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Research Article

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Improving the Performance of Oil Spill Floating Boom Using a Hybrid System: Floating Boom Integrated With Surface Weir skimmers

Ahmed A. Abdel-Naby

Mechanical Engineering Department, Faculty of Engineering, Alexandria University, Alexandria, Egypt

Abstract Cleaning up oil spills can be a measure challenge to engineers. Cleaning process is carried out mainly using mechanical surface skimmers. Floating booms are used to contain the spilled oil in one region and prevent it from spreading out. Booms also increase the oil thickness by gathering the oil in smaller area and increasing oil recovery rate and oil recovery efficiency for the mechanical skimmer used, which allows the skimming process to be more effective.

In the present experimental study a hybrid system is proposed and built. Surface weir skimmers are built in with the floating boom. When the skimmer is deployed, it surrounds the oil spill and begins with the recovery process at the same time. By combining the equipment altogether, the recovery process is more efficient. The problem of synchronizing the two procedures will no longer exist, since they will be designed to operate simultaneously.

Keywords Oil spill, oil boom, oil skimmer, oil recovery rate, oil recovery efficiency

1. Introduction

Pollution is one of the greatest concerns nowadays. Oil spill represent one of the dangerous contributors to the environment. Oil spill may occur due to accidental events, oil pipeline breakdown, oily waste dumping in water ways by industrial sector, oil refineries, car service workshops and stations.

According to API and NOAA [1], cleaning up oil spills is carried out mainly using:

- Chemical methods such as dispersants and solidifiers as well as biological treatments which include bioremediation.
- Off-shore oil burning at the spill location.
- Physical response methods which include mechanical methods such as skimmers and booms.

The choice of which method to be used depends on many factors and restrictions such as the area of the accident, sea conditions, oil properties, environmental and geographic nature all affect the decision of the proper type of oil removal procedure. Although the use of chemical dispersants is spreading, the use of dispersants is not favored over the mechanical techniques. Burning also used in case of large scale and offshore area. The most dangerous consequence in burning is the smoke propagation. Mechanical methods are classified as the most commonly used category in oil spill response. The mechanical method includes many types of surface skimmers and their corresponding booms. However, when using the mechanical cleanup methods, there are set of aspects related to the oil spill that should be considered before choosing which type of skimmer to be used. Many types of skimmers are designed and tested to improve oil skimming performance. Grill and Linde [2] divided the performance of skimmers into three categories which include: Oil recovery rate, oil recovery efficiency and throughput efficiency. Removing the oil spill can be grouped into two methods, oleophilic and non-oleophilic. The oleophilic way depends on the adhesion of the spilled oil to a surface. The other method, which is the non-oleophilic, uses mechanical equipment to extract the oil. Oleophilic skimmers have high recovery efficiency and are highly effective when dealing with medium oil viscosities like disc, drum, belt and weir skimmers all as practical examples. Disc skimmer performance was investigated by Christodoulou and Turner [3], Christodoulou et al. [4], El-Minshawy [5], Turner et al [6-8], Hammoud and Khalil [9-10], El-Zahaby et al [11]. Drum skimmer tested by Hammod and Khalil [12], Broje and Keller [13]. Keller and Clark [14] suggested a novel skimmer surfaces- V-Patterned or grooved drum recovery surface- to improve drum skimmer performance. Abdel-Naby and Hammoud [15] modified drum skimmer performance using air injection and air stream in oil/waste water treatment applications. Belt skimmer was examined by Shoier [16] experimentally and theoretically. Hammoud and Khalil [17] tested belt skimmer in oil spill recovery under different operating parameters. Afify [18] studied the flow over the belt surface as well as the flow patterns of oil over the water surface. Kassab *et al* [19-20] examined the operating and environmental parameters on the performance of belt Skimmer. Kassab [21] predicted by empirical correlations for the two most important parameters displayed the performance of the belt skimmer as function of operating and environment parameters. Mamta Patel [22] compared various belt skimmer designs concluding their efficiency. Burungale et al [23] developed free floating endless belt oil skimmer to remove the oily effluent from wastewater of sugar factory. Weir skimmer is used as oil skimming mechanical device by setting its edge on the interface of oil/water surface. McCracken [24 and 25] started their experimental study on the performance of adjustable weir skimmer. Jensen et al. [26 and 27] concluded that weir skimmers performance improved by gravity forces. Topham [28] developed a model using two-layer flow over a broad crested weir for different weir skimmer characteristics. HUDSON industries [29] engineered a slotted pipe weir skimmer across wastewater tank to improve oil recovery performance. Hammoud [30] enhanced oil spill recovery using integrated weir skimmer and water jet vortex flow. Containment of the oil spill is the first and most critical step in the process of oil spill control. Floating booms are used to collect the oil in one region and prevent it from spreading out. Also booms increase the thickness of the oil film by gathering the oil in smaller area. This allows the skimming process to be more effective. Booms have a wide diversity of shapes, manufacturing materials and sizes so that they can comply with the needs of the different conditions and environments. Booms can be lightweight, cheap and small when the application is not demanding such as deploying barriers at harbors for fencing. On the other hand, the size and cost of large booms can be very high and are deployed using heavy machinery such as cranes. This type of booms is usually used for offshore sites. Booms can be used for different purposes and applications. They can be divided into three categories: Fence, Curtain and shore-sealing booms. Muttin [31] analyzed the structure of oil spill containment booms. Shi et al [32] examined the performance of flexible floating oil booms experimentally.

From the previous literature it is found that most of published researches are classified either for the mechanical skimmer itself and how to improve its performance to recover the spilled oil or for the boom to contain or direct the spilled area. In the present paper a new design is proposed to minimizing the time between the spill occurrence and the recovery initiation, as well as increasing the encounter rate as much as possible. Minimizing the time decreases the spreading rate, and the high encounter rate increases the recovery rate and efficiency. The Hybrid System proposed is a combination of the containment and recovery process where the suggested skimmer is a surface weir skimmer integrated and attached to floating booms to construct one unit ready for operation at same time.

2. Experimental Test Rig

The hybrid system constructed to test the effectiveness of the suggested system by reducing oil spill area resulting in increasing the oil thickness in the controlled area integrated with weir skimmers as mechanical skimming devices operating at the same time. The proposed system is presented in a 3-D drawing, Fig. 1. Each skimmer is placed between two floating booms having its outlet connected to the main pipe attached the suction pump. The floating boom and pipes are fixable to obtain the ability to change the controlled spilled area. The main components of the test rig are illustrated in Fig. 2 It consisting of water and oil testing pool, 12 floating boom segments, 12 weir skimmers, suction pump, collecting and measuring graduating tank. Figure3 represents the mechanism for area reduction for the controlled spilled oil. Figure 4 is the actual test rig used in the experiments.

3. Test Procedure

The hybrid suggested system consists of 12 surface weir skimmers integrated with 12 floating boom segments connected in a circular pattern as shown in Figs. 2 and 4. The number of skimmers involved was reduced in each experiment. Five experiments were made using 12, 10, 8, 6 and 4 skimmers. Figures 3 and 4 show the effective number of skimmers in action for each experiment. When the number of skimmers was reduced, the area containing the spilled oil decreased resulting in increasing the thickness of the oil film. Several trials were conducted to study the effect of decreasing the oil spilled area on the oil recovery rate and oil recovery efficiency of the hybrid system. Two trials were followed in series of experiments.

The first trial was examined by keeping the oil volume constant in all experiments whatever the number of effective skimmers and the controlled area. That was done by compensating an amount of oil equivalent to the amount of the skimmed volume in the previous experiment.

The second trial was performed for all experiments without adding oil to replace the skimmed amount.

In the first trial the weir edges were adjusted by adding or removing water to the floating booms. Certain volume of oil was added to the controlled area to have certain oil thickness for the first experiment of 12 skimmers active to control the suggested area. The suction pump was turned on and the skimmed oil was collected in the measuring and graduated tank for a certain time. Oil and water volumes were measured after 24 hours to avoid oil emulsion and obtaining two separate volumes for the skimmed oil and water. The oil recovery rate (ORR) was calculated from the equation:

$$ORR = \frac{skimmed\ oil\ volume}{Time} = \frac{V_o}{T} cm^3/s$$

And the oil recovery efficiency (ORE) was deduced from the equation:

$$ORR = \frac{skimmed\ oil\ volume}{Total\ skimmed\ volume\ of\ water\ and\ oil} x\ 100$$

The second experiment was performed for 10 skimmers and for the corresponding reduced area related to the number of active skimmers. The skimmed oil volume in the previous experiment was added to have same oil volume in all experiments for the first trial only. Same procedure was conducted for other experiments to calculate ORR and ORE for 8,6 and 4 effective skimmers.

In the second trial, certain oil volume was used in the controlled area of 12 skimmers as the first trial but no oil compensation was done for the rest of experiments 10, 8, 6 or 4 skimmers. The oil volume in this trial was decreased in each experiment since no oil was added for make up the sucked volume. This methodology is the more realistic case since it simulates the oil spill recovery process in open sea. The hybrid system is deployed at the spill site to contain the oil volume. Then the number of skimmers is decreased as the amount of oil diminishes throughout the recovery process. Same experiment procedure was performed but the oil volume was not constant and oil thickness as well.

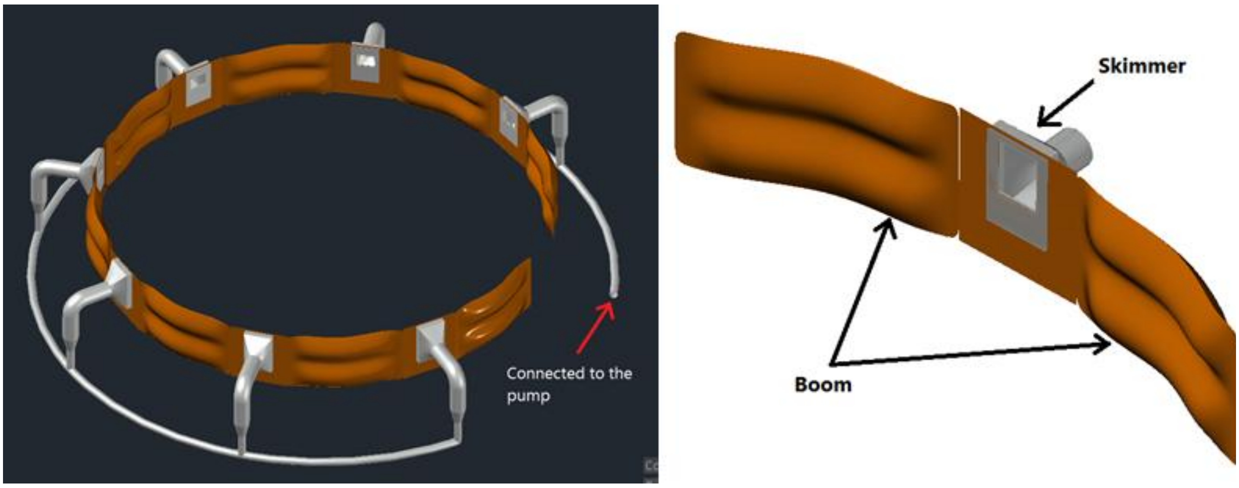

Figure 1: Weir Skimmers built-in with Floating Boom

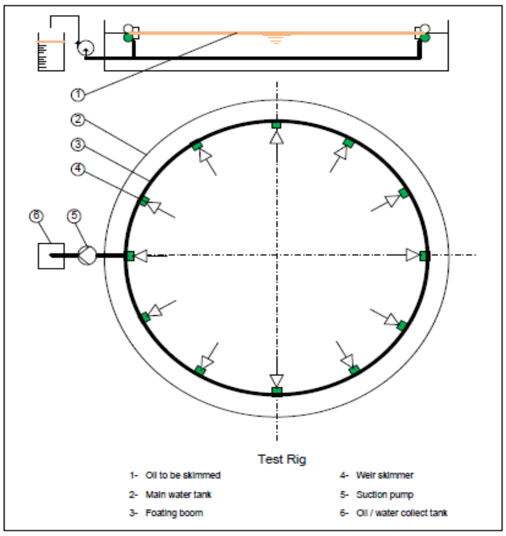

Figure 2: Main components of the test rig

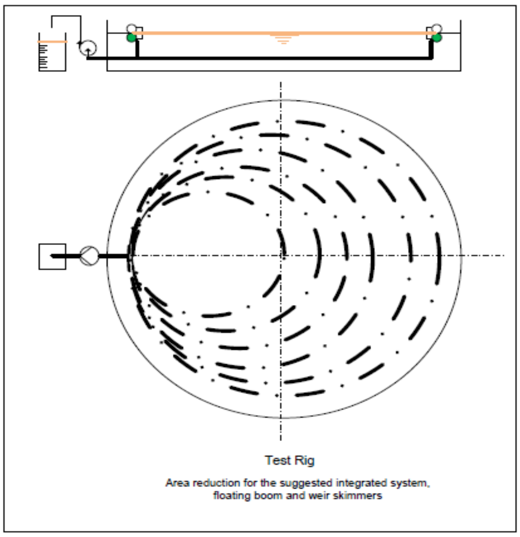

Figure 3: Mechanism for area reduction for the controlled spilled oil

Figure 4: Tested Integrated System

4. Results and Discussion

Figure 5: displays the oil recovery rate vs. number of skimmers graph with decreasing oil controlled area throughout the experiments for different number of effective skimmers with oil compensation (constant oil volume in all experiments). The oil recovery rate has an inversely proportional relation with the number of skimmers for constant oil volume. Decreasing the number of skimmers shows an improvement in the oil recovery rate that is due to controlled area reduction and increasing in oil thickness as well. The oil recovery efficiency as shown in Fig. 6 illustrates the effect of decreasing the number of skimmers involved on the recovery efficiency of the hybrid system. The experiments proved that as the area containing the oil was minimized, the skimmers became more effective even with a reduced amount of skimmers in action. This indicates the great significance of the oil thickness due to the containment technique on the recovery process.

Figure 7 displays the oil recovery rate vs. number of skimmers graph without oil compensation throughout the experiments. The oil recovery rate also has an inversely proportional relation with the number of skimmers as resulted in the first trial. Decreasing the number of skimmers shows an improvement in the recovery rate. Also the oil recovery efficiency as shown in Fig. 8 illustrates the effect of decreasing the number of skimmers involved on the recovery efficiency of the hybrid system. The experiments proved that as the area containing the oil is minimized, the skimmers become more effective even with a reduced amount of skimmers in action due to area reduction relating in increase of oil thickness.

Figures 9 and 10 compare the oil recovery rate and oil recovery efficiency for the two trial procedures. Both figures demonstrate the decrease in the oil recovery rate and efficiency when the controlled spilled area is large or increase the number of skimmers used related the area size for the two trials examined in the present study. This is due to the lower oil thickness resulted to area increase. The second trial for experiments having no oil compensation had lower ORR and lower ORE due to lower oil thickness. The two methods provide similar results at the beginning, but as the number of skimmers is decreased furthermore, the gap between both curves increases. This is due to the decreased oil film thickness in the second trial (without compensation). Also the second trial has lower oil recovery and lower efficiency compared to the first one; it is more realistic to the actual case in real life. The main target is to contain the oil spilled area and skim oil at the same time with higher rates and greater efficiencies by area reduction without using other separate mechanical devices in addition to time saving to control the problem.

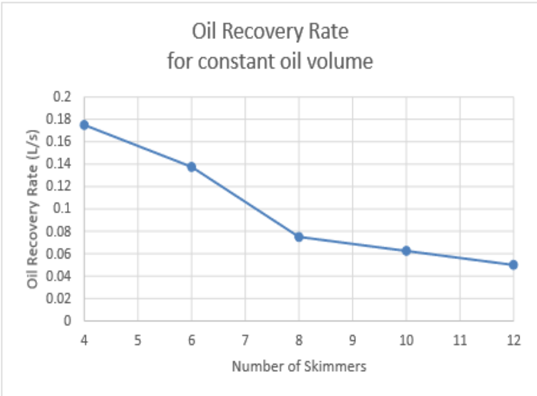

Figure 5: Oil recovery rate for different number of weir skimmers for constant oil volume

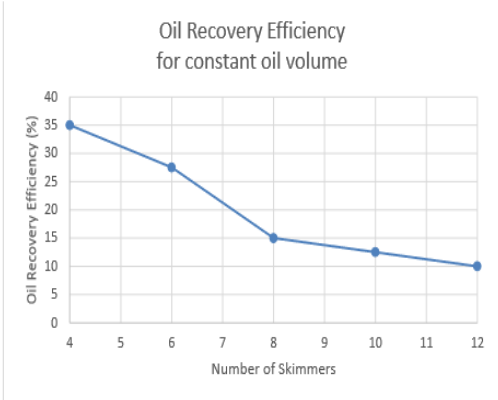

Figure 6: Oil recovery efficiency for different number of weir skimmers for constant oil volume

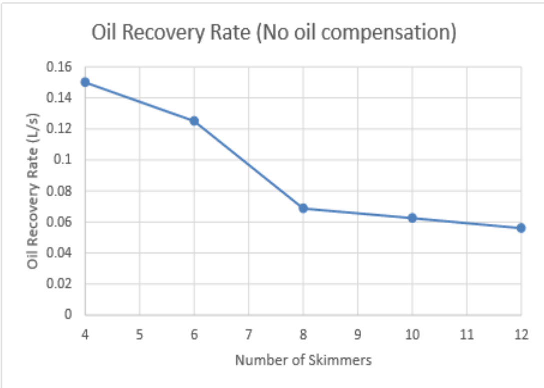

Figure 7: Oil recovery rate for different number of weir skimmers without compensation

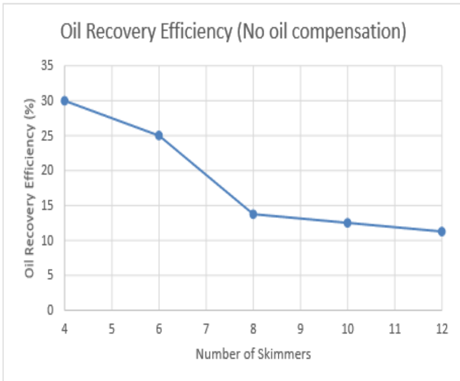

Figure 8: Oil recovery efficiency for different number of weir skimmers without compensation

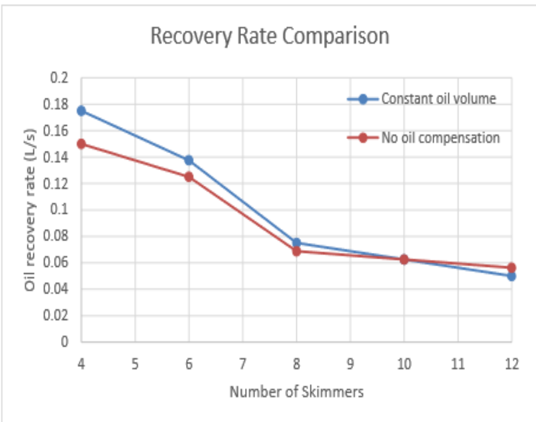

Figure 9: Comparison of the oil recovery rate of the two methods

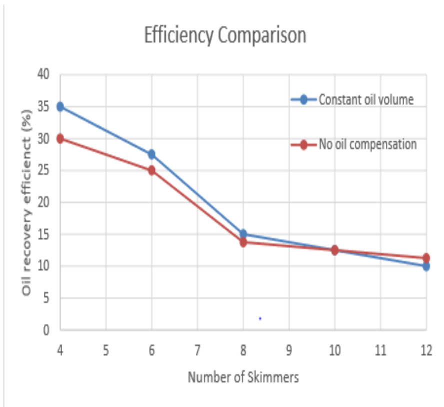

Figure 10: Comparison of the oil recovery efficiency of the two methods

5. Conclusions

- As the controlled spilled area decreases, the optimum performance for the proposed hybrid system is obtained.
- Better performance is obtained for less controlled area even with using less number of effective skimmers.
- Using the hybrid system of a floating boom integrated with weir skimmers will save controlled time and operation compared by using separate boom and separate mechanical skimming device.

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