

Observational study on occupational exposure of dairy farmers to formaldehyde

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ABSTRACT

Objectives To provide insights into exposure of Dutch dairy farmers to formaldehyde derived from formalin footbaths used for cows. Dutch safety norms are set at a limit of 0.122 ppm during an 8-hour time-weighted average (TWA) and 0.407 ppm for a 15-min TWA.

Methods At 20 farms formaldehyde air concentrations were determined using stationary active air sampling with impingers next to the footbath and in the milking parlour during footbath usage. Formalin footbath concentrations were tested and meteorological conditions were collected using a climate monitor to assess associations with formaldehyde concentrations. A structured interview inquired on potential exposure routes and exposure duration.

Results Formaldehyde concentrations next to the footbath ranged from <0.003 to 0.316 ppm, with seven measurements exceeding the 8-hour TWA threshold. None of the measurements exceeded the 15-min TWA threshold at either location. Formaldehyde air concentrations in the milking parlour were generally lower, yet at two farms exceeded the 8-hour TWA limit during sampling. Self-reported exposure time of the dairy farmers to the formalin footbath never exceeded 15 min. Although due to the small sample size, no significant associations between most predictor variables and formaldehyde levels in the air were found, the direction of effects were as expected.

Conclusions The exposure of Dutch dairy farmers presumably falls within the established safety norms. Nonetheless, substantial levels of formaldehyde could be detected. This study further emphasises the importance of substitution of formalin in dairy practice and the relevance of informing dairy farmers on proper handling of formalin to reduce exposure.

INTRODUCTION

Formaldehyde occurs in unpolluted air as a natural compound as a result of photochemical oxidation of hydrocarbons.¹ In unpolluted air, formaldehyde concentrations usually fall below 0.001 ppm.² The International Agency for Research on Cancer concluded there is sufficient evidence in humans for the carcinogenicity of formaldehyde.³ Formaldehyde is classified as a carcinogenic and suspected mutagenic (CM) substance, which puts restrictions on its use.⁴ The no-observed-effect-level of the compound is 0.02 ppm; eye and airway irritation can occur at 0.489 ppm; effects in the lungs can occur above 0.814 ppm.⁵ In the Netherlands, an occupational exposure limit of 0.122 ppm during an

WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ Formaldehyde is classified as a carcinogenic and suspected mutagenic substance, which puts restrictions on its use.
- ⇒ A study on a single heifer facility in the USA estimated exposure of dairy farmers to formaldehyde with formaldehyde levels ranging between <limit of detection and 2.28 ppm and an average of 0.34 ppm.

WHAT THIS STUDY ADDS

- ⇒ This study substantially expands insights into the occupational formaldehyde exposure of dairy farmers by determining formaldehyde exposures on 20 farms.
- ⇒ The study also gives insights into the handling of the formalin footbaths by the dairy farmers.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ From this study several recommendations to dairy farmers can be deducted, to ensure proper use of formalin to reduce exposure.
- ⇒ Results from the study put emphasis on the need for additional research on suitable alternatives to formalin.

8-hour time weighted average (TWA) and a 15-min TWA of 0.407 ppm is set in working places.^{6,7} Moreover, dermal contact with 1–2% formalin solutions can cause dermatitis.⁸

Bovine digital dermatitis (DD), also called Mortellaro's disease, is an infectious disease in cows characterised by inflammatory dermatitis of the skin, which can cause lameness.^{9–11} Lameness is associated with decreased productivity, reduced fertility rates and an increased risk of premature culling.^{12–16} Footbaths with formalin can be used to prevent new cases of bovine DD through increased hygiene, and can also serve as treatment of clinical cases.¹¹ Formalin consists of formaldehyde gas dissolved in water with methanol added as stabiliser to prevent polymerisation of formaldehyde.¹⁷ Of the approximate 15 000 dairy farms in the Netherlands, a large majority use formalin footbaths (personal communication, T Van Werven).¹⁸

Exposure to formaldehyde derived from formalin footbaths can occur by inhalation, ingestion or through dermal contact with fluids from the footbath itself or preparation fluids.¹ No systematic



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research to assess the risk of formaldehyde exposure and associated health effects in dairy farmers has been done in the Netherlands. Limited information is available from the USA, where a range of acute health reactions were reported most likely as a result of high formaldehyde exposure, including dizziness, vomiting, nausea and nosebleeds.¹⁹

Moreover, very little is known about the occupational exposure of dairy farmers to formaldehyde evaporated from formalin footbaths. Merely one study estimated the exposure of dairy farmers to formaldehyde evaporating from these footbaths. Formaldehyde levels on a heifer facility in the USA ranged between <LOD and 2.28 ppm with an estimated average of 0.34 ppm. The majority of the concentrations fell between the safety guidelines established by the Occupational Safety and Health Administration of the USA of 0.75 ppm 8-hour TWA and 2 ppm within a maximum exposure time of 15 min. However, 83% of the concentrations reported would exceed the 8-hour TWA and 21% would exceed the 15-min TWA that is set in the Netherlands. In this study temperature and air humidity did not affect formaldehyde levels in the air.⁸ However, as an increase in ambient temperature results in the decrease of vapour pressure of formaldehyde and thus in higher evaporation rates of formaldehyde from the footbath, it is expected to result in higher formaldehyde emission.²⁰ Moreover, a high air humidity can result in lower evaporation rates and can thus lower the formaldehyde emission rate.^{21 22} No further research on occupational formaldehyde exposure of dairy farmers could be identified in literature, thus stressing the scarcity and further need for research

on the topic. This leads to the research question: What is the occupational exposure of Dutch dairy farmers to formaldehyde derived from formalin footbaths and does this exposure fall within the established safety norms?

MATERIALS AND METHOD

Participating farms

This study used a sample of 20 farms that used formalin footbaths and expressed willingness to participate in the study when approached by two veterinary practices. A total number of 20 farms were included due to logistic constraints, 10 farms were provided by the University Farm Animal Practice and 10 by the Veterinary Practice Flevoland. All farms were freestall housing farms with cow cubicles, slatted floors and natural ventilation. For farm size see table 1.

Exposure monitoring

Formaldehyde air sampling

Sampling was conducted between June and November 2021. Stationary active air samples were collected on the day of footbath use according to Environmental Protection Agency (EPA) Method 316 with slight modifications. Two serial impingers containing 25 mL MilliQ water (catching agent) were used and sampling flow was established with a Gillian Gill Air constant flow pump set at 1L/min.²³ To avoid dust entering the system a filter holder with glass fibre filter was installed prior to the impingers. After sampling, the catching fluid was transferred into

Table 1 Descriptives of farm characteristics: farm size, milking time, footbath time and formaldehyde air concentrations near the footbath and in the milking parlour during footbath usage

Farm	Number of milking cows	Milking time (min)	Number of cow passages before refreshing	Estimated time the footbath is present in the stable*	Formaldehyde concentration near footbath (ppm)	Formaldehyde concentration in milking parlour (ppm)
1	80	70	80	70 min	0.112	0.036
2	200	134	200–250	134 min	0.036	0.005†
3	200	89	200	89 min	0.107	0.082
4	120	89	120	89 min	0.003†	0.003†
5	150	93	150	Unknown‡ §	0.316	0.025
6	179	168	350–360	≥ 1 < 2 days‡	0.305	0.009
7	45	95	630	7 days‡	0.034	0.039
8	105	103	105	103 min	0.028	0.022
9	110	187	200	≥ 1 < 2 days‡	0.171	0.129
10	96	120	95	Unknown‡§	0.130	0.005†
11	400	209	200	209 min	0.003†	0.018
12	155	46	155	Unknown‡§	0.147	-¶
13	115	64	230	≥ 1 < 2 days†	0.176	0.009†
14	65	101	65	101 min	0.027	0.006†
15	195	142	390	≥ 1 < 2 days†	0.062	0.004†
16	210	157	210	157 min	0.039	0.011
17	92	108	184	≥ 1 < 2 days†	0.026	0.017
18	55	104	110	≥ 1 < 2 days†	0.113	0.231**
19	85	94	510	3 days†	0.167	0.006†
20	248	46	265	46 min	0.065	0.065
Average	145	111	224	<1 day	0.103	0.027
95% CI					0.061 to 0.146	0.011 to 0.044

*If the footbath is emptied directly, the time estimate is based on the recorded milking time on the sampling day. If not emptied directly, the time estimate is based on the number of cow passages before footbath refreshment, with the assumption of twice daily milking sessions and the consecutive use of the formalin footbath in these milking sessions.

†Measurements are <LOD. LOD values are represented with two-third of the LOC.

‡Footbath is emptied after two subsequent milking sessions.

§The structured interview suggests the dairy farmer empties the footbath before the subsequent milking session, but not directly after use. Thus, the duration before emptying the footbath cannot be deducted.

¶No measurements were conducted in the milking parlour, as milking does not coincide with footbath use on this farm.

**This score is considered an outlier (Z-score>3) and not used in analyses or calculating averages.

LOC, limit of concentration; LOD, limit of detection.

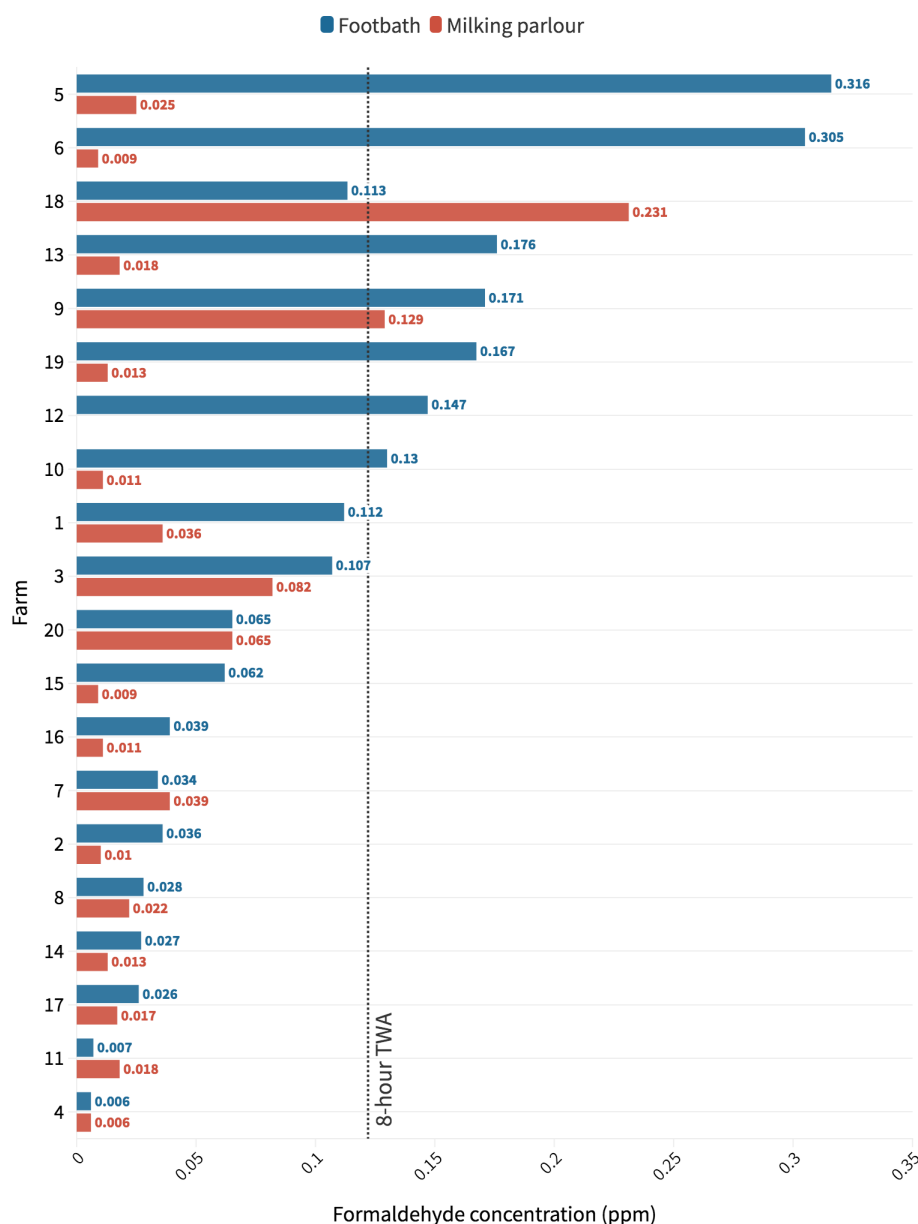


Figure 1 Formaldehyde air concentrations next to the footbath and in the milking parlour. Formaldehyde levels (ppm) indicate the average levels throughout the whole sampling time. Formaldehyde levels next to the footbath and in the milking parlour after footbath preparation are indicated per farm (n=20). Samples <LOD are marked with an asterisk. LOD, limit of detection; TWA, time-weighted average

polystyrene tubes, transported on dry-ice and stored at -20°C at the institute the same day until further analysis. The sampling air flow was checked each sampling day prior to sampling.

At each farm, three air samples were collected: a background sample near the footbath prior to footbath preparation, followed by concurrent collection of a sample next to the footbath and in the milking parlour during footbath usage. The background sampling lasted for approximately 1 hour or shorter until the footbath was prepared (minimal 21 min). Formaldehyde air sampling next to the footbath and in the milking parlour were sampled starting from footbath preparation until the end of footbath usage during the milking round. Per farm two field blanks were collected handling the sampling train similar to other samples except for air suction.

Footbath samples and characteristics

Formalin concentrations and the evaporation surface of the footbaths were determined to identify possible association with formaldehyde air concentrations. Samples of the homogenised footbath solutions were taken prior to and after the milking round at each farm, by transferring some of the footbath solution to a propylene tube. Samples were transported on dry-ice and preserved at -20°C until further analysis.

Formaldehyde analysis

Formaldehyde in air and footbath samples was analysed using the pararosaniline method according to EPA Method 316 with slight adaptations.²³ In brief, footbath samples

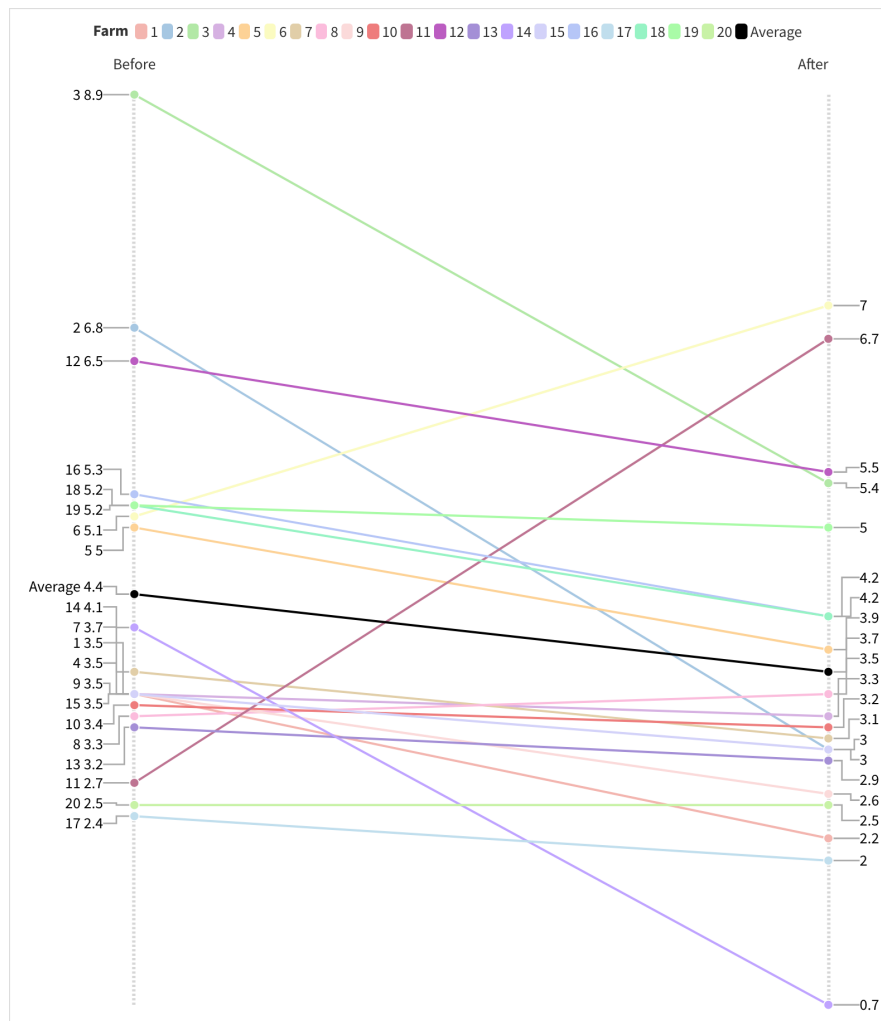


Figure 2 Footbath formalin concentrations before and after cow passages. Formalin concentrations are indicated in volume %. Footbath samples ($n=20$) were taken directly after preparation of the footbath and after all cow passages. Lines indicate the direction of the difference between the concentrations before and after cow passages within a farm.

were centrifuged at 3000 rpm for 20 min prior to analysis. Formaldehyde in the sample reacts with acidic pararosaniline hydrochloride and sodium sulphite, forming a purple product, which is measured spectrophotometrically. Samples were tested in duplicate, and the mean value was used.

To determine the formaldehyde air concentration expressed in ppm the following formula was used:

$$\text{Formaldehyde air conc (ppm)} = \frac{(C_{IF} \times V_{IF})}{M} \times (M_V \times \frac{(273 + T_a)}{273})$$

C_{IF} = concentration of formaldehyde in the impinger fluid ($\mu\text{g/mL}$)

V_{IF} = volume of the impinger fluid (mL).

M = molar mass of formaldehyde, being 30.1 ($\mu\text{g/mol}$).

M_V = molar gas volume = 22.4×10^{-3} (m^3).

T_a = ambient temperature ($^{\circ}\text{C}$).

V_{air} = air sampling volume (m^3).

The limit of detection (LOD) was set to $0.05 \mu\text{g/mL}$. For each sample below LOD, the corresponding limit of concentration (LOC) was calculated, and was substituted with a value of two-third of the corresponding LOC for data analysis.²⁴

Reproducibility and sample preservation were tested prior to sample collection and the method showed very low variability

and approximately 90% or more of the sample concentration is preserved at -20°C (data not shown).

Indoor climate

Concurrently to the formaldehyde air sampling, ambient temperature, relative humidity and carbon dioxide (CO_2) concentration were monitored at 5-min intervals using a data-logging Delta Ohm Indoor Air Quality climate monitor. The monitor was generally placed near the formalin footbath, with the exception of one farm as a result of practical constraints; there the logger was placed near the milking parlour. Data was logged for the duration of sampling. CO_2 was measured as a surrogate for ventilation, where higher CO_2 values represent lower ventilation rates. Mean values were used in data analysis.

Structured interview

On the day of sampling, an approximate 15-min in-person structured interview was conducted with the person involved with the footbath preparation and subsequent milking procedure. Interviews provided information on exposure routes, exposure time and intended formalin concentrations in the footbaths/jerry can (online supplemental A).

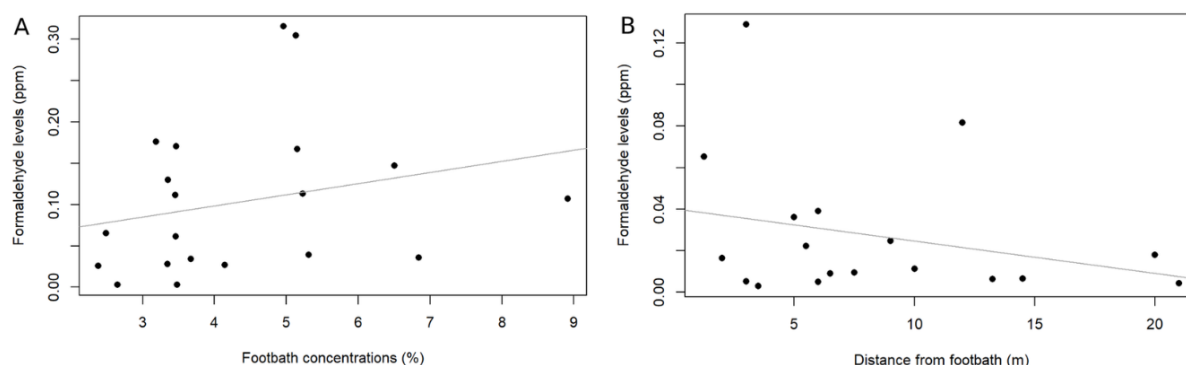


Figure 3 Scatter plots of univariable regression analyses. (A) Regression analysis of formaldehyde levels (ppm) in the air next to the footbath and footbath formalin concentrations (%) before cow passages ($\beta=0.014$; 95% CI = -0.013 to 0.040 ; $R^2=0.061$). (B) Regression analysis of formaldehyde levels (ppm) in the air in the milking parlour and the distance of the sampling set from the footbath ($\beta = -0.002$; 95% CI = -0.004 to 0.001 ; $R^2=0.074$).

Statistical analysis

Histograms and spaghetti plots were used to depict data. Outliers were detected using a Z-score method; scores surpassing (\pm) 3 were considered outliers. A Wilcoxon signed rank test was performed to assess whether formaldehyde levels next to the footbath and in the milking parlour differed. Analyses were conducted both with and without outliers, <LOD samples were included in all analyses and substituted with two-thirds of corresponding LOC values. Univariable and bivariable regression analyses were performed with formaldehyde concentrations as dependent variable and footbath formalin concentrations, meteorological conditions and distance from the footbath as independent variables. A least-squared method to estimate the intercept and regression coefficient was used. Residuals were calculated and checked for Gaussian distribution using a Kolmogorov-Smirnov test. All analyses were carried out in RStudio V.2021.09.1.²⁵

RESULTS

Information on farm size, milking time duration and information on footbath usage are described in table 1. On average, the number of milking cows was 145 and the milking time was 111 min. Data from the structured interview on the frequency of footbath refreshment and measuring time during milking was used to estimate the duration of the formalin footbath presence. On average, the presence of the footbath in the stable is less than 1 day per time of usage (range=46 min to 7 days). For further results of the structured interview, see online supplemental A.

Self-reported footbath preparation time lasted a maximum of 5 min from the point where formalin is added. Most farmers declared the preparation time after formalin addition to only take a few seconds. For emptying the footbath, a maximum duration of 15 min was reported, while the majority of the respondents indicated this action to take less than 1 min (online supplemental A, table 2). However, no distinction was made in the emptying routine, thus the time indicated here can include cleaning of the footbath after it is turned over. The majority (55%) revealed to not empty the footbath directly after every milking (online supplemental A, table 1). Besides preparing and emptying the footbath, at 35% of the farms other activities taking place within 2 m of the footbath was reported, but these did not last longer than 5 min (online supplemental A, tables 1 and 2).

The majority of farmers used a formalin footbath once per week or once per 2 weeks during housing season (70%) and grazing season (55%). None reported to use the footbath more than two times per week. The majority of the farmers (73.7%)

used formalin footbaths for over 10 years (online supplemental A, table 1). Half of the respondents indicated to always have the same person preparing and emptying the footbath.

The majority (65%) of the dairy farmers did not wear gloves when preparing the footbath, but 55% did while emptying the footbath. Only 25% declared to sometimes have dermal contact with the formalin solution in the footbath (online supplemental A, table 1).

Formaldehyde concentrations (table 1) were significantly ($p<0.05$) higher next to the footbath (mean=0.103; 95% CI=0.061 to 0.146 ppm) compared with in the milking parlour (mean=0.027; 95% CI=0.011 to 0.044 ppm), which was asserted by a Wilcoxon signed rank test. All background measurements and field blanks were <LOD. Observed formaldehyde concentrations are also depicted in figure 1, alongside with the 8-hour TWA threshold value. Seven of 20 measurements next to the footbath exceeded the 8-hour TWA of 0.122 ppm, with the highest concentration reaching 0.316 ppm. While most values in the milking parlour did not come near the 8-hour TWA, still 2 of the 20 measurements exceeded this limit, although 1 of these was considered an outlier and excluded during analyses.

Observed formalin concentrations in the footbath are indicated in figure 2. Lines indicate the direction of the difference between formalin concentration before and after cow passages. Concentrations range between 2.4% and 8.9% directly after footbath preparation, with an average of 4.4%. After footbath use concentrations range between 0.7% and 7.0%, with an average of 3.7%. While most concentrations decrease after use, three increase.

Figure 3 shows the results of univariable regression analyses, additional results are presented in online supplemental A, figure 1. Although not statistically significant, directional indications of the regression model suggest a positive relationship between formaldehyde levels in the air next to the footbath and footbath formalin concentrations (95% CI = -0.013 to 0.040 ; $R^2=0.061$; $\beta=0.014$). A negative relationship between formaldehyde levels in the milking parlour and the distance of the milking parlour from the footbath is suggested (95% CI = -0.004 to 0.001 ; $R^2=0.074$; $\beta = -0.002$).

Table 2 presents the results of the bivariable regression analyses. Although non-significant and lacking power, the analyses suggest that formaldehyde concentrations increase as formalin concentrations, temperature or CO₂ increase. Moreover, it is suggested formaldehyde concentrations decrease as relative humidity and distance to the footbath increases.

Table 2 Results of bivariable regression models for the associations between climatic conditions and formaldehyde levels, corrected for the measured formalin concentrations of the footbath

Dependent variables	Intercepts and independent variables	Estimate	SE	Pr (> t)	Adjusted R ²
Formaldehyde levels next to the footbath	Intercept	−0.056	0.082	0.500	0.101
	Formalin concentration (%)	0.011	0.012	0.367	
	Temperature (°C)	0.006	0.004	0.110	
	Intercept	0.252	0.134	0.077	0.104
	Formalin concentration (%)	0.012	0.012	0.317	
	Relative humidity (%)	−0.003	0.002	0.107	
	Intercept	−7.23e−03	6.97e−02	0.919	0.044
	Formalin concentration (%)	1.06e−02	1.25e−02	0.406	
	Carbon dioxide (ppm/100)	9.53e−05	7.38e−05	0.214	
Formaldehyde levels in the milking parlour	Intercept	0.028	0.024	0.259	−0.018
	Formalin concentration (%)	0.003	0.005	0.511	
	Distance (m)	−0.002	0.001	0.239	

DISCUSSION

Stationary air sampling was used to provide insight into the occupational exposure of Dutch dairy farmers to formaldehyde derived from formalin footbaths. No levels exceeded the 15-min TWA. Seven of 20 measurements next to the footbath exceeded the 8-hour TWA of 0.122 ppm. Formaldehyde levels in the milking parlour were significantly (Wilcoxon signed rank test; $p < 0.05$) lower than next to the footbath.

While this study provides substantially more insights into possible exposure of dairy farmers, it is important to note limitations to our study. No personal measurements were conducted as well as measurements did not last for 8 hours, with duration of sampling ranging from 46 to 220 min, so the exact 8-hour TWA personal exposure cannot be deducted from this study. The results were obtained through stationary air samples by the impinger method, which does not allow personal measurements. Generally personal exposure measurements result in higher levels than stationary measurement due to closeness of exposure sources and handling differences.^{26 27}

If the assumption is made there is no exposure at all after the air measurements, the highest estimated level of 8-hour TWA formaldehyde would be 0.107 ppm, which is slightly below the 8-hour TWA. This is derived from a measurement near the footbath. However, it is difficult to estimate the exact 8-hour TWA, as information on the location of other activities of the farmers is limited, so we cannot make a valid presumption about exposure during these hours. Nonetheless, exposure levels in the milking parlour, where farmers spent a considerable amount of time when formalin footbaths are used, were generally low but in the majority of farms detectable.

A structured interview provided additional insights into habits, which aids to estimate personal exposure. The structured interview showed that exposure time within close proximity of the footbath, where the majority of concentrations exceeding or approaching the 8-hour TWA, is short. Dairy farmers spend the majority of their time in the milking parlour when the footbath is in use. Hence, their personal exposure is likely to be more similar to formaldehyde levels in the milking parlour. Although the time spent in the milking parlour is substantially longer than within close proximity of the footbath, the estimated time still does not reach 8 hours (online supplemental A). Nonetheless, as the majority of farmers indicated to not empty the footbath directly after use, exposure time can be longer than the milking time. Moreover, dermal exposure may be an important exposure route that is not considered in this study.

The highest frequency of footbath use is twice per week. The 8-hour and 15-min TWA's are set for daily exposure to formaldehyde. Hence, exposure presumably fell well within the established Dutch safety norms. Moreover, it should be noted the TWA's set in the Netherlands are stricter than those in other European countries or in the USA.²⁸ Direct health effects like eye and airway irritation and lung effects can be observed from 0.489 and 0.814 ppm, respectively.⁵ Hence, formalin footbaths are presumed to not cause direct health effects.

We observed indications for positive relationships between formaldehyde levels and formalin concentrations, temperature or CO₂ (online supplemental B). For formaldehyde levels and relative humidity or distance negative relationships are suggested. These suggested relationships are as expected, considering previous findings in literature.^{20–22}

Formalin concentrations directly after footbath preparation ranged between 2.4% and 8.9%, having less variety than a previous study, where concentrations ranged between 0.9% and 9.6%. Nonetheless, the average formalin concentration (4.4%) of this study is fairly comparable to the previously observed average (3.8%).²⁹ Of the observed formalin concentrations, 55% fell below the recommended 4% formalin. However, only one farm did not maintain a concentration of at least 2% formalin. Thus, it is expected the efficacy of formalin for bovine DD control is maintained for all farms except one.

Literature only reports one previous study on formaldehyde exposure levels on a single heifer facility.⁸ This study only included short-term measurement with exposures ranging from <LOD to 2.28 ppm, which is higher than our findings. Although the sample size of our study is relatively small, it is the first study to investigate exposure at 20 different farms; vastly more than previously reported in literature. Hence, our study substantially expands insights into the exposure of dairy farmers to formaldehyde. Nonetheless, within-farm variability is not represented in this study, signifying a requirement for future studies to explore exposure variation within individual farms as well.

Despite the slight over-representation of larger farms in this study, with an average farm size of 145 milking cows per farm in the study while the Dutch average is 107, the convenience sample of 20 farms is assumed to be representative of the range in the Dutch situation.¹⁸ The farmers participated voluntarily in this study following a request from their respective veterinary practices, where some farmers were motivated by health concerns, while others expressed worries about future unavailability of formalin for claw health. Hence, it is assumed the

results are not biased towards overuse or underuse of formalin, but represent common usage.

Formaldehyde is currently already a classified candidate for substitution if suitable alternatives are available. Priority of substitution is given to applications that are expected to result in human exposure, including formalin footbaths. Currently no suitable substitutes for animal hoof disinfection have yet been identified.³⁰ Hence, it is stressed that dairy farmers should be informed on their exposure to formaldehyde, to ensure proper handling of a CM substance to reduce exposure. From this study several recommendations can be deducted. First of all, air concentrations were generally highest directly next to the footbath, hence dairy farmers should consider limiting their activities within close proximity. Second, farms where the formaldehyde levels exceeded the 8-hour TWA in the milking parlour, could consider increasing the distance of the footbath from the milking parlour. Third, it can be important to advise dairy farmers to wear gloves when preparing and emptying the footbaths to prevent dermatitis.

In conclusion, exposure of dairy farmers presumably falls below the Dutch 8-hour TWA occupational exposure limit value, since exposure time in close proximity to the footbath is generally short and even time in the milking parlour falls below this limit. Nonetheless, as this study indicates substantial concentrations of formaldehyde can be found on farms, emphasis is put on the need for additional research on suitable alternatives.

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Patient consent for publication Not applicable.

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SUPPLEMENT A – STRUCTURED INTERVIEW

The results of the structured interview (n=20) are indicated in percentages (table 1 and 2).

Table 1.

Structured interview results of binary questions (n=20).

	Yes	No (%)
1. Do you ever come into dermal contact with either the formalin solution before addition to the footbath or the formalin mixture in the footbath?	5 (25%) ¹	15 (75%)
2. Do you wear plastic gloves (e.g. latex or nitrile gloves) when preparing the footbath?	7 (35%)	13 (65%)
3. Do you wear plastic gloves (e.g. latex or nitrile gloves) when emptying the footbath?	11 (55%)	9 (45%)
4. Do you refresh the footbath directly after every milking?	9 (45%)	11 (55%)
5. Are there other instances (besides preparing and emptying) were you have to be within two meters of the footbath?	7 (35%)	13 (65%)
6. Is the person preparing and emptying the footbath always the same?	10 (50%)	10 (50%)
1. The formalin mixture in the footbath		

Table 2.

Structured interview results of open-ended questions (n=20).

	Answer	Number and percentage of farmers
1. What concentration can be seen on the label of the formalin solution you use?	37% 2% ¹	19 (95%) 1 (5%)
2. How much litre of the formalin solution do you add to the footbath?	3-4 5-6 7-8 9-10 >10	2 (10%) 3 (15%) 5.5 (27.5%) ² 5.5 (27.5%) ² 4 (20%)
3. How do you measure the amount of formalin solution added to the footbath?	Bucket without litre division Use litre division Add part of the jerrycan	3 (15%) 7 (35%) 10 (50%)
4. How long does preparing the footbath approximately take? ³	A few seconds 30 seconds <1 minute 2 minutes 3 minutes 5 minutes	5 (35.7%) 2 (14.3%) 3 (21.4%) 2 (14.3%) 1 (7.1%) 1 (7.1%)
5. How long does emptying the footbath approximately take? ⁴	< 1 minute 1.5 minutes 3 minutes 5 minutes 10 minutes 15 minutes Not needed	9 (47.4%) 2 (10.5%) 1 (5.3%) 2 (10.5%) 2 (10.5%) 2 (10.5%) 1 (5.3%)
6. How do you empty the footbath? Describe actions.	Turn over Use shovel Not needed	15 (75%) 4 (20%) 1 (5%)

7. How long do these other instances within two meters of the footbath last? ⁴	Few seconds	2 (33.3%)
	30 seconds	1 (16.7%)
	Few minutes	2 (33.3%)
	3-5 minutes	1 (16.7%)
8. How many times do you use the footbath during grazing season?	2 times per week	2 (10%)
	1 time per week	5 (25%)
	Once per 2 weeks	6 (30%)
	Once per 2-3 weeks	3 (15%)
	Once per 3 weeks	1 (5%)
	Once per 4 weeks	1 (5%)
	Once per 4-5 weeks	1 (5%)
	Never	1 (5%)
9. How many times do you use the footbath during housing season?	2 times per week	2 (10%)
	1 time per week	7 (35%)
	Once per 2 weeks	7 (35%)
	Once per 2-3 weeks	2 (10%)
	Once per 3 weeks	2 (10%)
10. How many times per month are you the one to prepare the footbath?	Almost always	5 (50%)
	Half of the time	3 (30%)
	One third of the time	1 (10%)
	One fourth of the time	1 (10%)
11. How many times per month are you the one to empty the footbath? ⁵	Almost always	7 (77.8%)
	Half of the time	1 (11.1%)
	One fourth of the time	1 (11.1%)
12. How long have you been using formalin footbaths on your dairy farm? ⁴	< 5 years	3 (15.8%)
	5-10 years	2 (10.5%)
	11-20 years	1 (5.3%)
	21-30 years	1 (5.3%)
	31-40 years	4 (21.1%)
	41-50 years	2 (10.5%)
	> 50 years	6 (31.6%)

1. Presumably the respondent was referring to the concentration in the footbath and not the concentration of the formalin solution before mixture with water
2. An amount of 8-9 L formalin was mentioned, hence this is divided over the categories of 7-8 and 9-10 L formalin.
3. Responses were only included if the preparation time after the addition of formalin was mentioned.
4. Unclear answers to the question were excluded.
5. One footbath empties automatically; a total of nine responses are included.

SUPPLEMENT B – REGRESSION ANALYSES WITH METEOROLOGICAL CONDITIONS

In all univariable regression analyses the 95% CI includes 0, indicating a lack of statistical significance. However, directional indications suggest a positive relationship between temperature and carbon dioxide with formaldehyde and a negative relationship with relative humidity and formaldehyde (figure 1). High temperature and low humidity can lead to a higher evaporation rate, leading to higher formaldehyde concentrations. Higher carbon dioxide values may indicate less ventilation, leading to higher formaldehyde levels. The collected data of this study seems to support these assumptions.

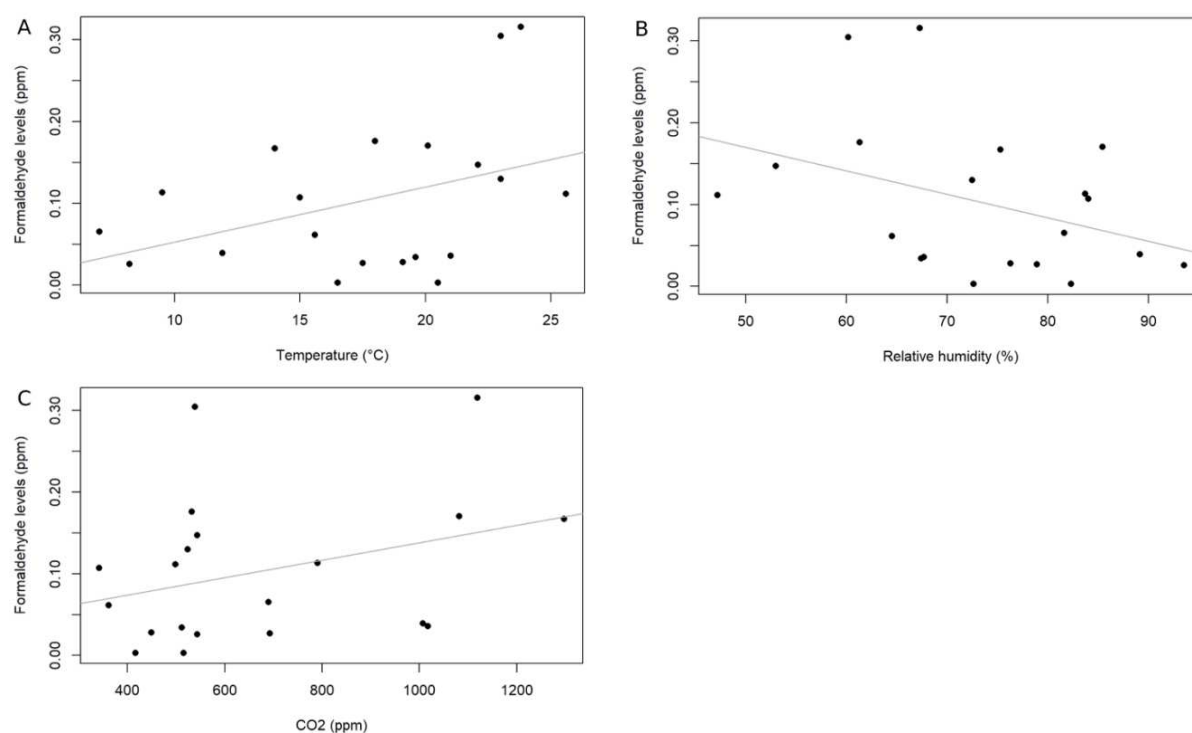


Figure 1. Scatter plots of univariable regression analyses of meteorological conditions and formaldehyde levels near the footbath. A) Univariable regression plot of formaldehyde (ppm) and temperature (°C) (95% CI = - 0.001 to 0.014; R² = 0.155; β = 0.007). B) Univariable regression plot of formaldehyde (ppm) and relative humidity (%) (95% CI = - 0.006 to 0.001; R² = 0.148; β = - 0.003). C) Univariable regression plot of formaldehyde (ppm) and CO₂ levels (ppm) (95% CI = - 4.47e-05 to 2.58e-04; R² = 0.108; β = 1.06e-04).

