A New Sampler to Assess Dermal Exposure During Wet Working

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In the UK ~30% of cases of dermatitis reported to the national surveillance scheme are associated with wet working or exposure to aqueous mixtures. There is evidence that the duration and frequency that hands are wet are key determinants of risk, but there are no objective methods to measure these exposure factors. This research aimed to develop a practical tool to measure the duration and the number of occasions hands are wet. We developed an electronic sensor that is worn on the finger, which detects wetness from evaporative cooling. The output signal is recorded in electronic memory and the frequency and duration of exposure calculated using a simple data processing algorithm. The device has been tested in a variety of environmental conditions and for a standardized wet-work task. Wetting events were detectable in all the standardized tests, with the proportion of time the hands were wet ranging from 15 to 49% (mean 30%). The electronic sensor is slightly affected by abrupt changes in air temperature and rapid air movements, but these do not seem to impose any practical limitations. This IOM Wet-Work sampler has the potential to provide reliable measurements of exposure that may be used to assess the risk of contact dermatitis.

Keywords: exposure analysis; irritant contact dermatitis; wet-work

INTRODUCTION

The German Federal Ministry for Economics and Labour has introduced technical guidance (TRGS 531) designed to protect the skin of people who have to work with water or wear water resistant protective gloves (English translation available at http://www.cdc.gov/niosh/topics/skin/pdfs/WetWorkTRGS531.pdf). The guidance essentially recommends that workers should not have their hands wet for more than 2 h or more than 20 times each day and that impervious gloves should not be worn for more than 4 h per day.

This technical guidance and other preventative measures introduced in Germany have had an impressive impact on the incidence of occupational skin disease in Bavaria. Overall incidence of occupational skin disease in Bavaria decreased from 10.7 cases per 10 000 workers between 1990 and 1992 to 4.9 per 10 000 in the period from 1993 to 1999. Dickel et al. (2002) subsequently showed a 10-fold reduction in the incidence of dermatitis amongst hairdressers from 1990 to 1999. Much of the disease observed in these studies was attributed to wet-work and the reductions in the incidence of skin disease to the restrictions on wet-work introduced in Germany.

There is scientific interest in developing a clearer understanding of the causal relationship between irritant dermatitis from wet-work and occlusion of the skin from wearing impervious gloves. Coenraads and co-workers (2004) have investigated the exposure of nurses to wet-work by using a questionnaire and direct observation. They found that the direct observation, which they considered a ‘gold standard’, produced estimates of the average duration of wet-work that were about half that based on the questionnaire data and the frequency was twice that reported in the questionnaires. They argue that the risk of dermatitis may be related to the frequency of
wetting-and-drying cycles within a defined period of time and that reliable data on these parameters will be needed for epidemiological investigations.

Measurement of dermal exposure to liquids is still not fully developed. There are three basic approaches that have been used to measure skin exposure to hazardous agents: interception methods such as absorbent patches that collect contaminants before they land on the skin, recovery techniques based on washing or wiping contaminants from the skin surface and in situ visualization methods that rely on the fluorescent properties of tracer compounds added to the source of the contaminant (CEN, 2005). All these methods provide measures of the average mass of contaminant that either lands on the skin or is retained in the skin contamination layer (Schneider et al., 2000). It seems to us that none of the existing exposure assessment protocols are suited to quantifying skin exposure to water and none are useful for estimating risk in such situations.

We have been experimenting with different approaches for measuring dermal exposure of workers using metalworking fluids, where we consider the main risk factor for irritant contact dermatitis is wet-working (Semple et al., 2005). The use of an interception sampler comprising a patch of cotton gauze attached to the wrist of the worker was completely unsatisfactory, because it failed to capture the exposure to the hands. An alternative approach of using absorbent gloves was unsatisfactory because of the risk of entanglement in the moving machinery. A more successful approach was to use a removal technique where the residue on the hands at the end of a work period was wiped off with a moist cloth and then analysed for a component of the metalworking fluid (in this case boron). However, this approach does not give any information about the frequency or duration of exposure, the main irritant dermatitis risk factors hypothesized by Jungbauer et al. (2004).

Wassenius et al. (1998) carried out a study to examine the variability of skin exposure of machine operators exposed to cutting fluids. Using video recording of work tasks and data on fluid evaporation times this paper describes how workers’ hands were wet for anything from 0 to 100% of the job time. Tasks with short cycle times were more likely to have a higher degree of relative wet time but overall the degree of skin exposure was shown to be highly variable and independent of machine type or task process. This approach is very labour intensive.

Recently we have invented a new sampler for measuring exposure during wet-work. The sampler provides a real-time indication of the wetness of the hand by making use of the changes in temperature that occur when the hand is in contact with water-based products and the subsequent cooling when the water evaporates from the skin. In this paper we provide details of the sampler design and some preliminary laboratory investigations to demonstrate its potential.

**THE PROTOTYPE IOM WET-WORK SAMPLER**

The IOM wet-work sampler is a simple device that comprises two thermocouples mounted in a holder and linked to a data-logger. The first thermocouple is located ~2 mm above the skin, while the second thermocouple is located under the holder in contact with the skin surface. Figure 1 shows the prototype holder with the two thermocouples.

The holder is held on the subject’s finger using an elastic band (Fig. 2). The wires from the thermocouple are kept in place with a Velcro wristband or tape and the data-logger may be worn in a pocket, on a belt or as shown on the arm. The total cost of the system is approximately £500 excluding the time to fabricate the holder for the sensors.

When the sensors are dry the thermocouple close to the skin indicates skin temperature and the other a value slightly below skin temperature. However, if the person immerses her hand in water both sensors are influenced by the liquid temperature, with the one above the finger responding most quickly to

![Fig. 1. The prototype IOM wet-work sampler.](https://academic.oup.com/annweh/article-abstract/51/1/13/173457)
the change in temperature. Once the hand is removed from the liquid it begins to warm because of blood flowing through the hand, but this warming process is slowed by the exchange of heat energy from the skin to the water enabling the water to evaporate. Figure 3 shows a typical trace of the thermocouple readings and the difference in temperature between the two sensors for the following exposure sequence (15 min rest, 5 min wet wiping, 15 min dry wiping and 15 min rest), which was then repeated.

The difference curve shows a distinct pattern with a spike at the start of the wet-work followed by a fairly consistent decline in the temperature difference. The apparent drying time for the sensors in this example is about 10 min plus the 5 min wet-work task, i.e. ~15 min in each cycle when the hand was wet.

Temperature data was acquired every 10 s throughout the experiment and this was then downloaded to a computer spreadsheet for analysis. The temperature difference was calculated for each time point and then smoothed using an exponential smoothing routine (damping factor 0.7). The average and the standard deviation of the smoothed temperature difference were obtained for periods when the hand was dry, i.e. at the 15 min at the beginning of each test. Any measurement where the temperature difference was more than the mean plus two standard deviations (SDs) derived from the ‘dry’ data was categorized as ‘wet’. Periods of wetness were identified from a consistent series of ‘wet’ time points.

**EVALUATION OF THE SAMPLER**

The wet-wiping task described above was undertaken on two separate occasions by four volunteers (two male and two female). Table 1 shows the overall average skin temperatures, the average difference between the readings from the two thermocouples and the proportion of time spent in wet-work based on the data analysis described above.

The two males had average skin temperature during the tests between 32 and 34°C, whereas the females’ average skin temperature was between 24 and 27°C. The overall range of finger temperature is similar to that reported by others (Niu et al., 2001). The lower skin temperature of the two female volunteers resulted in a correspondingly smaller difference in temperature between the two sensors, which is the more important parameter for detecting wet-work.

![Fig. 2. The prototype IOM wet-work sampler worn on finger.](image)

![Fig. 3. Typical thermocouple measurements from an immersion test with the prototype IOM wet-work sampler. Arrows show start of each experiment.](image)
and this made the identification of periods of wet-work more difficult against the random fluctuations in temperature. However, all the temperature difference traces produced the characteristic sign of two immersions in a cool liquid, i.e. a spike in the temperature difference between the sensors and then to varying degrees a period of increased temperature difference above background as the water evaporated from the sensors. The fraction of time that the task was assessed to involve wet-work ranged from 15 to 49%, which corresponds to sensor drying times between 0 and 15 min. The average sensor drying time was 7 min. Independent experiments carried out by us have shown that hand drying occurs in about 10 min (Semple et al., 2005).

We have also explored how the IOM wet-work sampler responds when the water is hotter than skin temperature. In this case the initial spike is in the opposite direction to that shown in Fig. 3, i.e. the sensor above the finger increases first and then the skin surface sensor follows suit. Once the hand is removed from the water the sensor above the skin starts to cool first and the temperature difference reverts to that seen in the earlier experiment.

There are a number of circumstances that we have identified where there is the potential for the sensor to give false positive readings. These may occur when there are changes in environmental temperature, changes in air movement over the sensor or the wearing of protective gloves. We have undertaken some experiments to assess the potential importance of each of these circumstances.

To assess the effect of ambient temperature we exposed subjects to 10 min in a relatively low temperature room (18°C), then in a moderate temperature room (22°C), a warm room (27°C) and then back to the low temperature room. The sensors were dry throughout. There were one or two instances where the difference in temperature between the two sensors increased, on both occasions around the time of transition between different temperature regimes. However, these changes did not show the characteristic spike associated with the immersion of hands and the difference generally only lasted for about a minute. We, therefore, do not believe that ambient temperature or changes in air temperature are an important source of bias for the IOM wet-work monitor.

We carried out tests where the sensor was worn first with the hand held still and then while it was moved vigorously from side to side (at ~1 m s⁻¹). During the periods of hand movement the thermocouple reading for the sensor above the finger showed a marked dip and the one on the skin showed a smaller decrease, which gives rise to an increased difference in temperature between the sensors. Using the simple data analysis approach to that described earlier these periods would be classified as wet-work. However, the pattern of the temperature difference was quite different from that seen with actual wet-work and so we do not believe it would be difficult to discern these incidents. Also, the movement of the hand was much more vigorous than was likely in most situations, and certainly during the wiping tasks described above, there was no indication that the sampler was being seriously affected by air movement.

The prototype IOM wet-work sampler was also tested while wearing a glove (Fig. 4). In this test we ran the sampler for 15 min with the hand dry, then wet the hand for 1 min, then put the glove on for 15 min and, finally, took the glove off. The characteristic dip in temperature associated with the wetting event is clearly seen in the temperature difference trace, but once the gloves are donned the two temperature sensors quickly converge to show almost identical readings. This is not unexpected since the environment inside the glove is insulated and the water can easily flow inside the glove providing a more homogeneous environment. The temperature inside the glove increases as the blood flow through the hand heats the water on the skin. Once the glove is removed the temperature of the sensors is seen to diverge as the water evaporates from the skin.

We have also carried out experiments when gloves are worn over dry skin. In this case the sensor readings converge when the glove is worn and diverge when the glove is removed. This response provides a possible way for us to identify periods of glove wearing, e.g. when the two temperatures are less than ~0.5°C apart.

### DISCUSSION

The IOM wet-work sampler provides a cost-effective way of collecting exposure data that is likely

<table>
<thead>
<tr>
<th>Subject</th>
<th>Gender</th>
<th>Test 1</th>
<th>Test 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA</td>
<td>M</td>
<td>Average skin temp (°C)</td>
<td>Average difference between sensors (°C)</td>
</tr>
<tr>
<td>SS</td>
<td>M</td>
<td>33</td>
<td>0.8</td>
</tr>
<tr>
<td>KC</td>
<td>F</td>
<td>25</td>
<td>0.4</td>
</tr>
<tr>
<td>AM</td>
<td>F</td>
<td>25</td>
<td>0.4</td>
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</tbody>
</table>

Table 1. Results from the preliminary evaluation of the IOM wet-work sampler
to be relevant to the risk of dermatitis. Up until now it has only been possible to obtain such data by qualitative observation or questionnaire. The former approach has been shown to be unreliable (Jungbauer et al., 2004), while the latter strategy is costly and time consuming and may also be prone to error.

The German guidance (TRGS 531), which has been a clear success in reducing the incidence of dermatitis, is based on restricting the amount of time and the number of occasions the hands are wet; both measures can be obtained from the IOM wet-work sampler. The preliminary data we have obtained from controlled tests suggest that there is relatively large inter-subject and intra-subject variation in exposure and so an objective measurement tool is an important prerequisite for appropriate risk management. The sampler, therefore, provides a convenient basis to set practical objective guidance for industry to help reduce the incidence of dermatitis from wet-work. Specific dermatitis risk-management initiatives could also be assessed for their effectiveness in a timely way using the IOM wet-work sampler.

We have separately shown that after wetting the hand dries in about 10 min (Semple et al., 2005). This has been an important design criterion for the new sampler, and we believe that the sensor reflects the time taken for the skin to dry. This should ensure that measurements made with the sampler provide a realistic indication of the total time the hands are wet rather than an arbitrary assessment of wetness. It may be possible to design the data analysis routines for the sampler to enable periods of glove wearing to be identified. If this type of information could be provided then it would offer additional useful data to help evaluate risk-management strategies. It is certainly known that prolonged wearing of impervious gloves increases the risk of irritant dermatitis. Further work is necessary to investigate the practicability of putting on and removing gloves in the workplace while wearing the sensor.

One limitation of our approach is that the sampler does not give any indication of the area of skin exposed, although this is unlikely to be an important factor for jobs that involve total immersion of the skin. We believe that it is the frequency and duration of wet-work that are of most importance and probably provide the key variables for managing risk. Therefore, we do not see this as a serious limitation. However, it would be possible to combine the IOM wet-work sampler with fluorescence monitoring to assess the area exposed as well as the frequency and duration of wet working.

It is not the authors’ intention to patent the IOM wet-work sampler as they believe it is important to make the design widely known so that it can be rapidly used in studies investigating the causes of dermatitis from wet-work and in designing appropriate control strategies. IOM retains copyright on the design but will cooperate with any scientist who wishes to use this method.

The IOM wet-work sampler is still at a prototype stage and there is some further development and testing necessary. The following improvements could be made to the measurement system:

- development of a smaller flexible holder for the thermocouples;
- investigate more thoroughly the effect of environmental conditions, e.g. air temperature, humidity and air flow;
- investigate the effect of other liquids with other thermal properties and their evaporation rate from the skin;
investigate more the effect of liquid temperature on sensor response;
- development of a more reliable and user-friendly data analysis routine;
- evaluation of the suitability of the device to assess periods of glove wearing;
- checks on the reproducibility of sensor manufacture.

In addition, we believe that the sampler should be tested in a number of workplaces where wet-work occurs to assess the reliability and suitability of the system. This could be done by comparing it with self-assessed wet-work parameters and direct observation data on frequency and duration of wet-work.

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REFERENCES


