Produced Water Remote Monitoring

Dzyan Maroef

Andy Fourie
Civil, Environmental and Mining Engineering
University of Western Australia

Tim Robertson
Chevron Australia Pty Ltd

Abstract

Produced water can be a significant by-product from oil and gas operations with potential impacts to the environment if not appropriately managed. This study wishes to explore the use of remote sensing, specifically UV sensors, as a new method of measuring produced water plume concentrations. The main objectives were to derive Total Petroleum Hydrocarbons (TPH) concentrations from the sheen intensity of produced water samples and evaluate the effect of different variables on sheen formation. A factorial experimental design of different levels of condensate added, mixing rate, mixing duration and salinity was carried out. Sheens were recorded using the PCO UV camera and analysed using ImageJ. Corresponding TPH concentrations of samples were measured using ERAcheck Pro. Mixing rate was found to have the most effect on sheen formation, with mixing intensity having a lesser effect, and salinity having a negligible effect. Tests indicate a limit of detection between 1.885 mg/L and 18.85 mg/L, and the ability to derive TPH from varying grades of sheen intensity. Recommendations include improving experimental approaches to reduce error, considering other factors in a factorial design, and carrying out supporting field tests and models.

1. Introduction

1.1 Background

Produced water is derived from fresh or brine water that has been trapped with oil and gas formations within a reservoir of porous sedimentary rock between layers of impermeable rock (Lee 2011). Produced water may contain salts, heavy metals, hydrocarbon constituents and/or radioisotopes, and according to Lee 2011 represents around 80% of the volume of waste produced from oil and gas operations internationally. Due to the large volumes and potential for environmental toxicity of its composition, managing and monitoring produced water is important to help manage water impacts. Current methods for monitoring produced water include end of pipe sampling, followed by modelling of the plume dynamics to estimate the dilution at the compliance radius (Nedwed et al. 2004). This study wishes to explore the use of remote sensors to measure the extent and concentration of the produced water plumes from their ocean surface expression.

1.2 Literature review

Figure 1 shows the different phases of oil in water. E&OCL (2003) describes oil concentration to be present in water in dispersed concentrations, as immiscible droplets suspended in the water column, and in dissolved concentrations, as the soluble amounts of oil in the water.

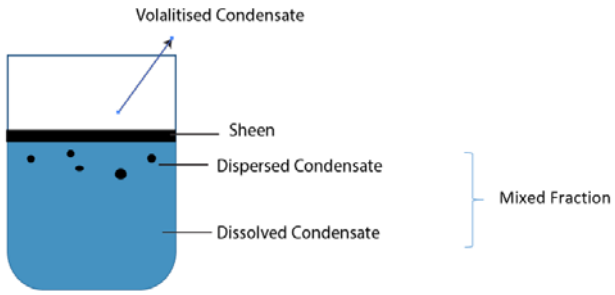

Figure 1 Theorized oil components in water

E&OCL (2003) describes sheen formation from produced water plumes to be the result of the dynamics of the dispersed and aqueous concentrations. Aman et al. (2015) describes droplet sizes and notes that oil break up is due to turbulence and shear effects on the droplet. Replicating field mixing conditions is important for lab tests. Solid amounts are also known to stabilize emulsifications and increase dispersed concentrations (E&OCL 2003). Finally, E&OCL (2003) relates the interaction between dissolved concentrations and sheen formation to solubility. This can be a function of temperature, where decreased temperatures from the treatment stage to the discharged state can cause oil to leave the dissolved state.

1.3 Objectives

The objectives of this project were: 1) to find the limit of detection or the TPH concentration at which a sheen is first detectable, 2) to further correlate sheen intensity and TPH concentration to show the possibility of deriving concentrations from grades of sheen intensities, and 3) to examine the effects of factors that may affect sheen formation, including mixing rate, mixing duration and salinity.

2. Process

2.1 Factorial Design

The experiment uses a factorial design for observing the effect of multiple variables on sheen presence. The variables being changed, and all testing conditions are shown in Table 1.

Condensate Added	Mixing Rate	Mixing Duration	Salinity
1uL (1.8835mg/L)	Low (1500rpm)	Short (1 min)	Distilled Water
10uL (18.835mg/L)	High (3500rpm)	Long (10 min)	Filtered Seawater
30uL (56.505mg/L)			

Table 1 The factorial design set up, with the factors of condensate added, mixing intensity, mixing duration and salinity, each with 2 or 3 levels. The full design consists of all combination of factors and levels with 24 experimental conditions in total.

2.2 Measuring Sheen Intensity

For the purposes of this study, a sheen refers to any type of water surface expression of hydrocarbons, whether it is a homogenous film of oil on the surface of water, dispersed droplets of oil that sit on the surface of water, or anything in between. During preliminary tests, the sheen revealed itself as dispersed droplets of oil that sit on the surface of water, which was further shown to be quantifiable by the amount of light reflected by the sheen multiplied by the total surface area the sheen took up. This was termed the sheen intensity

Samples were mixed under different experimental conditions, then the surface expression of the sample was recorded using PCO UV camera. The target wavelength of the camera was 250-385 nm, achieved with the attachment of a shortpass filter. The samples were observed under a 365 nm 30 W UV flood light, from a 70-degree angle down from the vertical, with external lighting isolated using curtains over the fume hood. Six sheets of baking paper were used to diffuse the light from the light source to reproduce a similar effect of ambient lighting, analogous to the dispersed light experienced in real world / field conditions. 30 repeat pictures were taken per sample to reduce the error due to fluctuating light conditions of the light source. The pictures were processed and analysed using ImageJ (Figure 2). To calculate the area percentage taken up by the sheen, the images are were processed through multiple steps:

1. Flat field correction: To remove the underlying “spotlight effect”/light gradient
2. Thresholding: To define an intensity threshold that separates the sheen from water
3. Particle area calculations: To calculate the percentage area taken up by the sheen

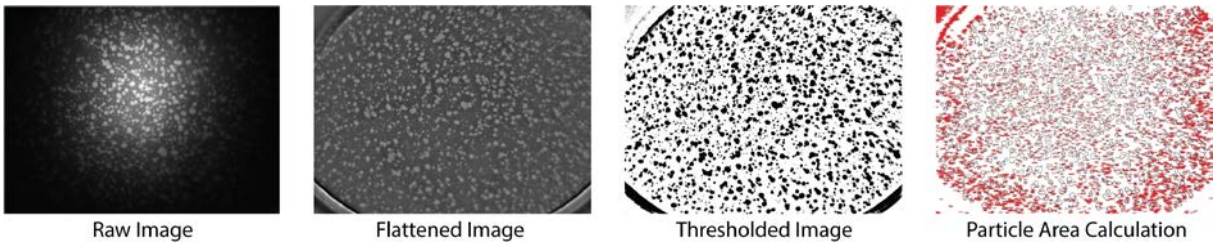

Figure 2 ImageJ processing of images to find sheen area of samples

2.3 Measuring TPH Concentrations

For the experimental design, 400 mL samples of mixed oil (a condensate) and water were divided into a bottom 200 mL half and a top 200 mL half. The bottom extract is to represent the TPH concentration in the mixed fraction. The top extract is to be used with the bottom extract to determine the total mass of condensate left in the sample and estimate volatile losses. The extraction procedure starts after the preparation of samples, and UV Imaging. The sample was then funnelled into a separator vessel. The bottom and top 200 mL was poured out into separate 500 mL Schott bottles, 15 mL of cyclohexane is poured in each, then shaken together for 5 minutes. When pouring the cyclohexane in, the sides of the separator vessel were rinsed and put into the Schott bottle for the top extract. The same was done with the sample beaker where mixing occurs. The cyclohexane was left to settle from the water, 12 mL is extracted from the top layer of cyclohexane into a 15 mL glass vial.

The Absorbance (mAU), oil in solvent (mg/L) and oil in water (mg/L) concentrations of each sample were measured using ERA-Check, after calibration. Measurements were done from lowest concentrations to highest concentrations to prevent cross-contamination.

2.4 Statistical Analysis

Software Minitab 18 and 19 was used to carry out the statistical analysis for this study. Factorial Regression analysis was used to determine standardised effects of each factor on sheen detectability (in terms of Relative Average Intensity) and TPH concentration. For sheen intensity, all main effects (amount of condensate added, mixing intensity, mixing duration and salinity alone) were considered, while only the interaction between mixing duration and mixing intensity on sheen detectability were considered. For TPH concentration only the effects of condensate added, mixing intensity, mixing duration were examined. A one-way ANOVA was used to test for statistical difference between added condensate values.

3. Results and Discussion

3.1 Standard Effects of Factors that affect sheen formation

The standardised effects of each factor are further exemplified in the Pareto Chart of Standardised effects (Figure 3), with only condensate added and mixing duration crossing the reference line ($\alpha = 0.05$). Condensate Added was shown to increase sheen detectability with increasing amounts added, with significant effect ($p = 0$). Mixing Duration was shown to decrease sheen detectability with increasing duration, with significant effect ($p = 0.021$). Both Mixing rate ($p = 0.495$) and Salinity ($p = 0.33$) were shown to not have a significant effect on sheen detectability. There was also no significant interaction between mixing rate and mixing duration ($p = 0.694$).

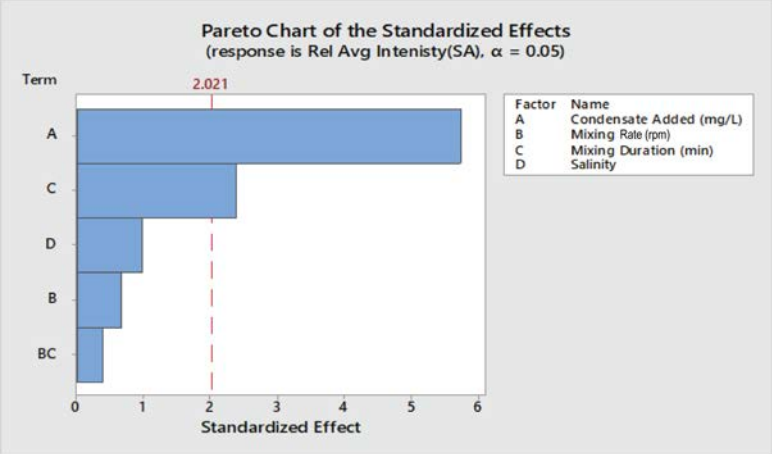

Figure 3 Pareto Chart of Standardized effects for Condensate added (mg/L), Mixing Rate (rpm), Mixing Duration (min) and Salinity. Reference line for statistical significance (α = 0.05) is 2.120.

3.2 Volatized fractions analysis from TPH measurements

TPH analysis of volatised fractions reveal an error in the experimental design, leading to volatile losses not being able to be ascertained. The standardized effects of condensate added, mixing rate and mixing duration are shown in the Pareto Chart of Standardised effects (Figure 4), with only condensate added crossing the reference line ($\alpha = 0.05$). Condensate added effects the results by a larger magnitude than expected, suggesting this may be due to error in condensate residue left on glassware walls. This error may be overshadowing the effects of the other factors, leading to apparent negligible effects.

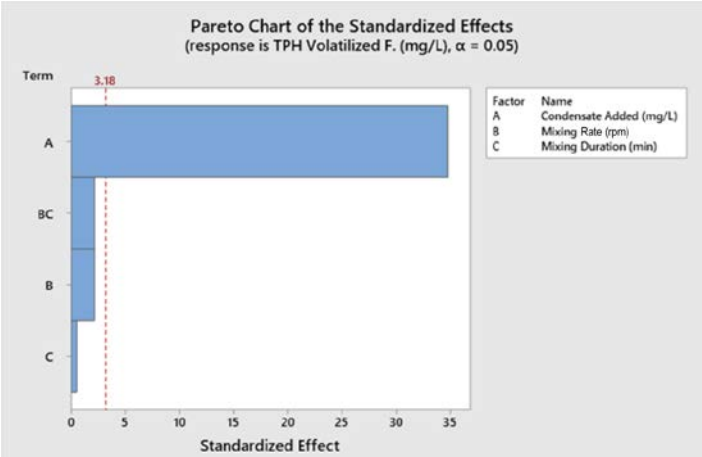

Figure 4 Pareto Chart of Standardized effects for Condensate added (mg/L), Mixing Rate (rpm), Mixing Duration (min), for the TPH concentration in the Volatilized Fraction. Reference line for statistical significance (α = 0.05) is 3.18.

3.3 Significant Difference – Assessing the ability to extrapolate TPH concentrations from sheen intensity

Since volatile losses could not be ascertained, assessing the ability to extrapolate TPH concentrations from sheen intensities was done based on amount of condensate added, with negligible volatilisation assumed. A one-way ANOVA Tukey's analysis was carried out on the different condensate levels. Figure 5 shows the results with a, b, and c representing separate statistical groupings. A significant difference from the control (0 mg/L) was found for 18.835 mg/L and 56.505 mg/L of condensate added, as well between each other, under varying experimental conditions. There was no significant difference from 0mg/L is apparent for 1.8835 mg/L. Thus, the limit of detection sits between 1.8835 mg/L and 18.835 mg/L, under most conditions. This also shows that different grades of TPH concentrations can be interpolated from different grades of sheen intensity. However, it remains that volatile losses must be ascertained to validate these findings.

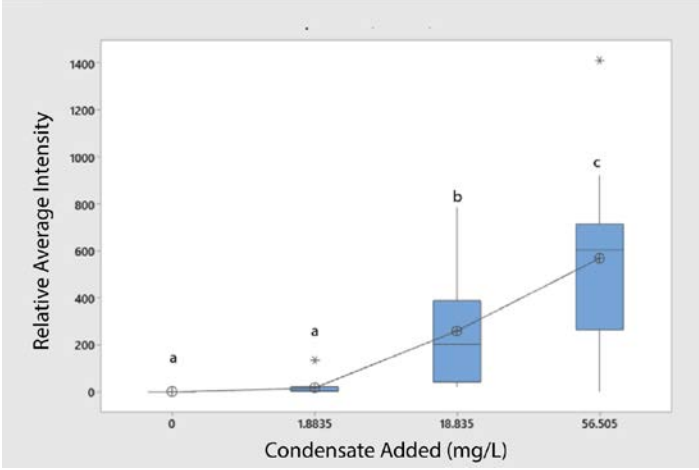

Figure 5 Box plot of Relative Average Intensity for Condensate added (mg/L) at different amounts. Statistical grouping using ANOVA Tukey's method using a, b, and c.

4. Conclusions and Future Work

Mixing rate was found to have the most effect on sheen formation, with mixing intensity having a lesser effect, and salinity having a negligible effect. Tests indicate a limit of detection within a range of 1.885 mg/L and 18.85 mg/L, and the ability to extrapolate TPH from varying grades of sheen intensity. However due to an error of condensate residue on glassware walls not sufficiently dissolving into solvent, volatile losses could not be ascertained. The findings are thus made based on total amount of condensate added and, on an assumption, that volatile losses are negligible.

Recommendations of this study include: 1) Finding experimental approaches to fully capture condensate amounts in measured TPH concentrations or mitigating volatile losses completely. 2) Other factors can be considered in a factorial design to comprehensively identify which factors play a significant part in sheen formation. 3) Further replicates and data points can be used to create curves of different experimental conditions for interpolating TPH concentrations. 4) Field scale monitoring coupled with sampling and analysis, to measure TPH concentrations and evaluate sheen applying the methods developed through this research at broader scale. 5) Sample recovery and analysis (of both TPH, sheen and droplet size) closer to the location and time of produced water generation to measure more representative fluid conditions generated through oil and gas processes.

5. Acknowledgements

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6. References

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