A Diffusion Prevention and Recovery Scheme for Spilled Oil on Land

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\textbf{Abstract:} A set of quick response vehicle group and scheme was investigated to solve the current diffusion and recovery problems of spilled oil on land. A spilled oil recovery plant was simulated via FLUENT, the simulation result was verified by a control test, and it appeared that this plant could reach the recovery rate of above 50 m\textsuperscript{3}/h and diffusion prevention scope of 4,000 m\textsuperscript{2}. Hence, it can, to some extent, guarantee the quick response on the field, so as to reduce secondary disasters and protect the field environment.

\section{1. Introduction}

With the ever-increasing storage tank facilities and tank volumes in China, the recovery problem of spilled oil from storage tanks is becoming increasingly severe. Therefore, studying the recovery problem of spilled oil from storage tanks is of great environmental value and economic value. A total of about 242 oil spill accidents have taken place over the forty years since 1980\textsuperscript{[1-2]}. To facilitate the quick and better response to storage tank accidents, a recovery scheme that can recover the spilled oil quickly and lower the pollution to the minimum level is required. The foreign companies dedicated to the recovery of spilled oil from storage tanks include Lamor Corporation Ab, wholly-owned subsidiary of U.S SLICKBAR—J.B. F Environmental Engineering Corporation, and VIKOMA in UK\textsuperscript{[3-4]}. No complete set of systematic schemes has been formed in China, yet. In domestic (Chinese) studies regarding the spilled oil on land, the accumulation places of spilled oil on land have been summarized, the hazards have been analyzed and compared with spilled oil on water surface, and a relatively systematic oil spill emergency response scheme on land has been established\textsuperscript{[5-6]}. In this study, a set of quick response vehicle group and scheme with regard to diffusion prevention and recovery of spilled oil was explored, with the recovery rate of 50 m\textsuperscript{3}/h and diffusion prevention scope of 4,000 m\textsuperscript{2}.

This plant was mainly divided into two parts: diffusion prevention plant and recovery plant for spilled oil:
The main components of the first part included roller, oil-absorbing fence, speed reducer, motor, etc. (Figure 1).

In the diffusion prevention plant, the total length of oil-absorbing fence is 225 m, which could effectively prevent the oil diffusion in liquid bath below 4,000 m².

The main components of recovery plant included oil filter, vacuum pump, horizontal tank, gas-water separator, etc. (Figure 2).

2. Numerical Simulation of Recovery Plant for Spilled Oil

2.1 Physical model
To simplify the process and save the computing resources, the model was simplified into a model only containing storage tanks with the same volume, pressure inlet and pressure outlet (Figure 3). Meanwhile, the frictional head loss of the complete set of plant was calculated and incarnated in the parameter setting for the pressure outlet.
2.2 Mathematical model

The most part of fluid in the pipeline and vacuum tank was under the turbulence status, and its kinetic characteristics could be described by the continuity equation (Equation (1)) and N-S equation (Equation (2)).

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (1)
\]

\[
\begin{align*}
X - \frac{1}{\rho} \frac{\partial p}{\partial x} + v \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right) &= \frac{\partial u}{\partial t} \\
Y - \frac{1}{\rho} \frac{\partial p}{\partial y} + v \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \right) &= \frac{\partial v}{\partial t} \\
Z - \frac{1}{\rho} \frac{\partial p}{\partial z} + v \left( \frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \right) &= \frac{\partial w}{\partial t}
\end{align*} \quad (2)
\]

The velocity, pressure, etc. [7-8] in the fluid could be acquired by solving the above two equation sets.

2.3 Boundary conditions

In the simplification process, the linear hydraulic loss of the complete set of plant could be divided into frictional head loss and local head loss.

When the spilled oil flows in the pipeline, the energy loss caused by the friction between fluid micelles or fluid layers, that between fluid and pipe wall, and that between fluid and tank body is called frictional energy loss, also called frictional head loss [9-11]. The frictional head loss of fluid per unit gravity is denoted by \( h_f \) and calculated by the following Equation (3):

\[
h_f = \frac{\lambda L v^2}{d g} \quad (3)
\]

Where \( h \)——frictional head loss in pipeline, m;
\( \lambda \)——hydraulic friction resistance coefficient;
\( L \)——pipeline length, m;
\( v \)——fluid velocity in pipeline, m/s;
\( d \)——inner diameter of pipeline, m;
\( g \)——gravitational acceleration, 9.80 m/s².

When the spilled oil flows through all kinds of local obstacles like valve, elbow and pressure valve, a vortex is generated within local scope inside the pipeline due to the flow deformation, directional change and velocity redistribution of spilled oil, and the energy loss triggered by the collision between fluid micelles is called local energy loss, abbreviated as local loss. To simplify the calculation, it is approximately deemed that the local loss is concentrated on one cross section of this pipeline. The local loss of fluid per unit gravity is expressed by \( h_w \) and calculated through Equation (4).

\[
h_w = \zeta \frac{v^2}{2g} \quad (4)
\]

Where \( \zeta \)——local resistance coefficient.

The overall hydraulic loss of the complete recovery plant prototype is calculated as follows:

\[
h = h_{ftotal} + h_{wtotal} = 0.455 + 4.205 = 4.66m
\]

The maximum vacuum degree of pump can be calculated through the list of technical parameters, and the vacuum degree inside the tank is as below:

\[
P = 700mmhg = 93.32kpa
\]

The parameter of crude oil was chosen as \( \rho = 0.8837 \times 10^3 \) kg/m³, so the energy head is:

\[
H = \frac{P}{\gamma} = \frac{93.32 \times 1000}{0.8837 \times 9800} = 10.78m
\]

According to the energy head of water-ring vacuum pump and the calculated total frictional head loss, the pressure value at the pressure outlet of the simplified model can be acquired as follows:

\[
P = \rho g (H - h) = 1.0 \times 10^3 \text{ kg/m}^3 \times 9.8 \text{ N/kg} \times (10.78m - 4.66m) = 59976Pa
\]
2.4 Mesh generation
As the simplified model was quite simple, the mesh generation was implemented directly using the Fluent meshing module in ANSYS, as seen in Table 1.

Table 1 Mesh Independence Test Results

| Mesh  | Number of nodes | 360s flow (m³/h) | Deviation value |
|-------|-----------------|------------------|-----------------|
| 11 mm | 156313          | 0.758            | 7.04%           |
| 12 mm | 134455          | 0.708            | 4.05%           |
| 13 mm | 102885          | 0.738            | 5.13%           |
| 14 mm | 86108           | 0.778            | 11.36%          |
| 15 mm | 76813           | 0.878            | 0               |

From Table 2.1, the five groups of mesh independence test data showed that the deviation value of mesh elements in the second group was smaller than 5%, so they were the optimal mesh elements.

2.5 Fluent setting
The steady-state and transient-state solutions to the recovery of spilled oil were acquired via Fluent simulation. The \( k-\varepsilon \) turbulence model was used. The wall surface was treated to realize zero-slipping. Pressure-based solver was used. The pressure at the pressure outlet and inlet was \( 8.8 \times 10^4 \) Pa and 0, respectively, and the fluid characteristics were as follows: The density was \( \rho = 0.92 \times 10^3 \) kg/m³ and kinematic viscosity was \( \nu = 1.012 \times 10^{-2} \) kg·s/m.

2.6 Result analysis

2.6.1 Simulation results
By simulating the recovery process of spilled oil, the time-dependent change curve of fluid volume in the tank could be acquired as shown in Figure 4.

The curve chart showed that with the increase of fluid volume, the recovery rate was gradually reduced under the gravity effect, and it was 0.708 m³/h at 360 s.

2.6.2 Result verification
A prototype test of this model was conducted, the 150 s and 360 s average recovery rates were taken, and the test results are as shown in Figure 5.
According to the simulation results (Figure 5), the flow rate at 150 s was 0.528 m$^3$/h (average value: 0.492 m$^3$/h) with a relative deviation of 7.32%. The flow rate at 360 s was 0.708 m$^3$/h (average value: 0.679 m$^3$/h), with a relative deviation of 4.27%. The deviation value between simulation result and experimental data was smaller than 10%, so the simulation method accorded with the physical truth.

3. Simulation of Recovery Plant for Spilled Oil and Scheme

3.1 Reliability prediction model

The real plant was simulated through the same method of prototype simulation, but the data was altered into design data, namely, the inlet pressure and output pressure were 169, 976 Pa and 0, respectively, the fluid density was $\rho=0.8837\times10^3$ kg/m$^3$, and the kinematic viscosity was $\nu=5.71\times10^{-5}$ m$^2$/s, while others were unchanged, and the simulation results are as shown in Figure 6.

Through the simulation results of design scheme, it could be known that before the fluid volume in the tank reached 60%, the average flow rate could reach up to 63.53 m$^3$/h, and the recovery operation took 169 s each time.

3.2 Diffusion prevention and recovery process scheme for spilled oil

In this process, the spilled oil was recovered by the diffusion prevention vehicles and recovery vehicles for spilled oil, and the specific operation process was as follows:
(1) After the leakage signal was received, the leakage area and rough leakage rate were confirmed. On this basis, the quantity of diffusion prevention vehicles and recovery vehicles was determined. After the arrival, the diffusion prevention vehicles started operation and put down the oil-absorbing fence, in order to rapidly obstruct the oil diffusion and prevent the increase in area of liquid bath.

(2) Before the recovery of spilled oil, the water supply pipe valve and tap water valve were firstly opened, water was pumped into the gas-water separator until flowing out of the overflow pipe, then the tap water valve was closed, while the inlet valve of vacuum pipe was opened so that the vacuum pump was filled with liquid.

(3) The oil inlet valve and outlet valve on the tank were closed, and the gas inlet valve and outlet valve of pump were opened to start the vacuuming operation. After the pump was started, the air in the tank was pumped out by the vacuum pump. When the vacuum tank reached a certain vacuum degree, the oil pumping valve in the tank was opened, and thanks to the pressure difference between the vacuum tank and the outside, the spilled oil was filtered in the oil filter from the suction head and then flowed into the vacuum tank.

(4) With the reduction of oil products on the ground in the recovery process, the thickness of liquid bath was decreased, leading to suction failure of recovery suction nozzle. The oil from oil-absorbing fence could be synchronously recovered, to reduce the area of liquid bath and increase the thickness of liquid bath.

(5) After the spilled oil recovery reached 3/5 of the vacuum tank, the oil recovery should be stopped and the recovered crude oil in the vacuum tank should be discharged, in an effort to prevent the crude oil in the vacuum tank from flowing into the vacuum pump. At the time, the oil pumping valve of vacuum tank and gas inlet value and vent valve should be firstly closed to prevent the liquid in the pump from being sucked into the vacuum tank, which could result in the recontamination of recovered spilled oil. Next, the pump was closed and the recovered spilled oil was discharged.

(6) After the pump was stopped, the water supply to the vacuum pump should be stopped. If the pump was stopped for a too long time, the water in the pump and gas-water separator should be completely discharged in order to lengthen the service life of equipment. In addition, attention should be paid to the water freezing in the pump and separator when the pump is stopped for a short time due to oil discharge. Clean diesel oil can be used as the working solution to guarantee the normal operation of vacuum pump.

4. Conclusions

(1) In order to solve the oil spill problem on land, a set of spilled oil recovery plant on ground was designed in this study through the numerical simulation and test. It is verified that this plant can effectively block a leakage area of less than 4,000 m2, and the recovery rate of spilled oil reaches above 50 m3/h.

(2) A complete diffusion prevention and recovery process of spilled oil on land is formed, which facilitates the quick response to and active coping with the oil spill accident on land. It can reduce the occurrence probability and economic loss of secondary disasters in the accident and effectively protect the environment.

(3) The spilled oil recovery scheme developed in this study is capable of oil recovery in different environments and regions, but the disposal after the operation has not been discussed.

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