한국해양공학회지 제21권 제6호, pp 1-6, 2007년 12월 (ISSN 1225-0767)

A Study on the Development of Active Circulating Type Oil Recovery Vessel

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KEY WORDS: Active circulation type oil-water separation system, buoy type oil guiding system, Oil recovery vessel, Oil-water separation system

ABSTRACT: *A study on the new active circulation type oil-water separation system including buoyancy type guidance system was carried out in this paper. Newly developed oil-water separation system is composed of several oil separation steps. In the beginning of these steps, buoy type separation system would be used. Buoy type oil guiding system was developed based on the difference of density of water and oil.*

1. Introduction

The arrival/departure of oil cargo from oil tankers at the port poses a big threat due to the problem of leakage, thereby making it a necessity for the improvement of the existing devices and techniques. These leakage accidents hampers the fishing activities causing a menace for the fishermen's lives and business. Therefore these kinds of detrimental events have to be prevented at the earliest. The prevention techniques of these accidents, followed recently in Korea, are physical methods, chemical methods and the micro-organic methods, of which none prove to be satisfactory. The Oil-recovery vessels have higher efficiency because they are self-propelled and have high maneuverability thereby making them more effective in covering larger areas of operation and easily adapt themselves to the surrounding environment. Oil-recovery vessels uses the active circulation type O/W (Oil-water) separation system. This paper makes an effort to improve the efficiency of this mechanism by using a new technology viz. buoy type oil guiding system.

The other Oil-recovery systems are fixed-type whereas the ORVs (Oil-recovery vessels) are more flexible due to their high maneuverability thereby creating a wider and faster recovery area and remain unaffected by the waves and tidal currents. The vessels that recover oil from the ocean are ORVs, oil booms, tugs, recovered oil carriers, recovered-oil storage vessels, supply vessels etc. Generally the fixed type oil-Recovery mechanism is more effective near the shore but are rendered less efficient offshore where waves and tidal currents are unpredictable and on the Western Coast of Korea where numerous number of islands are present.

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2. Basic Theory

Oil-water gravity separation is based on the density difference between oil and water. Oil droplets due to less density will be pushed up by buoyancy force and stressed by viscosity oppositely. The rise rate is the velocity at which oil particles move toward the free surface as a result of the differential density of the oil and the aqueous phase of the wastewater.

The basic principles of separation by gravity differential can be expressed mathematically and applied quantitatively. When a particle is allowed to move freely in a fluid and is subjected to gravitational force, its rising or settling velocity with respect to the fluid becomes a constant when the resistance to motion equals the weight of the particle in the fluid. In other words, the resistance to motion of a particle in a liquid medium is equal to the effective weight of the particle when the terminal velocity V_S has been reached, namely, when the acceleration caused by gravity becomes zero. Terminal velocity of droplet rising can be calculated in such a case from the forces balance. The expression for the effective weight of the particle is as follows:

where D is the diameter of the oil spherical droplet, ρ_w and

$$W=\frac{\pi D^3 g}{6}(\rho_w-\rho_o) \tag{1}$$

ρ_o are densities of the pure water and oil, correspondingly, g is the gravity acceleration. Resistance force R_P of a small spherical oil particle at its terminal velocity was first calculated by Stokes as follows:

$$R_P = 3\pi\mu_w V_S D, \tag{2}$$

here μ_w is the dynamic viscosity of water.

Equality the effective weight W of the oil particle to its drag force R_P gives the well-known form of Stokes' law for the terminal velocity of spheres rising in a liquid medium:

$$V_S = \frac{g(\rho_w - \rho_o)D^2}{18\mu_w} \tag{3}$$

Theoretically, consideration should be given to the deformation of an oil globule as it rises through a liquid medium, because of a change of shape caused by its contact with the liquid through which it is rising. Changing of shape results from internal flow so that the particle's resistance to motion is minimized and a higher rise rate results. This effect can be expressed by introducing the deformation coefficient C, theoretically applicable to equation (3):

$$V_S = C\frac{g(\rho_w - \rho_o)D^2}{18\mu_w} \tag{4}$$

and C can be presented in terms of the viscosities of the particle and the medium as follows (Drew and Passman, 1999):

$$C = \frac{1 + \mu_o/\mu_w}{2/3 + \mu_o/\mu_w}$$

where μ_o is the dynamic viscosity of oil.

Equations (2) and (3) are strictly correct only when the rising particle's Reynolds number (based on the particle diameter) is less than 0.5. For the range of Reynolds numbers considering here (all substantially less than unity), however, the deviation from Stokes' law is negligible for design purposes.

From an analysis of equation (4) one can determine most of what needs to be done to enhance the separation of the phases:

- The droplet diameter is squared and therefore has considerable influence on the rate of separation. It is important to increase the droplet size. In practical separator engineering this is done by coalescing devices such as porous media, coalescence plates, etc.
- The droplet separation velocity is also increased if we are able to increase the acceleration beyond that normally provided by gravity (i.e. 9.81 m/s^2). This can be done in a centrifuge or hydro cyclone which can be developed for just this purpose.
- The rate of separation is also increased if we can increase the density difference of the phases. This might be done by adding buoyant gas bubbles to the oil droplets. This process named vacuum flotation forms gas bubbles in the dispersed oil droplets and can be very effective in clearing out oily water.

3. Form of Oil-Recovery Vessel

SWATH form is considered as suitable form for Active Circulation Mechanism as well as a high speed hull, and the dimension of designed hull form is shown in Table 1.

4. Design of Gravity Type Separator

The simplest gravity type separators (Fig. 1) are nothing more than large holding tanks which may be coupled together in series (Gaaseidnes and Turbevill, 1999). Debris laden oily water is pumped in and allowed to separate under the action of gravity alone. The surfaced oily flotsam may be skimmed or pumped off and the separated water is drained or pumped off from near the bottom of the tank. When such tanks are coupled in series the oil from the top of the first tank is fed into the second tank and any dispersed water remaining in the oil will have additional opportunity to separate and of course the water quality removed from the bottom of the second tank will exceed that of the first. For cases where the pumping is continuous, the pumping rate determines the

Table 1 Dimension of SWATH type oil recovery vessel

Length PP	37 m
Breath	18 m
Depth	7 m
Draft	4 m

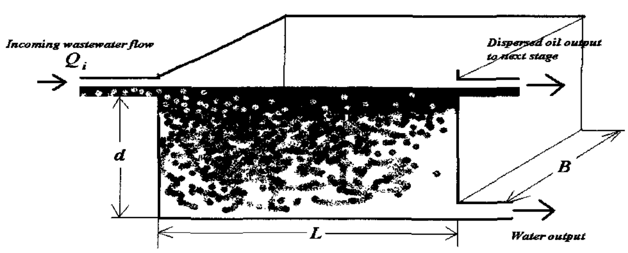


Fig. 1 Principle scheme of the gravity type separator

residence time and this affects the degree of separation.

Proper design of a separator includes the certain tank length, width and depth that provide a wide, quiet spot in the pipeline to give oils time to rise. Let us estimate the main geometrical scales of the separator, necessary for its proper working.

Using the design flow of wastewater to the separator $Q_I(m^3/s)$ and selected its total cross-sectional area $S_V = dB$, where d and B are the depth and width of separator, respectively, we can define the horizontal fluid velocity V_H by following way:

$$V_H = \frac{Q_i}{S_V} = \frac{Q_I}{dB} \tag{5}$$

Minimum necessary length of the separator L can be calculated from the condition of full ideal separation: time sufficient for oil droplet to rise to the surface even from the bottom has to be less or equal to the time of horizontal path of liquid particles through the separator:

$$\frac{d}{V_S} = \frac{L}{V_H} \tag{6}$$

Equation. (5) and (6) lead to the most important property of ideal oil-water separator:

$$\frac{Q_i}{LB} = V_S \tag{7}$$

The ratio of incoming flow Q_i to the horizontal cross-sectional area of separator $S_H = LB$ is named as overflow rate. It is proportional to the terminal rising velocity of oil droplets V_S, depending only on liquids physical properties and oil droplet size.

Wastewater flow in a real separator, of course, is not ideally laminar and includes also effects of inlet and outlet turbulence, vortexes, circuits etc. Usually all these effects are taking into account by introducing the turbulence factor coefficient F that a composite of an experimentally determined short-cutting factor of 1.21 and a turbulence factor whose value depends on the ratio of mean horizontal velocity V_H to the rise rate of the oil globules V_S. Corresponding correction for the separator length Eq. (6) and overflow rate expression (7) are look like follows:

$$L = F\frac{V_H}{V_S}d; \tag{8}$$

$$\frac{Q_I}{LB} = \frac{V_S}{F} \tag{9}$$

An experimental graph of F versus the ratio V_H/V_S is given in Fig. 2 (Drew and Passman, 1999).

Several experimentally verified recommendations also can be made to minimize the effects of inlet and outlet turbulence on the main separator channel:

- a length-to-width ratio (L/B) has to be at least 5 is suggested to provide more uniform flow distribution;
- separator water depth (d) should not be less than 1 m, to minimize turbulence caused by oil/sludge flight scrapers and high flows;

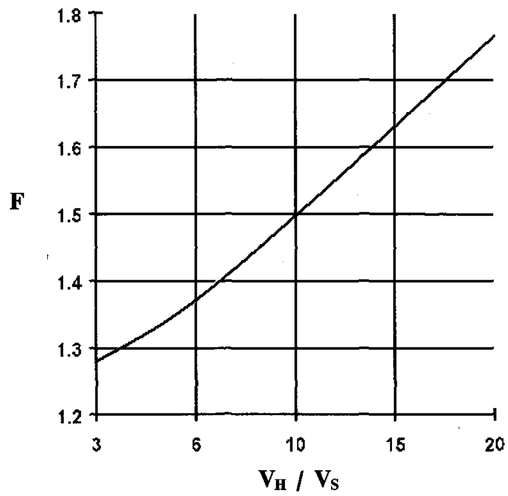


Fig. 2 Turbulence factor F versus the velocities ratio V_H/V_S

- additional depth may be necessary for installations equipped with flight scrapers. It is usually not common practice to exceed a water depth of 2.4 m.

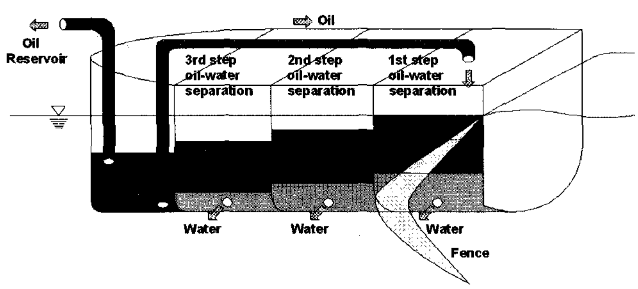


Fig. 3 Active type of oil separation system

O/W separation system of spontaneous circulation type is shown in Fig. 3. The oil which passes through the inlet undergoes active separation in 3 stages and this process is repeated continuously thereby resulting in high filtration effect. The sea water is thrown out of the vessel automatically through outlet holes located at the bottom of the vessel in between hulls. So the momentum of inflow and outflow is large as a result of which this Oil-recovery vessel can recover oil at a very high rate compared to the other recovery vessels in operation now a days.

Now we discuss about the components installed inside the last tank. In the last tank, a Oil-Level Sensor is installed which senses the difference in density of oil and separates the oil from the preceeding tank. This sensor can sense above 90% of the density level and this separated oil is moved out to a storage tank.

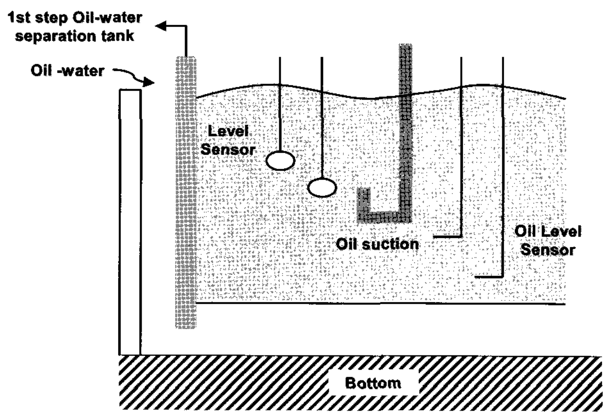


Fig. 4 Arrangement of sensor in oil-water separation system

5. Buoy Type Oil Guiding System

Buoy type oil guiding system as shown in Fig. 5 is mainly based on the simple principle of difference in specific gravity of oil and water. The system is such devised as to use this principle to allow the inflow of only oil into the hull more effectively.

This guiding system minimizes the spreading of oil on ocean water due to wind, waves and tides as shown in Fig. 6. The main purpose of this type of system is to guide maximum amount of oil in to the hull space.

6. Model Test

Model tests has been carried out in the circulating water channel(CWC) of Chosun University with the SWATH model scaled 1/52 for which dimension is shown in Table 1, and main characteristics of CWC are summarized as follows with a schematic diagram as shown in Fig. 7.

The results of resistance test are analyzed by Eq. (10) and Eq. (11), and the calculated result of C_R at full load condition is shown in Fig. 8.

$$C_R = C_{TM} - C_{FM} \tag{10}$$

$$C_{FM} = \frac{0.075}{(\log Rn - 2)^2} \tag{11}$$

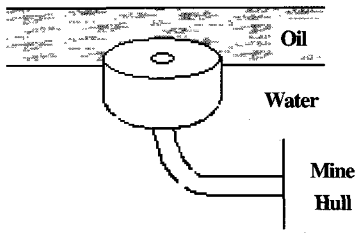


Fig. 5 Sketch of buoy type oil guiding device

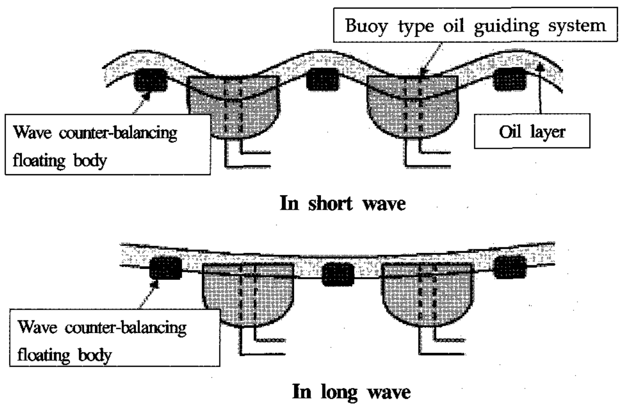


Fig. 6 Motion of buoy type oil guiding device in wave condition

Type : 2 impeller, vertical type

$L \times B \times D$(whole body) : 14.8 m × 1.7 m × 3.6 m

$L \times B \times D$(measuring body) : 3.6 m × 1.2 m × 0.9 m

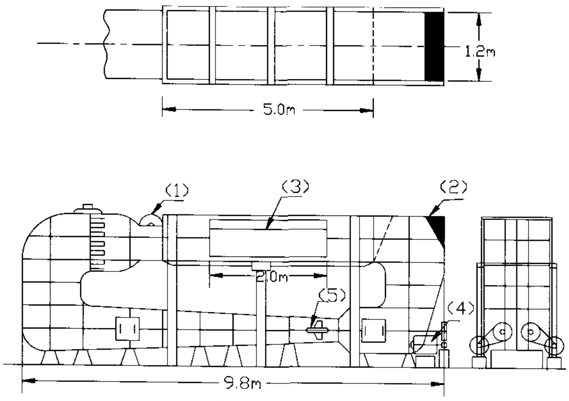
Velocity range 0.4~1.08 m/s

Velocity distribution : ±1.5 % at 1.0 m/s

Standing wave : 0.8 mm at 1.0 m/s

Surge wave : ±1 mm at 1.0 m/s

Water surface inclination : 1/400 at 1.0 m/s



(1) Surface flow accelerator (4) 22kw motor
(2) Wave maker (5) Impeller
(3) Measuring section

Fig. 7 Schematic diagram of CWC

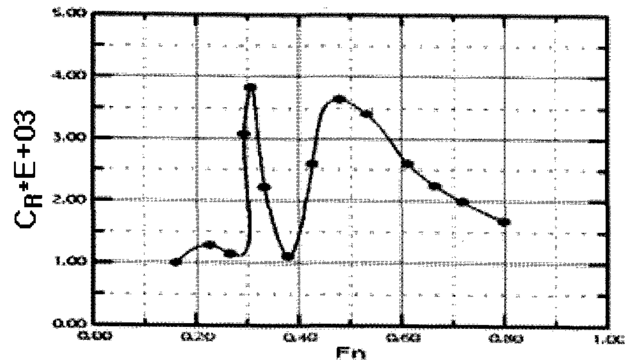


Fig. 8 *CR* vs *Fn* curve at full load condition

It is proved that the *CR* is comparatively lower at the expected oil recovering speed of 2 knots (*Fn* = 0.4), and also at the expected operating speed of 30 knots (*Fn* = 0.8).

7. Oil Recovery Efficiency Test

For the verification of oil recovery efficiency of newly developed active type oil-water separation system as shown in Fig. 3 and Fig. 4, an aluminum model ship has been manufactured and tested in small square basin, and the dimension of trial ship is shown in Table 2.

Figure 9 is photograph of oil recovery test and Fig. 10 shows final process of oil-water separation.

The oil recovery efficiency obtained by model test is shown in Fig. 11. In Fig. 11, RE means the ratio of recovered oil by spilled oil.

Table 2 Dimension of trial ship

Length PP	2.5 m
Breath	1.5 m
Depth	1 m
Draft	0.6 m

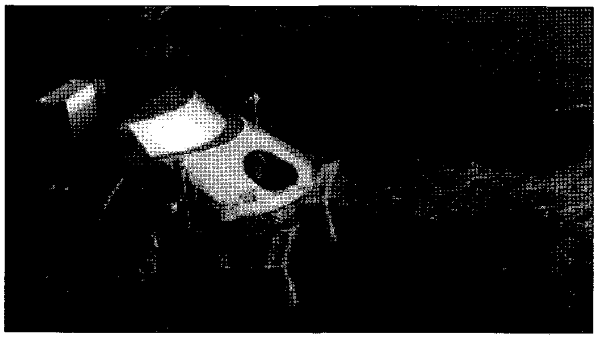


Fig. 9 Oil recovery test

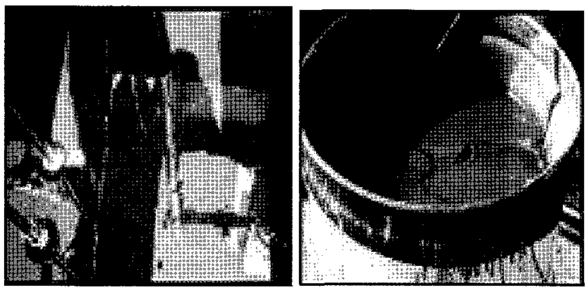


Fig. 10 Process of oil water separation

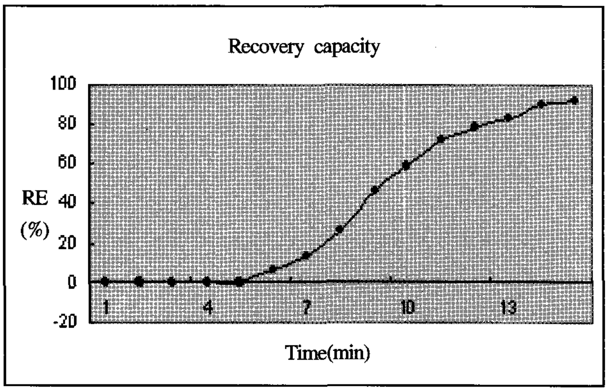


Fig. 11 Recovery efficiency

8. Conclusions

(1) Recovery time and efficiency are in the range of satisfaction as shown in Fig. 11.

(2) Buoy type oil guiding system proves to be more efficient in guiding the oil into the hull space not disturbing the free surface.

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2007년 5월 30일 원고 접수
2007년 11월 28일 최종 수정본 채택