Subject Matter Study Report

**Analyses of Oil (Petroleum) Spill Migration on**

**Ground Surfaces**

August 2022

By

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**Executive Summary**

Title 49 CFR Part 195 for hazardous liquids does not contain a procedure for calculating the impact radius or hazardous distance for a hazardous liquid release. This study provides a procedure to calculate the migration distance on land of a petroleum spill. These calculations are critical for determining the potential impact distances of a low vapor pressure petroleum spill due to an ignition of the low vapor pressure spill. The procedure in this study is not appropriate for a highly volatile liquid such as butane or propane which possess very high evaporation rates which migrate through the air. Vapors from highly volatile liquids are much heavier than air and can migrate close to the ground for a significant distance, especially if the wind speed is not high.

The capability to calculate the migration distance of an oil or petroleum spills is also critical for compliance with Title 49 CFR Part 194 which is titled *Response Plans for Onshore Oil Pipelines*. In this regulation, a worse case spill of high volume and adverse weather conditions must be calculated and its migration to environmentally sensitive and economically sensitive areas must be determined. Plans must be made to minimize the volume of these spills and the capability to control and remove the spills must be included in this regulation.

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**Introduction**

Title 49 CFR Part 194 requires oil (petroleum) spill response plans for onshore oil pipelines. The oil spill response plan shall be required to respond to a worst case discharge of oil or the substantial threat of such a discharge from each response zone along a pipeline system. The response plan must provide for the deployment of spill response capabilities to the worst case discharge from each response zone.

The worse case spill volume and its worse case mitigation along pathways toward populated and environmentally sensitive areas. The purpose of this study is to show how to calculate the potential migration along pathways of the worse case spills toward populated and environmentally sensitive areas.

**Evaluation of Surface Spreading of a Spill of Oil on Wet Ground**

Stefano Grimaz et al in their study “Predictive Evaluation of Surface Spreading Extent for the Case of Accidental Spillage of Oil on the Ground” published in the *Journal of Fluid Mechanics* referenced two studies written by H.E. Huppert in 1982 and 2006. The procedure published in 1982 covers the extent of two-dimensional spill spreading on a horizontal impermeable surface such as wet saturated ground as calculated below:

 (1)

where:

*L* = migration distance from point of spill, ft.;

*a* = 0 for instantaneous release;

*a* = 1 for constant flow rate release;

*a* = 2 for linearly increasing release;

*n* = 0 for line release source;

*n* = 1 for point release source;

*C* = 1.411 for instantaneous line release source;

*C* = 1.01 for constant flow rate line release resource;

*C* = 0.85 for linearly increasing flow rate line release;

*C* = 0.894 for instantaneous point release resource;

*C* = 0.715 for constant flow rate point release resource;

*C* = 0.623 for linearly increasing flow rate point release resource;

*g* = 32.2 ft. per sec.2;

*q* = spill rate, ft.3 per sec.;

*v* = oil viscosity, ft.2/sec.; and

*t* = spill travel time, sec.

The conversion factor for viscosity is 1 centistoke = 0.0000108 ft.2/sec.

**Refined Products Spill Example**

A refined products spill will be used to illuminate the process to analyze oil spill migration. For refined products at 60°F, *v* = 1.0 centistoke (cSt.) (0.0000108 ft.2/sec.) and release volumes for the example are:

Table 1

 Release Rate, Accumulated Spill Volume

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Release Time, Hrs. | Accumulated Time, Sec. | Bbl./Hr. | Ft.3/Sec. | Bbl. | Ft.3 |
| 0 |  0 | 10,000 |  15.6 |  0 |  0 |
| 1 |  3,600 | 10,000 |  15.6 | 10,000 |  56,150 |
| 2 |  7,200 | 10,000 |  15.6 | 20,000 | 112,300 |
|  3\* | 10,800 |  2,000 |  3.1 | 30,000 | 168,450 |
| 4 | 14,400 |  2,000 |  3.1 | 32,000 | 179,680 |
| 5 | 18,000 |  2,000 |  3.1 | 34,000 | 190,910 |
|  6\*\* | 21,600 |  0 | 0 | 36,000 | 202,140 |
| 7 | 25,200 |  0 | 0 | 36,000 | 202,140 |
| 8 | 28,800 |  0 | 0 | 36,000 | 202,140 |
| 9 | 32,400 |  0 | 0 | 36,000 | 202,140 |
|  10\*\*\* | 36,000 |  0 | 0 | 36,000 | 202,140 |

\* Pipeline pumping stopped and pipeline valves closed.

 \*\* Spill stopped with a clamp installed over the pipeline release point.

 \*\*\* Spill migration stopped by a spill response crew using a spill retainer (boom).

Equation (1) is revised as follows for our example:

  (2)

 where:

 *L* = spill migration traveled during previous hour, ft./hr.;

 *q* = average accumulated volume of spill during previous ft.3, sec.; and

 *t* = unit of spill time travel, hour.

Equation (2) is revised as follows to calculate two-dimensional migration speed of travel of the spill:

  (3)

 where:

 *S* = speed of spill migration, ft./sec.

In our example the speeds of migration are:

Table 2

|  |  |  |  |
| --- | --- | --- | --- |
| Release Time, Hrs. | Release Rate,*q* , Ft.3/Sec. | Spill Migration,Ʃ Ft./Hr. | Average Speed of Spill Travel, Ft./Sec. |
| 0 | 0 |  0 |  0 |
| 1 |  15.6 |  676 | 0.188 |
| 2 |  15.6 | 1,239 | 0.172 |
|  3\* |  15.6 | 1,767 | 0.164 |
| 4 |  3.1 | 2,090 | 0.145 |
| 5 |  3.1 | 2,390 | 0.133 |
|  6\*\* |  3.1 | 2,675 | 0.124 |
| 7 | 0 | 2,889 | 0.115 |
| 8 | 0 | 3,089 | 0.107 |
| 9 | 0 | 3,276 | 0.101 |
|  10\*\*\* | 0 | 3,453 | 0.096 |

\* Pipeline pumping stopped and pipeline valves closed.

 \*\* Spill stopped with a clamp installed over the pipeline release point.

 \*\*\* Spill migration stopped by a spill response crew using a spill retainer (boom).

The accumulated spill distance and areas for two-dimensional migration flow are:

  (4)

 where:

  = accumulated area, ft.2 and

  = accumulated spill travel distance, ft.

Spill migration distances are:

Table 3

 Spill Travel Distance, Ft.

|  |  |  |  |
| --- | --- | --- | --- |
| Release Time, Hrs. | Incremental | Accumulated | Accumulated Spill Area, Ft.2 |
| 0 |  0 |  0 |  0 |
| 1 | 676 |  676 |  1,435,640 |
| 2 | 563 | 1,239 |  4,822,740 |
|  3\* | 528 | 1,767 |  9,808,980 |
| 4 | 323 | 2,090 | 13,722,820 |
| 5 | 300 | 2,390 | 17,945,130 |
|  6\*\* | 285 | 2,675 | 22,480,110 |
| 7 | 214 | 2,889 | 26,220,800 |
| 8 | 200 | 3,089 | 29,976,900 |
| 9 | 187 | 3,276 | 33,716,200 |
|  10\*\*\* | 177 | 3,453 | 37,457,950 |

 \* Pipeline pumping stopped and pipeline valves closed.

 \*\* Spill stopped with a clamp installed over the pipeline release point.

 \*\*\* Spill migration stopped by a spill response crew using a spill retainer (boom).

 Table 4

 Spill Depth, Ft.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Release Time, Hrs. | Accumulated Spill Volume, Ft.3 | Accumulated Spill Area, Ft.2 | Average | Maximum |
| 0 |  0 |  0 |  0 |  0 |
| 1 |  56,150 |  1,435,640 | 0.0391 | 0.0782 |
| 2 | 112,300 |  4,822,740 | 0.0233 | 0.0466 |
|  3\* | 168,450 |  9,808,980 | 0.0172 | 0.0344 |
| 4 | 179,680 | 13,722,820 | 0.0131 | 0.0262 |
| 5 | 190,910 | 17,945,130 | 0.0106 | 0.0213 |
|  6\*\* | 202,140 | 22,480,110 | 0.0090 | 0.0180 |
| 7 | 202,140 | 26,220,800 | 0.0077 | 0.0154 |
| 8 | 202,140 | 29,976,900 | 0.0067 | 0.0135 |
| 9 | 202,140 | 33,716,200 | 0.0060 | 0.0120 |
|  10\*\*\* | 202,140 | 37,457,950 | 0.0054 | 0.0108 |

 \* Pipeline pumping stopped and pipeline valves closed.

 \*\* Spill stopped with a clamp installed over the pipeline release point.

 \*\*\* Spill migration stopped by a spill response crew using a spill retainer (boom).

Spill depths at the spill release point are:

  (5)

  (6)

 where:

 *Avg. D* = average spill depth of migrating spill, ft. and

 *Max. D* = maximum spill depth at the point of release, ft.

The flow rate of a liquid in pipe or on the ground is proportional to the square root of the pressure profile, *P ÷ L*, is as follows:

  (7)

 where:

 *q* = flow rate, ft.3 per hour;

 *Z* = flow parameter that describes the path of liquid flow, hour per ft.3;

 *P* = pressure at the origin of the liquid, ft. of liquid; and

 *L* = length of flow on the ground, ft.

On level land, the flow rate of a liquid spill is:

  (8)

 where:

 *D* = depth of liquid at the spill site, ft.

On unlevel ground, the flow rate of a liquid spill is:

  (9)

 where:

 *H* = elevation difference between spill site and distance *L* from the spill site, ft.

For a spill on level ground under similar flow resistance conditions, flow rate is proportional to the square root of the hydraulic (flow) profile, (*D/L*), as follows:

  (see equation 7)

 where:

 *D* = depth of spill at spill site, ft.;

 *L* = length of spill from the spill site, ft.;

 *q* = spill flow rate, ft.3/hr.; and

 *Z* = flow parameter for spill site, hr./ft.3.

For the previous example, *Z* is:

 

For a spill on unlevel ground in our previous example, the length of spill travel for various values of *H* are:

1. a. For *H* = 0.0782 *ft.*,

b. *L* = 

c. *L* = 676 *ft*.

1. a. For *H* = 0.5 *ft.*,

b. *L* = 

c. *L* = 4,303 *ft.*

1. a. For *H* = 1 *ft.*,

b. *L* = 

c. *L* = 8,605 *ft.*

1. a. For *H* = 2 *ft.*,

b. *L* = 

c. *L* = 17,210 *ft.*

If another spill pathway is 100 feet wide, the accumulated length of two direction migration from a spill on level ground is:

  (10)

 where:

  = accumulated length of migration from spill site, ft./hr.;

  = accumulated volume of spill migration, ft.3/hr.;

 *W* = width of linear migration area, ft.; and

 *D*  = depth or height of spill at release site, ft.

The accumulated lengths of migration along a level 100 ft. wide migration pathway based on equation (7) are shown below.

Table 5

 Spill Volume, Ft.3

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Release Time, Hrs. | Incremental | Accumulated  | Length of Spill Migration, Ft. | Ʃ Lengths of Spill Migration, Ft. |
| 0 |  0 | 0 |  0 |  0 |
| 1 | 56,150 | 56,150 | 2,200 |  2,200 |
| 2 | 56,150 | 112,300 | 1,554 |  3,754 |
|  3\* | 56,150 | 168,450 | 1,267 |  5,021 |
| 4 | 11,230 | 179,680 | 1,229 |  6,250 |
| 5 | 11,230 | 190,910 | 1,192 |  7,442 |
|  6\*\* | 11,230 | 202,140 | 1,158 |  8,600 |
| 7 |  0 | 202,140 | 1,158 |  9,758 |
| 8 |  0 | 202,140 | 1,158 | 10,916 |
| 9 |  0 | 202,140 | 1,158 | 12,074 |
|  10\*\*\* |  0 | 202,140 | 1,158 | 13,232 |

 \* Pipeline pumping stopped and pipeline valves closed.

 \*\* Spill stopped with a clamp installed over the pipeline release point.

 \*\*\* Spill migration stopped by a spill response crew using a spill retainer (boom).

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