Appendix F.

Near-Field Produced Water Plume, Platform Irene
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Prepared for:
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1 Introduction

This report provides detailed near-field effluent concentration contours associated with produced water discharged from platform Irene. Produced water is discharged following treatment to remove oil and gas condensates. Brandsma (2001) has modeled the Irene produced water plume with an effluent temperature of 60ºF and this report is an update to that work for effluent temperatures of 120 and 160ºF.

2 Discharge Scenario

Brandsma and Ayers (1996) conducted a study of dilution from California offshore platforms for the Western States Petroleum Association. This effort included extensive collection of discharge data from operators and ambient data from various sources. As a result of this study, typical ambient conditions pertinent to the California outer continental shelf were established. These conditions, listed in Table 1, were accepted by the Region 9 of the Environmental Protection Agency for use in its proposed general permit (http://www.epa.gov/region09/water/npdes/generalpermit1.pdf).

<table>
<thead>
<tr>
<th>Table 1</th>
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<tbody>
<tr>
<td>Typical Ambient Conditions for California OCS</td>
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<tr>
<td>Current speed</td>
</tr>
<tr>
<td>Ambient density at discharge port</td>
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<tr>
<td>Ambient density gradient</td>
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</tbody>
</table>

Platform Irene is located in 242 feet of water. Produced water is discharged from a 12.75 inch diameter pipe with its mouth 180 feet below the surface, oriented vertically downward. The discharge rate is 40,000 bbl/day.

Formation water produced from platform Irene has a salinity of 34 gm/L (equivalent to 34 ‰). Brandsma (2001) used a produced water temperature approximately equal to the ambient temperature, 60ºF (15.5ºC). The present work characterizes the produced water at the point of discharge with two additional temperatures, 120ºF and 160ºF (49ºC and 71.1ºC).

For modeling produced water, it is necessary to specify the ambient temperature and salinity at the water surface and at the seafloor. Choices of these parameters were made to be compatible with the ambient density and density gradient specifications in Table 1. The pertinent depths were converted from feet to meters, so that the water depth is 73.78 m and the discharge port depth is 54.88 m. The required surface ambient density is then 1025.6 – 0.01 x 54.88 = 1025.05 kg/m³. The required bottom ambient density is 1025.6 + 0.01 x (73.78 – 54.88) = 1025.79 kg/m³. An ambient salinity of 33.5‰ was selected for the surface. The temperature corresponding to the surface ambient density
must then be 14.01°C, according to the sea water equation of state. A bottom temperature of 12°C was selected, and the salinity corresponding to the required density must then be 33.94‰. The surface and bottom temperatures and salinities thus developed are characteristic of California waters and define the required ambient density gradient of 0.01 kg/m³/m.

3 Methodology

The Offshore Operators Committee (OOC) discharge model (Brandsma and Smith, 1999) was used to simulate the discharges from platform Irene under the ambient conditions in Table 1. The area of interest was the near-field (within 100 m). Water column cross-sections were defined in the OOC model so that concentration contours of the plume could be produced for longitudinal and transverse cross-sections of the plume. The cross-sections consist of sets of vertical concentration profiles in which concentrations are reported at regular intervals between two prescribed depths. A concentration of 100% conservative tracer was introduced to the effluent. The background concentration of the tracer was assumed to be zero. Results were reported as contours expressed in percent of the initial effluent concentration (following EPA practice).

The values in Tables 1 and information supplied by the platform operator were used to prepare input files for the OOC model. The model was enhanced for these runs by increasing the allowable number of concentration profiles and the number of points in each profile. This provided the resolution necessary to resolve the plumes in some detail. The model read the input file and produced corresponding output files. The output files were post-processed to prepare concentration contour plots showing the various cross-sections.

4 Results

The results begin with updated plots of the plume results prepared by Brandsma (2001). These original results are followed by results for initial plume temperatures of 120°F and 160°F. All figures are presented at the end of the report.

Figure 1 shows a longitudinal cross-section aligned with the center of the plume formed from a 40,000 bbl/day discharge of 60°F, 34 ppt produced water from the platform Irene outfall pipe. The plume, having no buoyancy, sinks under the influence of its initial momentum. After overshooting, the plume reaches equilibrium approximately 4.3 m below the discharge depth. The plume is trapped at this depth by the ambient density stratification. As the plume sinks and is diluted, it entrains ambient water of varying density. The effluent density becomes dominated by the much higher volume of ambient water entrained. The ambient water entrained at first, higher in the water column, is less dense than ambient water entrained later and deeper. At some depth, the density of the
diluted effluent plume becomes equal to the ambient density. As the plume continues to sink, its density becomes less than the surrounding ambient water and a buoyancy force is generated to arrest the descent of the plume. Eventually, the plume returns to a depth where its density matches the ambient density and remains at that depth. Dilution is rapid at first and slows once the plume has reached its trapping (neutral buoyancy) depth. The bottom boundary of Figure 1 corresponds to the sea floor depth. Transverse cross-sections at distances of 10, 20, 40, 60, 80 and 100 meters are shown in Figure 2. The collapse of the plume after its initial dilution is clearly shown. The collapse is driven by the difference in density gradients between the well mixed plume and the stratified water column. It takes about 14.5 minutes for the effluent to travel 100 m downcurrent after discharge.

Figure 3 is a longitudinal cross-section of the 120ºF plume and Figure 4 shows a series of transverse cross-sections of the same plume.

Figure 5 is a longitudinal cross-section of the 160ºF plume and Figure 6 shows a series of transverse cross-sections of the same plume.

The percents effluent and corresponding dilution factors at distances of 100 m from the point of discharge are summarized in Table 2.

<table>
<thead>
<tr>
<th>Effluent Temperature</th>
<th>Concentration at 100 m (percent effluent)</th>
<th>Dilution Factor at 100 m</th>
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<tbody>
<tr>
<td>60ºF</td>
<td>2.20</td>
<td>45.5</td>
</tr>
<tr>
<td>120ºF</td>
<td>0.55</td>
<td>181.8</td>
</tr>
<tr>
<td>160ºF</td>
<td>0.41</td>
<td>243.9</td>
</tr>
</tbody>
</table>

5 Discussion

The results reported here predict the dilution, trajectory and dimensions of a produced water plumes discharged from platform Irene. The 60ºF effluent originally modeled in 2001 is nearly neutrally buoyant and so it sinks a bit before reaching an equilibrium depth. The lack of buoyancy in the 60ºF Irene discharge led to relatively low dilutions and small plume cross-sections.

Increasing the temperature of the effluent results in a dramatic improvement in dilution. Increasing the effluent temperatures by factors of 2 and 2.67 makes the 120ºF and 160ºF plumes strongly buoyant. The buoyancy causes the heated plumes to reverse course shortly after discharge and rise through the water column until becoming trapped by the ambient density stratification. The increased vertical travel of the heated plumes, driven by their buoyancy, leads to the large increases in dilution factors reported in Table 2.
The plume behavior predicted in this report is based on standardized ambient conditions adopted by the EPA. Small variations in real ambient or discharge conditions could lead to different plume behavior. If the ambient salinity was increased from the values used for modeling or if the effluent salinity were decreased, a buoyant plume would be created and would rise in the water column. The rise is not likely to be large unless the salinity changes are large.

The OOC model used for this investigation has been tested against 681 sets of laboratory and field measurements (Brandsma, 2004; Nedwed et al, 2004; Smith, et al, 2004) and matched those results well. In particular the OOC model does an excellent job of predicting concentrations for a produced water plume in a field study in which divers took samples manually from a plume made visible with dye (Smith et al., 1994).

6 References


Figure 1. Longitudinal section of 40,000 bbl/day produced water plume (55.4°F = 15.5°C, 34 ppt) from platform Irene. Contour levels are percent effluent (100% at point of discharge).
Figure 2. Transverse cross-sections of 40,000 bbl/day produced water plume (60°F = 15.5°C, 34 ppt) from platform Irene. Contour levels are percent effluent (100% at point of discharge).
Figure 3. Longitudinal section of 40,000 bbl/day produced water plume (120°F = 49°C, 34 ppt) from platform Irene. Contour levels are percent effluent (100% at point of discharge).
Figure 4. Transverse cross-sections of 40,000 bbl/day produced water plume (120°F = 49°C, 34 ppt) from platform Irene. Contour levels are percent effluent (100% at point of discharge). Note that vertical coordinates in the frame for 10 m distance are 10 m lower than those in the other frames.
Figure 5. Longitudinal section of 40,000 bbl/day produced water plume (160°F = 71.1°C, 34 ppt) from platform Irene. Contour levels are percent effluent (100% at point of discharge).
Figure 6. Transverse cross-sections of 40,000 bbl/day produced water plume (160°F = 71.1°C, 34 ppt) from platform Irene. Contour levels are percent effluent (100% at point of discharge). Note that vertical coordinates in the frame for 10 m distance are 10 m lower than those in the other frames.
Figure 7. Maximum centerline concentration of Irene plumes for three temperatures (60, 120 and 160°F).
MEMORANDUM

To: Vida Strong, Aspen Environmental Group
Cc: David Rose, Plains Exploration and Production Company
From: Maynard Brandsma
Date: 31 July 2007

Dilution Times and Temperatures, Platform Irene Produced Water

Distances downcurrent can be converted to travel times downcurrent by dividing the distances by the current speed, 0.115 m/s. Figure 1 shows maximum plume concentrations, expressed as a percentage of the initial effluent concentration, as a function of time. Initial dilution is rapid, reaching 10:1 in under 50 seconds after release.

Figure 1. Maximum (centerline) produced water concentrations as function of time since release from the discharge pipe.
Maximum produced water plume temperatures are plotted in Figure 2. Owing to the effluent temperature being less than 3 times the ambient temperature at most and the rapid dilution, 10:1 within 50 seconds, plume temperatures drop to near ambient levels within 50 seconds of discharge.

![Figure 2](image)

Figure 2. Maximum (centerline) plume temperature as a function of time since release.

Longitudinal cross-sections of excess temperature, $\Delta T = T_{\text{plume}} - T_{\text{ambient}}$ (°F) are provided in Figures 3, 4 and 5 for initial exit temperatures of 60, 120 and 160°F. These plots correspond to Figures 1, 3 and 5 in Brandsma (2007).
Figure 3. Longitudinal section of 40,000 bbl/day produced water plume (60°F) from platform Irene showing excess temperature, $\Delta T$. 
Figure 4. Longitudinal section of 40,000 bbl/day produced water plume (120°F) from platform Irene showing excess temperature, $\Delta T$. 
Figure 5. Longitudinal section of 40,000 bbl/day produced water plume (160°F) from platform Irene showing excess temperature, $\Delta T$.

Reference