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Modeling of Oil Mist and Oil Vapor Concentration in the Shale Shaker Area on Offshore Drilling Installations

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The objective of this study was to develop regression models to predict concentrations of oil mist and oil vapor in the workplace atmosphere in the shale shaker area of offshore drilling installations. Collection of monitoring reports of oil mist and oil vapor in the mud handling areas of offshore drilling installations was done during visits to eight oil companies and five drilling contractors. A questionnaire was sent to the rig owners requesting information about technical design of the shaker area. Linear mixed-effects models were developed using concentration of oil mist or oil vapor measured by stationary sampling as dependent variables, drilling installation as random effect, and potential determinants related to process technical parameters and technical design of the shale shaker area as fixed effects. The dataset comprised stationary measurements of oil mist ($n = 464$) and oil vapor ($n = 462$) from the period 1998 to 2004. The arithmetic mean concentrations of oil mist and oil vapor were 3.89 mg/m^3 and 39.7 mg/m^3, respectively. The air concentration models including significant determinants such as viscosity of base oil, mud temperature, well section, type of rig, localization of shaker, mechanical air supply, air grids in outer wall, air curtain in front of shakers, and season explained 35% and 17% of the total variance in oil vapor and oil mist, respectively. The developed models could be used to indicate what impact differences in technical design and changes in process parameters have on air concentrations of oil mist and oil vapor. Thus, the models will be helpful in planning control measures to reduce the potential for occupational exposure.

Keywords air concentrations, determinants, offshore, oil drilling, oil mist, oil vapor

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INTRODUCTION

Workers on oil drilling crews are exposed to drilling mud that is used for many purposes, such as lubricating and cooling the drill stem and bit, providing pressure support in the well, and transporting cuttings to the surface. The oil-based drilling mud presently used on offshore drilling installations on the Norwegian continental shelf consists of nonaromatic base oils and a number of additives, such as weighting material, emulsifiers, brines, and viscosifiers. The operators in the mud handling areas are exposed to oil mist and oil vapor emitted from the mudflow lines, including the shale shakers where solids and liquids separate. For oil vapor and oil mist, recommended Norwegian occupational exposure limits (OEL) for 12-hr offshore shifts are 30 and 0.6 mg/m^3, respectively,(1) while the 8-hr threshold limit value for oil mist from ACGIH® is 5 mg/m^3.(2)

As part of a previous study(3) on occupational exposure among offshore workers, all available monitoring reports on air concentration of oil mist and oil vapor in the mud handling areas from 1985 to 2004 were collected from oil companies and their drilling contractors. Personal exposure measurements in workers' breathing zones had been performed to compare with the OEL. Steinsvåg et al.(3) reported that although personal exposures to oil mist and oil vapor declined from 1979 to 2004, levels exceeding the Norwegian OEL are still measured. Thus, further control measures to reduce the exposure in this industry need to be initiated. Analysis of the personal measurements identified several determinants of exposure, such as rig type, mud temperature, type of base oil, and base oil viscosity.(3)

However, the exposure models developed for the personal measurements were based on a coarse set of variables. This called for the need to refine the set of potential variables expected to explain the variability in measured concentrations. Thus, the present study introduces determinants related to design and function of the shaker area, such as localization of shale shakers, size of shaker room, mud channels, and systems for air supply and exhaust.

Furthermore, the models for personal exposure did not take into account the activity of the measured workers, since information on a worker's tasks and location during sampling was only rarely stated in the monitoring reports. In many cases, personal measurements had been supplemented by stationary air sampling of oil vapor and oil mist in the mud handling areas, but results from these measurements have not yet been published. Stationary measurements had been done partly to evaluate effects of technical measures to reduce air contamination and should not depend on the activity and movement of the workers. Exposure models based on existing measurements have been presented for different industries, such as in asphalt paving,[4] in rubber production,[5] and in furniture manufacturing,[6] and should be further developed for oil drilling.

The objectives of this study were to identify factors contributing significantly to the concentration of oil mist and oil vapor originating from drilling mud and to predict air concentrations of these pollutants in the shale shaker area for specified sets of determinant values. Thus, the study will provide important data for planning when preventive measures should be initiated. It will also predict concentrations during "worst-case" scenarios.

METHODS

Collection of Monitoring Data

Collection of monitoring reports (n = 65) of oil mist and oil vapor in the mud handling areas of offshore drilling installations was done in 2003 and 2004 during visits to eight oil companies and five drilling contractors as described by Steinsvåg et al.[3] The reports covered the period 1985–2004 and included both personal and stationary samples of oil mist and vapor.

The stationary samples comprised 892 measurements of oil mist and 908 of oil vapor from 39 drilling installations when two generations of mineral base oils had been used: (1) low-aromatic mineral oils (1985–1997; aromatic content 1–10%, boiling point range 220–325°C), and (2) nonaromatic mineral oils (1998–2004; aromatic content $<0.01\%$, boiling point range 230–320°C for normal viscosity oils, and boiling point range 210–260°C for low-viscosity oils).

Collection of Technical Information (Rig Form)

A questionnaire was sent to the owners of all 39 drilling installations represented in the collected monitoring reports, requesting that the individual responsible for Health and Safety fill in information about technical design and function of the shaker room/area, such as type of drilling installation, construction year, localization of shale shakers, size of shaker room, mud channels, air supply, exhaust systems, auxiliary ventilation systems (air grids in outer wall and air curtains in front of shakers) and on changes/modifications done since original construction. Thirty-two completed forms were returned. Seven rigs did not complete the form, and among these, six of the installations were either abroad, reconstructed, or not in use. For one installation, no reason was given for not participating.

Inclusion Criteria and Final Data Set

To develop representative models for the present drilling activity, the inclusion criteria were: (1) stationary measurement in the shaker operators' work area in front of or between the shale shakers; (2) measurements taken with the currently used sampling method; (3) drilling with the presently used, nonaromatic base oils; and (4) a completed rig form. The measurements that fulfilled the inclusion criteria comprised data from 29 drilling installations, totaling 462 oil mist and 464 oil vapor measurements from 1998 to 2004. The median number of measurements per drilling installation was 15 (range 3–45). The number of years the individual rigs had measurements varied between 1 and 5. Sixteen installations had measurements in only one of the years.

When information on the base oil was not available (n = 8), we assumed that nonaromatic mineral base oils of normal viscosity were used. The currently used method for 2-hr, simultaneous air sampling of oil mist and vapor was developed in 1989 and consists of a series coupling of a glass fiber filter placed in 37-mm, closed-faced Millipore cassettes (Millipore Corp., Bedford, Mass.) with a charcoal tube backup using a flow rate of 1.4 L/min.[3,7]

Potential Determinants

Potential determinants for oil mist and oil vapor concentration were selected as described in the authors' previous study,[3] and from the completed rig forms.

Information on technical design of the shale shaker area was collected mainly from the completed rig forms, which included size of the shaker room and number of shakers. The following technical determinants were dichotomized, i.e., defined as yes/no or present/not present; type of drilling rig being movable (alternatively fixed); shaker localized in separate room; mud channels in closed system; exhaust ventilation from mud channels; mechanical air supply in shaker area; closed exhaust hood over shakers; air curtain placed in front of shakers; and air grids in outer wall. Flow rates of mechanically supplied and exhausted air were not included in the analysis, since such information was obtained from only 11 and 13 installations, respectively.

Process technical determinants included viscosity of base oil used (normal or low); well section drilled (12¼" or 8½"); and the continuous variables, mud temperature and mudflow; which were all extracted from the monitoring reports. Number of shakers in use when measurements were performed was stated for only 52% of the samples.

Two potential determinants were constructed by combining two variables: (1) mudflow per area of shaker room, and (2) area per shaker. However, mudflow was missing for more than 100 measurements.

Climatic conditions could also be determinants, but information on weather conditions such as wind speed and air temperature was missing for 154 and 125 measurements, respectively. Season was used as a surrogate determinant and was defined as summer (May to October) and winter (November to April) based on the 6 months with highest and lowest mean monthly air temperatures, respectively. A determinant representing time trend in air concentration was defined as Years (after 1998; where year 1998 = 0).

Data Analysis

Data were entered into SPSS 13.0 for Windows for analysis. The frequency distribution of both oil mist and oil vapor was skewed. Thus, both these data were $\log_e$ transformed before the statistical analysis. For oil mist, two measurements under the limit of detection (LOD) were set as LOD/$\sqrt{2}$,[8] while three measurements were set as "missing" since no results were given.

In preparatory analysis, differences in $\log_e$-transformed concentration of oil mist and oil vapor, respectively, were analyzed by t-test. Correlation between continuous variables was tested with Pearson correlation.

Linear mixed-effects models were developed by using the $\log_e$-transformed concentration of oil mist or oil vapor as dependent variables and potential determinants as fixed effects. To account for repeated measurements taken from the same drilling rig, the individual rig was viewed as a random effect. The strategy for development of mixed-effects models for air concentration was analogous to the one used by Steinsvåg et al.[3] on personal exposure data. Variables tested in the models were selected on the basis of a significance level of $P < 0.20$ in preparatory analysis.

The final models were developed to show the influence of different variables on concentration of oil mist or oil vapor. Because of the relatively low number of repeated measurements on 29 drilling rigs, P to enter was set to <0.20. The time trend determinant was added to these final models to investigate any time component in air concentration after adjusting for other fixed factors.

RESULTS

The final dataset comprised 464 measurements of oil mist and 462 measurements of oil vapor from 17 fixed and 12 movable drilling installations from 1998 to 2004. The arithmetic mean (AM) concentrations of these stationary samples for both oil mist (AM 3.89 mg/m^3, GM 0.73, GSD 4.7, range 0.020–120.0) and oil vapor (AM 39.7 mg/m^3, GM 18.0, GSD 4.1, range 0.23–351.0) were higher than the recommended Norwegian OEL for 12-hr personal exposure of 0.6 mg/m^{3}and 30 mg/m^3, respectively.[1] About 46% of the oil mist and 40% of the oil vapor samples exceeded the OEL.

The omitted data from the shaker room, not complying with the inclusion criteria, constituted measurements when low-aromatic (n = 172) and nonaromatic (n = 28) base oils were used. The measured air concentrations of the omitted data were significantly higher for both oil mist (AM 5.6, GM 1.1, GSD 7.0, range 0.03–99.0) and for oil vapor (AM 61.5, GM 25.2, GSD 4.6, range 0.4–434.0) compared with the set of included measurements that comprised nonaromatic base oils only.

Preparatory Analysis

Table I shows the number of drilling rigs assigned the respective values (0/1) for potential dichotomous determinants and shows that in unadjusted analysis there were significant differences in air concentrations of both oil mist and oil vapor, respectively, at different levels of several of the categorical determinants.

Mud temperature and mudflow were both significantly higher ($p < 0.001$) when drilling in a 12¼" well section than in an 8½" section. Both area of shaker room and area per shaker were smaller on movable rigs than on fixed rigs. The movable rigs were constructed earlier (median building year 1983; range 1976–1999) than the fixed installations (1992, 1978–2003). There was an increasing time trend in fraction of measurements taken from fixed installation during 1998 to 2004. Reported wind speed was significantly higher when drilling in winter (12 m/s) than in summer (7 m/s). Mean air temperature during sampling was 12.3°C in summer and 6.7°C in winter.

Correlation analysis of continuous variables show that mud temperature was significantly correlated with oil mist ($p < 0.001$) but not with oil vapor ($p = 0.16$) (Table II). Mudflow was significantly correlated with oil mist, oil vapor, and mud temperature, but mudflow was stated for only about 76% of the measurements (Table II). The years after 1998 correlated negatively with both oil vapor and oil mist.

Determinant Models

Oil Vapor

The linear mixed-effects model including viscosity of base oil, mud temperature, type of rig, localization of shaker, mechanical air supply, air grids in outer wall, and air curtain explained 35% of the total variance in oil vapor (Table III). Figure 1 shows estimated concentrations as a function of mud temperature when the categorical determinants in the model have the most representative values (Table I).

As an example, this model predicts that oil vapor increases 2.1 times when drilling with low-viscosity base oils compared with normal-viscosity base oils. Furthermore, for a 10°C increase in mud temperature, the model predicts a 54% increase in oil vapor. Localization of shakers in separate rooms and the presence of mechanical air supply, air grids in outer walls, and air curtain predicted reduced concentration of oil vapor. Area of shaker room, mudflow per area, or area per shaker were not significant predictors and, therefore, were not included in the model.

There was a significant downward time trend when forcing the time variable into the final model. Explained total variance increased to 39%, mainly attributed to a decreased between-rig variance (between-rig variance 0.34, within-rig variance 1.01).

Oil Mist

The final model explained 17% of the total variance in air concentration of oil mist in the shaker area (Table III). Figure 1 shows estimated concentrations of oil mist as a function

TABLE I. Definition of Potential, Categorical Determinants of Oil Mist and Oil Vapor for Stationary Measurements in the Shaker Area, 1998–2004

Potential Determinants	Definitions	N[A]	n[B]	Oil Mist AM (mg/m^3)	Oil Vapor AM (mg/m^3)
Viscosity of base oil	1 = low viscosity (2.0–2.3 mm^2 per s at 40°C)	5	62	7.8	72.7
	0 = normal viscosity (3.0–4.5 mm^2 per s at 40°C)	27	402	3.3 p = 0.16	34.6 p < 0.001
Well section drilled	1 = 12¼"—drilling in upper part of the well	26	363	4.7	42.7
	0 = 8½"—subsequent to section 12¼ inches	8	61	0.4 p < 0.001	10.8 < 0.001
Rig type	1 = movable rigs—not permanently placed on oil field	12	154	7.6	54.5
	0 = fixed rigs—normally permanently placed on field	17	310	2.0 p < 0.001	32.4 p < 0.001
Shaker localization	1 = in separate room	22	357	2.9	34.2
	0 = colocalized with mud pit/tanks	7	107	7.2 p = 0.001	58.0 p = 0.002
Exhaust hood on shaker	1 = closed—hood directly on shaker in closed system	6	59	0.5	16.6
	0 = partly/not closed—all other alternatives than closed system	23	405	4.4 p < 0.001	43.0 p < 0.001
Mud channels	1 = closed system	6	102	5.0	45.7
	0 = partly/not closed—open without lids or partly open with lids	23	362	3.6 p = 0.11	38.0 p = 0.04
Exhaust from mud channels	1 = present	4	50	0.5	41.9
	0 = partly/not present	25	414	4.3 p < 0.001	39.5 p = 0.13
Air supply	1 = mechanical air supply present	22	346	4.2	37.2
	0 = naturally ventilated area	7	118	3.0 p = 0.62	47.0 p = 0.04
Air grids in outer wall	1 = present to support natural ventilation	7	127	1.4	19.2
	0 = not present	22	332	4.9 p < 0.001	46.8 p < 0.001
Air curtain	1 = present in front of shakers to improve efficiency of hoods	3	42	0.6	20.6
	0 = not present	26	422	4.2 p < 0.001	41.6 p < 0.001
Season	1 = summer (May–October)	18	223	2.2	40.6
	0 = winter (November–April)	20	242	5.4 p = 0.04	39.0 p = 0.03

[A]N = number of rigs with respective values (0 or 1) for the potential determinants.
[B]n = number of measurements.

of mud temperature when the categorical determinants in the model have the most representative values (Table I).

The model predicts that the oil mist concentration on movable drilling installations is 2.9 times higher than on fixed drilling installations. A 10°C increase in mud temperature predicts an 86% increase in oil mist. Localization of shakers in separate rooms, mechanical air supply, air grids in outer walls, and drilling during summer contributed to reduced estimates for oil mist.

When forcing the time variable into the final model of oil mist, there was a significant downward time trend, and the viscosity of the base oil fell out of the model. Explained total variance increased to 22% (between-rig variance 0.76, within-rig variance 1.21).

In contrast to the model for oil vapor, the low-viscosity base oils predict a decrease in concentration of oil mist. Separate analysis indicate that the concentration ratio of oil vapor to oil mist for low-viscosity base oils is significantly higher ($p < 0.001$) than for base oils with normal viscosity (arithmetic mean, 146 and 35, respectively). When stratified by tertiles of measured oil mist concentration, Figure 2 shows that above 0.89 mg/m^3 of oil mist there was no difference in the concentration ratio between the two main types of base oils. However, at lower concentrations of measured oil mist, the vapor/mist ratios were higher for both base oils, and the difference between the base oils with normal and low viscosity was significant.

DISCUSSION

This study identified determinants of air concentrations of oil vapor and oil mist in the shale shaker area of offshore installations when drilling with nonaromatic base oils. The final models, including significant determinants, explained 35% and 17% of the total variance in oil vapor and oil mist, respectively. These models predict air concentrations of oil

TABLE II. Correlations Between $\log_e$(oil mist concentration), $\log_e$(oil vapor concentration), and Continuous Determinants for Stationary Measurements in the Shaker Area of Drilling Rigs, 1998–2004

	Oil Mist	Oil Vapor	Mud Temperature	Mudflow	Mudflow/ Area	Area/ Shaker	Year (1998 = 0)
$\log_e$ oil mist concentration (mg/m^3)							
r	1	0.71**	0.20**	0.22**	0.16**	–0.15**	–0.14**
n	464	461	447	351	339	427	464
$\log_e$ oil vapor concentration (mg/m^3)							
r		1	0.07	0.21**	0.01	–0.01	–0.25**
n		462	445	349	338	426	462
Mud temperature (range 33–82°C)							
r			1	0.32**	–0.11*	0.12*	–0.15**
n			448	352	340	411	462
Mudflow (range 1800–4170 L/min)							
r				1	0.40**	–0.06	0.41**
n				352	340	340	352
Mudflow/area (range 6–61 L/min per m^2)							
r					1	–0.79**	0.44**
n					340	340	340
Area/shaker (range 9–59 m^2 per shaker)							
r						1	–0.34**
n						428	428

Note: r = Pearson correlation; **p ≤ 0.01; *p ≤ 0.05.

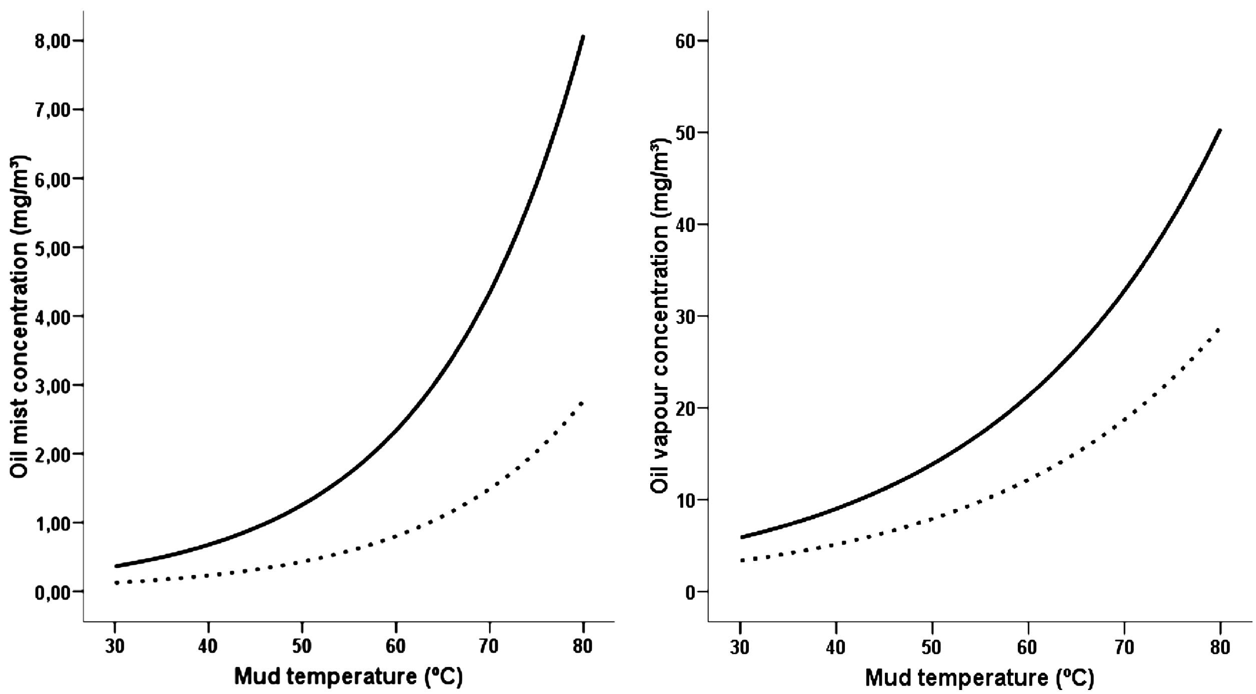

FIGURE 1. Examples of predicted concentration of oil mist and oil vapor in the shale shaker area as a function of the mud temperature at fixed (dotted line) and movable (solid line) drilling installations. When estimating concentrations, dichotomized determinants included in the respective concentration models in Table III have the most representative value (Table I); drilling in 12$^1/_4$" well section in winter season with base oil of normal viscosity on installations where shakers are localized in separate room having mechanical air supply but where air grids and air curtains are not present.

TABLE III. Linear Mixed Effects Models of $\log_e$ (oil mist) and $\log_e$ (oil vapor) Concentration (random effect: rig; fixed effects: other variables)

	Oil Vapor (mg/m^3)		Oil Mist (mg/m^3)	
	Random Effects Model β (SE)	Mixed-Effects Model β (SE)	Random Effects Model β (SE)	Mixed-Effects Model β (SE)
Intercept	2.78 (0.20)**	1.88 (0.56)**	−0.518 (0.188)**	−2.68 (0.73)**
Low (1) vs. normal (0) viscosity of base oil		0.76 (0.22)**		−0.82 (0.26)**
Mud temperature		0.043 (0.006)**		0.062 (0.01)**
Well section 12¼" (1) vs. 8½" (0)				0.42 (0.28)
Movable (1) vs. fixed rig (0)		0.56 (0.35)		1.07 (0.48)*
Shakers in separate room (1) vs. co-localized with mud pit/tanks (0)		−0.90 (0.40)*		−0.74 (0.54)
Mechanical air supply present (1) vs. not present (0)		−1.06 (0.27)**		−0.94 (0.37)*
Air grids in outer wall present (1) vs. not present (0)		−0.86 (0.38)*		−0.71 (0.49)
Air curtain present (1) vs. not present (0)		−0.69 (0.52)		
Summer (1) vs. winter season (0)				−0.74 (0.18)**
wrS^2	1.20	1.02	1.67	1.31
brS^2	1.01	0.42	0.85	0.78
% total variance explained by the fixed effects		35		17

Notes: β regression coefficient; SE, standard error of the regression coefficient; **, significant at $P \leq 0.01$; *, significant at $P \leq 0.05$; otherwise $P \leq 0.20$; wrS^2, within-rig variance; brS^2, between-rig variance.

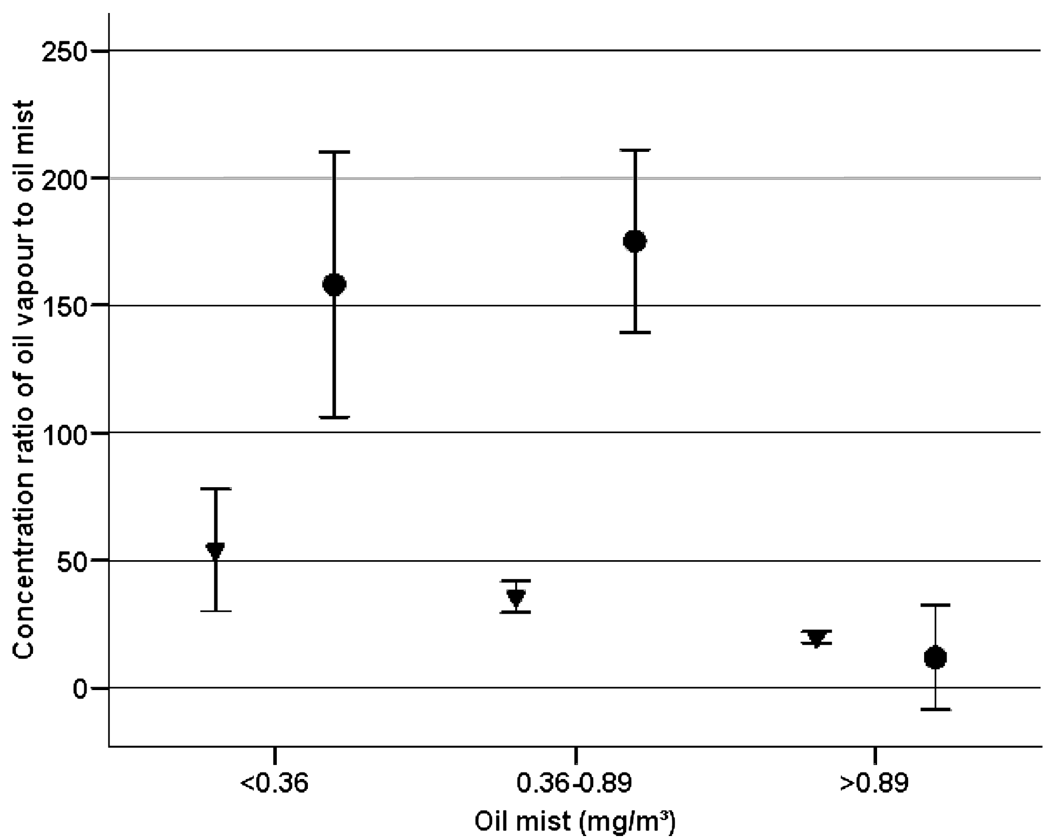

FIGURE 2. Air concentration ratio of vapor-to-mist in the shaker area when drilling with base oils with normal viscosity (triangles) and low viscosity (circles) (arithmetic mean and 95% confidence interval).

mist and vapor for specified determinant values and can be used to indicate what impact that changes in these variables may have. Thus, the models could be helpful in planning control measures to reduce the potential for occupational exposure.

A considerable fraction of the stationary measurements exceeded the recommended occupational exposure limits. Although such limit values are set for personal sampling in the breathing zones of workers, the stationary measurements indicate that workers are at risk of relatively high exposures when they work for shorter or longer periods in these areas. As expected from their intermittent stay in the shaker area, the corresponding personal exposure to oil mist and oil vapor found in our previous study were lower (0.54 and 16.1 mg/m^3, respectively) [3] than presently found for the stationary samples on the same rigs, but still 24% and 15% of the personal samples exceeded the respective limit values.[3] Thus, reductions in air concentrations are likely to be reflected also in reduced personal exposure. The present study is based on the stationary measurements to make more precise estimates of air concentrations by excluding the variability in measured concentrations due to workers' activity and location.

The aim of this study was to develop representative models for the present drilling activity. Thus, the measurements in the final models were restricted to those performed after 1998 when only nonaromatic base oils have been used. For personal exposure, Steinsvåg et al.[3] showed that the low-aromatic base oils used prior to 1998 were associated with higher exposure levels compared with nonaromatic oils. Thus, inclusion of low-aromatic base oils in the models could have predicted higher values than representative for today's drilling activity.

It is assumed that the included measurement data are representative for today's drilling in 12¼" and 8½" well sections, taking into account that they cover 29 drilling installations and mud temperatures ranging 33–82°C. Furthermore, the included measurements are standardized regarding the sampling method. Sampling time was restricted to the recommended 2 hr to reduce the possible impact of evaporation of oil mist from the filter to the subsequent charcoal tube.

Most determinants were common for the oil vapor and mist models and could be considered logical regarding expected impact on air concentration. Mud temperature correlated with mudflow, and since mud temperature was stated for most measurements, this variable was preferred to mudflow and to mudflow per area of the shaker room. Mud temperature was a significant, positive determinant in both models, increasing oil vapor and oil mist concentration by 54% and 86%, respectively, for an increase in temperature of 10°C.

Apparently, increases in mud temperature have more impact on stationary monitoring than on personal monitoring where analogous increases in concentrations were 16% and 19%.[3] This difference is probably explained by the personal measurements being influenced by the localization and activity of the operators. Drilling in a 12¼" well section was associated with higher mud temperature and mudflow than when drilling in an 8½" well section and predicted higher air concentrations of oil mist. Although a higher mudflow is reasonable for drilling in a 12¼" well section compared with an 8½" well section, the associated higher mud temperature was less expected, since drilling deeper in the well from an 8½" section and smaller is assumed to produce higher mud temperatures. Validation of this association could be performed in a future study by collecting process technical data as mud temperature, mudflow, and well length during drilling in different sections of a representative set of wells.

In the mixed-effects model, the increased concentration of oil vapor associated with low-viscosity base oils is probably a result of their lower boiling point ranges, indicating more rapid evaporation compared with the base oils with normal viscosity.[3] The reason for reduced concentration of oil mist when using low-viscosity base oils is less obvious. The concentration ratio of oil vapor to oil mist was significantly higher for low-viscosity base oils than for base oils with normal viscosity. It is not clear whether these findings are related mainly to a relatively smaller contribution from low-viscosity base oils to the oil mist fraction deposited on the sampling filter, or whether collected oil mist from low-viscosity base oils also have been lost during storage or by evaporation from the sampling filter to the following charcoal tube.[9]

We found a higher vapor-to-mist ratio at low oil mist concentration than at high oil mist concentration, which could indicate relatively more evaporative loss of oil mist from the filter at lower oil mist concentration than at higher oil mist concentration. In compliance with this, Raynor et al.[10] suggested that at low oil mist concentrations, evaporation of mineral oil retained on sampling filters occurs readily, while at high mist concentrations, significant evaporation from the filters is not expected because the vapor accompanying the airborne mist is already saturated. If this is the case, in the present study, oil mist concentration is probably underestimated due to evaporation from the sampling filter. This may be the case particularly within the lower range of measured oil mist concentration, being most pronounced for low viscosity base oils that presumably are more volatile than base oils with normal viscosity.

Raynor et al.[10] also discuss the possible negative bias when using sampling filters to measure oil mist at fluctuating concentrations. Such underestimation is also highly relevant for personal measurements of shaker operators who move between regions with high and low mist concentrations during the sampling period. In any case, the present results emphasize the need of validation of the standard air sampling method, particularly for the presently used base oils with low viscosity.

The technical design and measures taken to reduce air concentration in the shaker area had significant impact on the predicted levels of oil mist and vapor. The presence of a general mechanical air supply to the shaker area reduced the concentrations. The amount of air supplied was obtained from only 11 rigs and was therefore not used. An air curtain in front of the shakers and air grids in the outer wall of the shaker area reduced air concentration of pollutants, probably by improving the ventilation efficiency of the exhaust hoods and by diluting the pollutants, respectively.

However, ventilation efficiency might be expected to vary with many factors, such as mud temperature and climatic conditions. For instance, stronger winds during winter or high mud temperatures may create air turbulence and reduce the effect of exhaust hoods. Such turbulence could contribute to higher concentration of oil mist in winter.

Concentrations of both oil mist and vapor were lower on fixed installations than on the generally older movable installations. Even when including the selected set of determinants related to the structure and design of the shaker area, the main type of rig still contributed to the air concentrations. Type of rig, being either fixed or moveable, ideally should be replaced by other determinants to characterize the difference between these two main rig types. Area of the shaker room and area per shaker were smaller on movable than on fixed rigs, and area per shaker correlated negatively with oil mist. However, in the concentration models, the potential determinants including shaker area did not contribute significantly.

More detailed information on the ventilation systems such as amount of inlet and outlet air and efficiency of exhaust hoods could have contributed to the variance in air concentration between the rig types. In future measurements such information should be included in the monitoring reports together with data on climatic conditions.

The declining time trends in air concentrations should be interpreted with caution. Within the relatively short period between 1998 and 2004, 16 of the 29 installations had measurement data from only one of these years. Thus, the reduced between-rig variance associated with the time trend for oil vapor could be a function of the rigs selected for sampling each year and not related to a representative time-dependent reduction in concentration.

On the other hand, the declining time trend for oil mist seemed to be related mainly to a reduced within-rig variance. Viscosity of base oil fell out as a determinant when time was forced into the concentration model for oil mist. This could be because of low-viscosity base oils being used only the last year of sampling on installations where both types of base oils had been used and is an example of possible collinearities between determinants that could make the regression coefficients unstable.

In the present models, that precision of the estimated concentrations is dependent on the uncertainties of the included variables. A standard air sampling form is needed to ensure that relevant information is recorded in future monitoring reports. The standard form should include a minimum set of process technical data and information on the technical design of the shaker area. Validity of the presented models should be tested against measurement data from 2005 and onward.

Practical utilization of the results could be through a user tool designed as a web-based calculator for predicting point estimates and confidence intervals of oil mist and vapor concentrations for selected values of determinants.

CONCLUSION

The developed models predict air concentrations of oil mist and vapor for specified determinant values. Such information is useful when planning measures to reduce the potential for occupational exposure.

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REFERENCES

1. "Guidelines to Regulations Related to Conduct of Activities in the Petroleum Activities (the Activities regulations")." Section 34. [Online] Available at http://www.ptil.no/activities/category404.html (Accessed March 2009).
2. **ACGIH:** *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*. Cincinnati, Ohio: ACGIH, 2008.
3. **Steinsvåg, K., M. Bråtveit, and B.E. Moen:** Exposure to oil mist and oil vapour during offshore drilling in Norway, 1979–2004. *Ann. Occup. Hyg. 50*:109–122 (2006).
4. **Burstyn, I., H. Kromhout, T. Kauppinen, P. Heikkilä, and P. Bofetta:** Statistical modelling of the determinants of historical exposure to bitumen and polycyclic aromatic hydrocarbons among paving workers. *Ann. Occup. Hyg. 44*(1):43–56 (2000).
5. **Vermeulen, R., and H. Kromhout:** Historical limitations of determinant based exposure groupings in the rubber manufacturing industry. *Occup. Environ. Med. 62*:793–799 (2005).
6. **Mikkelsen, A.B., V. Schlünssen, T. Sigsgaard, and I. Schaumburg:** Determinants of wood dust exposure in the Danish furniture industry. *Ann. Occup. Hyg. 46*:673–685 (2002).
7. **Malvik, B., and E. Børresen:** "STF21 A88028. Methods for Measuring Oil Mist and Vapor." Trondheim, Norway: SINTEF Teknisk Kjemi, 1988. [In Norwegian]
8. **Hornung, R.W., and L.D. Reed:** Estimation of average concentration in the presence of nondetectable values. *Appl. Occup. Environ. Hyg. 5*:46–51 (1990).
9. **Simpson, A.T.:** Comparison of methods for the measurement of mist and vapour from light mineral oil-based metal-working fluids. *Appl. Occup. Environ. Hyg. 18*:865–876 (2003).
10. **Raynor, P.C., J. Volckens, and D. Leith:** Modeling evaporative loss of oil mist collected by sampling filters. *Appl. Occup. Environ. Hyg. 15*:90–96 (2000).