is 6.59%. Figure 5 shows the variation of the calculated oil recovery rate, ORR, using Equation (5), with the corresponding measurements obtained by Kassab et al. (2006) . The differences between this case and the results are shown in Figure 1, the wave height, H_W 0 and the oil film thickness, T= 10 mm. In addition, the differences between this case and the results shown in Figure 3 are that: H_W 0, and V_c = 0. The average difference between the calculated and the measured ORR results is 11.5%.

Figure 6 shows the variation of the calculated oil recovery efficiency, ORE, using Equation 6, with the corresponding measurements obtained by Kassab et al. (2006). The differences between this case and the results shown in Figure 2 are that: the wave height, H_W 0 and the oil film thickness, T = 10 mm. In addition, the differences between this case and the results shown in Figure 3 are that: H_W 0, and V_c = 0. The average difference between the calculated and the measured ORE results is 2.8%. Figure 7 shows a comparison between the calculated oil recovery rate, ORR, using Equation 7, with the corresponding measurements obtained by Kassab et al. (2006). This is the general case for the oil recovery rate, ORR, in which all the operating parameters, V, T, and θ, as well as the environmental parameters, V_c and H_W, are considered in both, empirical and experimental results. As pointed before, the scatter of the presented points around the straight line shown in Figures 7a and b is an indication of the deviation between the calculated and the measured ORR results. The average difference between the calculated and the measured ORR results is 44.7%. This percentage difference is too high. It is clear from Figure 7 that the differences in the small values of ORR (that is, ORR < 0.07) contributed a big share in this high average difference. Fortunately, the small values of ORR are impractical and can be disregarded without losing the

Table 1. The empirical correlations and their constants and constrains.

Equation	Correlation	Constants	Constrains
1	$ORR = aV^{b}T^{c}(sin\theta)^{d}$	a = 0.065, b = 1.016, c = 0.3405, d = -1.225.	$V_c = 0$ $H_w = 0$
2	$ORE = eV^{f}T^{g}(sin\theta)^{h}$	e = 47.819, f = -0.33999 g = 0.2472, h = 0.3242.	$V_c = 0$ $H_w = 0$
3	$ORR = kV^{i}V_{c}^{j}(sin\theta)^{L}$	k = 0.0269, i = -1.0813, j = -0.8063, L = -1.3576	T = 10 mm $H_w = 0$
4	$ORE = mV^{n}V_{c}^{q}(sin\theta)^{p}$	m = 53.14, n = -0.7315, q = -0.3933 p = 0.429	T = 10 mm $H_w = 0$
5	$ORR = rV^{s}(sin\theta)^{w}H_{w}^{u}$	r = 0.2255, s = 1.2907, w = -0.7795 u = -0.159	T = 10 mm $V_c = 0$
6	$ORE = xV^{y}(sin\theta)^{z}H_{w}^{z1}$	x = 130.824 y = -0.4157, z = 0.3619, z_1 = -0.1868	T = 10 mm $V_c = 0$
7	$ORR = aV^{b}T^{c}\left\|\left(1-\frac{V_c}{V}\right)\right\|^{d}(sin\theta)^{e}\left\|\left(1-\frac{H_w}{T}\right)\right\|^{f}$	a = 0.01735 b = 1.5363. c = 0.8161 d = 0.1335 e = -1.151 f = -0.0593	---
8	$ORE = aV^{b}T^{c}\left\|\left(1-\frac{V_c}{V}\right)\right\|^{d}(sin\theta)^{e}\left\|\left(1-\frac{H_w}{T}\right)\right\|^{f}$	a = 58.53 b = -0.11 c = 0.121 d = 0.18 e = 0.37 f = -0.088	---
9	$ORR = aV^{b}T^{c}\left\|\left(1-\frac{V_c}{V}\right)\right\|^{d}(sin\theta)^{e}\left\|\left(1-\frac{H_w}{T}\right)\right\|^{f}$	a = 0.0466 b = 1.146 c = 0.5 d = 0.155 e = -0.792 f = -0.0782	ORR 0.07 L/s
10	$ORE = aV^{b}T^{c}\left\|\left(1-\frac{V_c}{V}\right)\right\|^{d}(sin\theta)^{e}\left\|\left(1-\frac{H_w}{T}\right)\right\|^{f}$	a = 56.76 b = -0.148 c = 0.1404 d = 0.0564 e = 0.294 f = -0.0862	ORE 50%

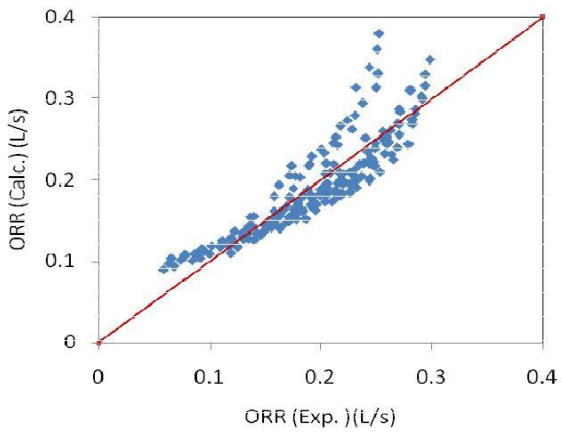

Figure 1. Variation of calculated, Equation 1, versus measured, Kassab et al. (2007), oil recovery rate, ORR, (V_c = 0, and H_w = 0).

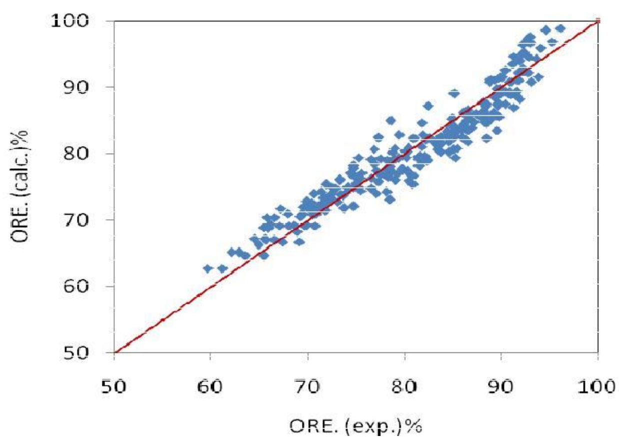

Figure 2. Variation of calculated, Equation 2, versus measured, Kassab et al. (2007), oil recovery efficiency, ORE, (V_c = 0, and H_w = 0).

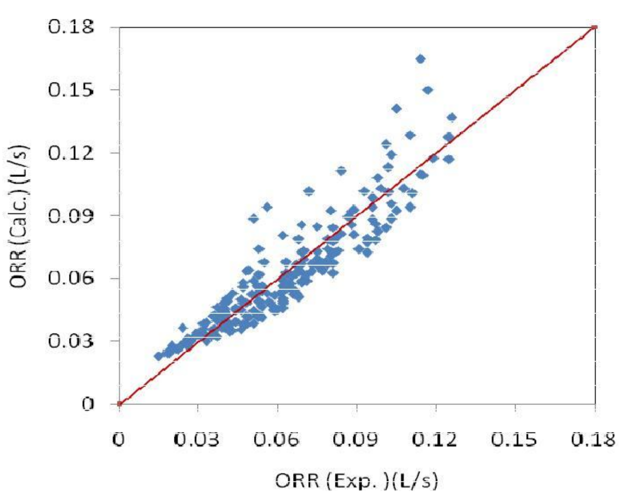

Figure 3 Variation of calculated, Equation 3, versus measured, Kassab et al. (2006), oil recovery rate, ORR. (T = 10 mm, and H_w = 0).

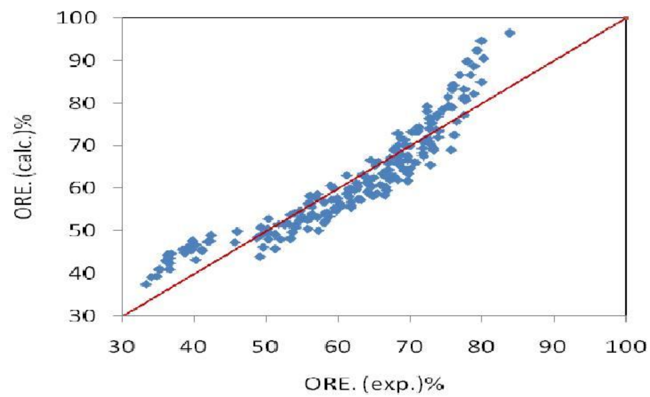

Figure 4. Variation of calculated, Equation 4, versus measured, Kassab et al. (2006), oil recovery efficiency, ORE (T = 10 mm, and H_w = 0).

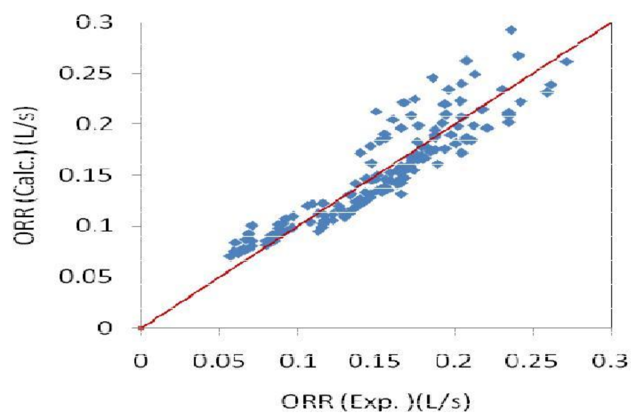

Figure 5. Variation of calculated, Equation 5, versus measured, Kassab et al. (2006), oil recovery rate, ORR (T = 10 mm, and V_c = 0).

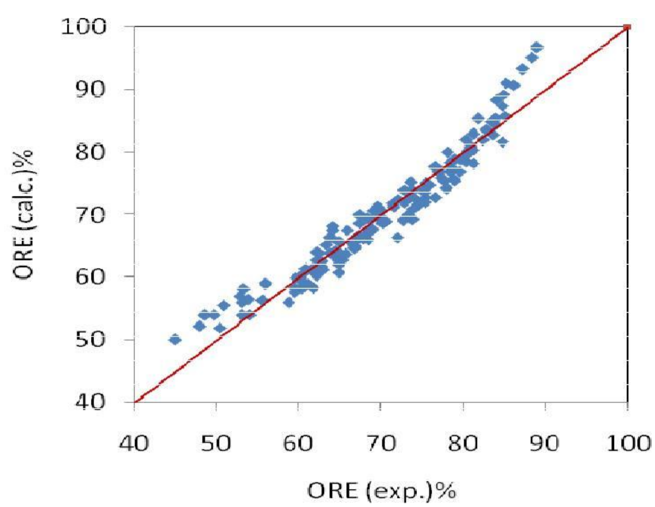

Figure 6. Variation of calculated, Equation 6, versus measured, Kassab et al. (2006), oil recovery efficiency, ORE (T = 10 mm, and V_c = 0).

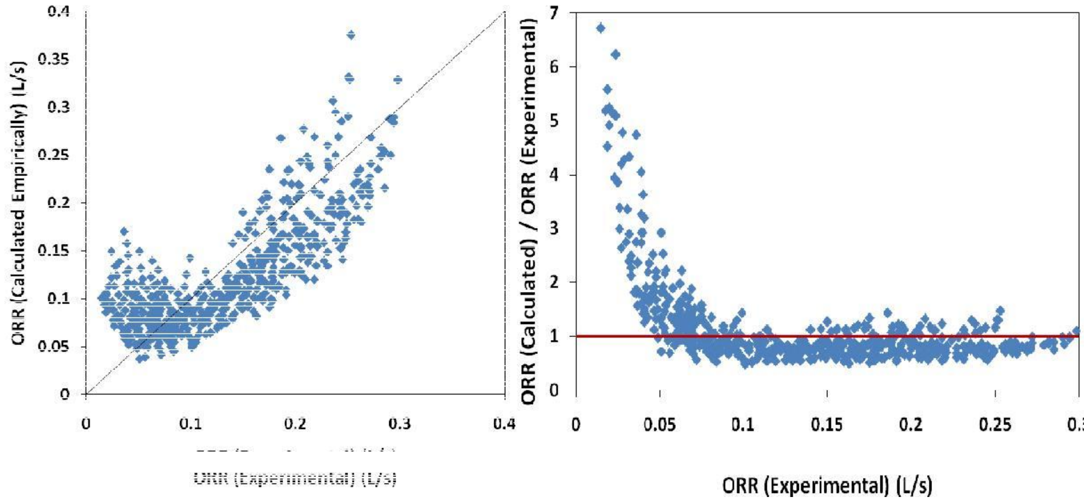

Figure 7. Comparison between the calculated, Equation 7, and the measured, Kassab et al. (2006), oil recovery rate, ORR, for the general case: V, T, , V_c and H_w are all varied.

accuracy.

Figure 8 shows a comparison between the calculated oil recovery efficiency, ORE, using Equation 8, with the corresponding measurements obtained by Kassab et al. (2006). This is the general case for the oil recovery efficiency, ORE, in which all the operating parameters, V, T, and θ, as well as the environmental parameters, V_c and H_W, are considered in both, empirical and experimental results. The average difference between the calculated and the measured ORR results is 14.7%. It is clear from Figure 8 that the differences in the lower values of ORE (that is, ORE < 50%) contributed a big share in this high average difference. Fortunately, the small values of ORE are impractical and can be disregarded without losing the accuracy. Figure 9 shows a comparison between the calculated oil recovery rate, ORR, using Equation 9, with the corresponding measurements obtained by Kassab et al. (2006). This is the general case for the oil recovery rate, ORR, in which all the operating and environmental parameters are considered. The only difference between this case and the case shown in Figure 7 is the applicable range. This range is ORR 0.0 L/s in Figure 7, while it is ORR 0.07 L/s in Figure 9. This difference in the ranges improved the average difference between the calculated and the measured ORR results from 44.7%, Figure 7, to 16.5%, Figure 9. Fortunately, this improved in the results is obtained without losing the practical validity of the deduced empirical correlation.

On the other hand, the same data presented in Figure 9b are replotted in Figure 9c using the logarithmic scale in the vertical axis. This is to demonstrate the usefulness of this type of presentation in damping the appearance of the scattered data. Figure 10 shows a comparison between using Equation 10, with the corresponding measurements obtained by Kassab et al. (2006). This is the general case for the oil recovery efficiency, ORE, in which all the

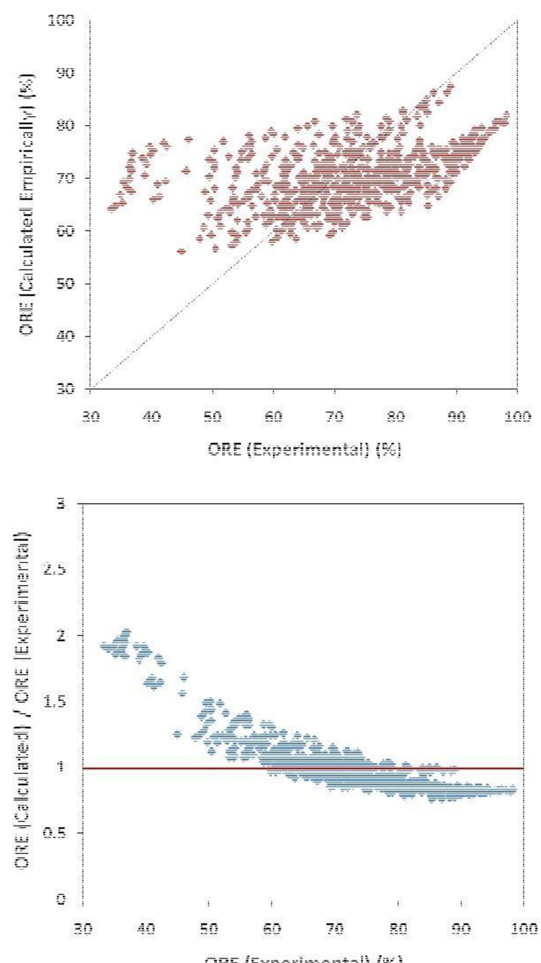

Figure 8. Comparison between the calculated, Equation 8, and the measured, Kassab et al. (2006), oil recovery efficiency, ORE for the general case: V, T, , V_c and H_w are all varied.

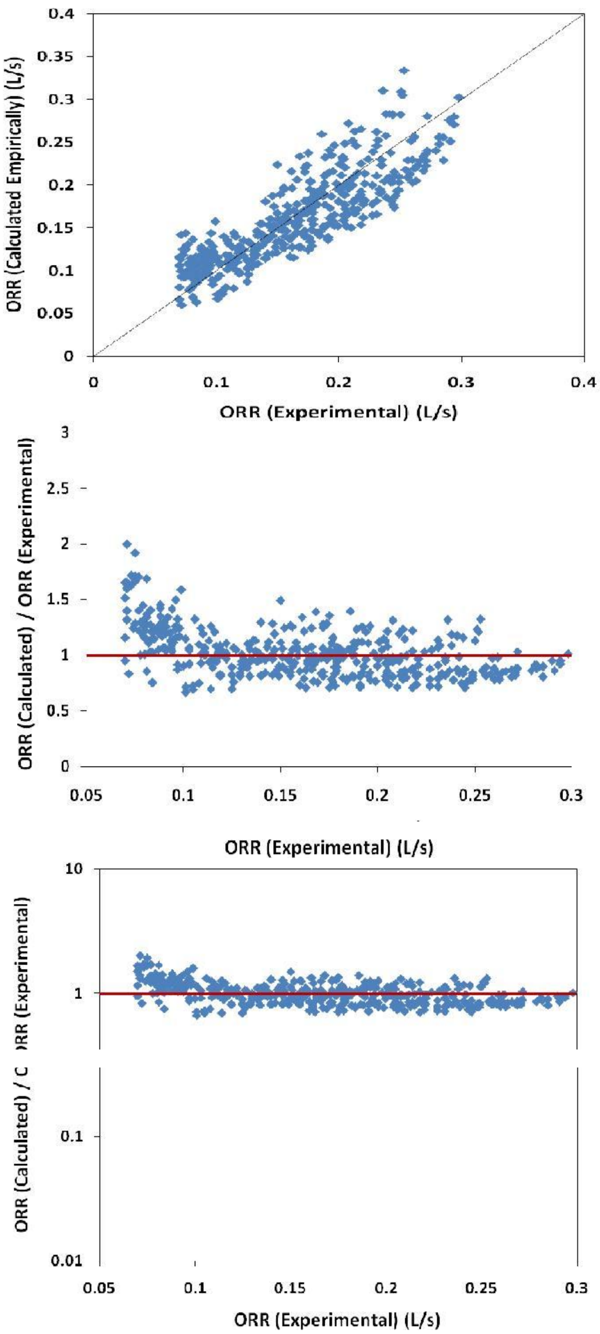

Figure 9. Comparison between the calculated, Eq. 9, and the measured, Kassab et al. (2006), oil recovery rate, ORR, for the general case: V, T, , V_c and H_w are all varied and ORR 0.07 L/s

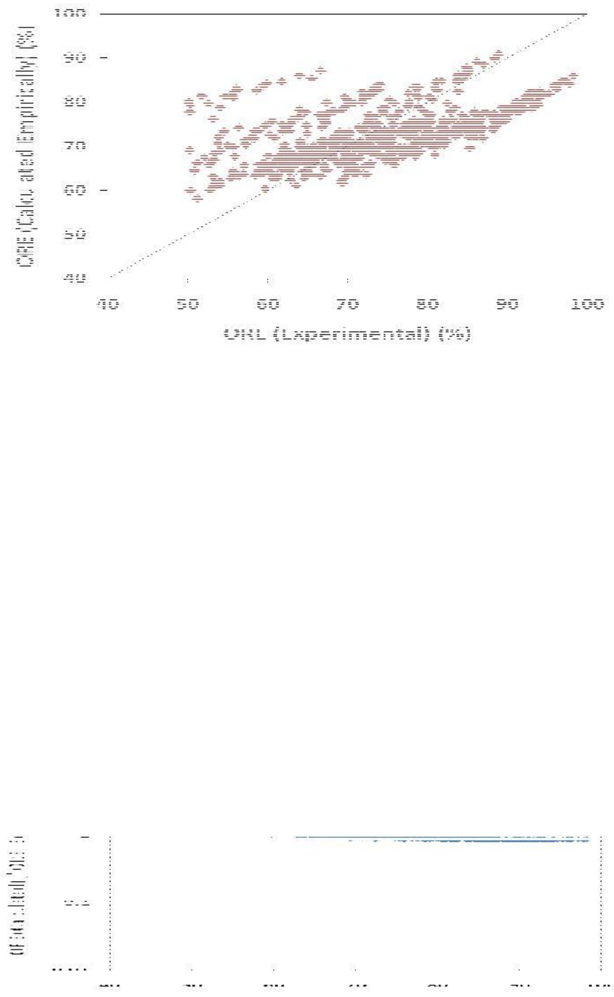

Figure 10. Comparison between the calculated, Equation 10 and the measured, Kassab et al. (2006), oil recovery efficiency, ORE, for the general case: V, T, , V_c and H_w are all varied and ORE 50%.

operating and environmental parameters are considered. The only difference between this case and the case shown in Figure 8 is the applicable range. This range is ORE 0.0 L/s in Figure 9, while it is ORR 50% in Figure 10. This difference in the ranges improved the average difference between the calculated and the measured ORE results from 14.7%, Figure 8, to 9.98%, Figure 10. Fortunately, this improved in the results is obtained without losing the practical validity of the deduced empirical correlation.

Conclusion

The present study is concerned with developing empirical correlations to estimate the belt skimmer oil recovery rate, ORR, and oil recovery efficiency, ORE, as a function of both operating and environmental parameters. The belt linear speed, belt inclination angle and oil film thickness are the operating parameters. The current speed and the wave height are the environmental parameters. The present study can be regarded as a study putting experimentally measured parameters on an empirical footing. Practically, this may make it easier for the designer of belt skimmer to take into consideration these effective parameters. Therefore, the following concluding remarks can be obtained from the present study:

(i) The deduced empirical equations extend the validity of the equations not only for the operating conditions, as previously deduced correlations by other investigators, but also for the environmental conditions, which represent the practical situation,

(ii) It is better to deduce and use the empirical correlations within a specified practical range. This makes the validity of these equations better,

(iii) General empirical correlations, cover practical operating belt skimmer ranges, are obtained and show reasonnnable agreement with the experimental data.

Finally, it is important to re-emphasize here that the empirical correlations, although valid for the test data used, are not necessarily applicable over the wide range of possible operating conditions. Therefore, the present proposed empirical correlations can be regarded as a step towards reducing the difference between experimental and theoretical results in the area of belt skimmer.

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