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RH measurements for assessing moisture conditions in concrete structures

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ABSTRACT: For assessment of the moisture conditions in concrete structures, measurements of relative humidity are often applied. Since such measurements only are an indirect way of testing the moisture conditions, proper interpretation of such measurements requires a good basic knowledge of thermodynamics in order to make a correct assessment of the moisture conditions. In the present paper, it is shown how thermodynamic relationships can be utilized for obtaining more useful information about the moisture conditions in concrete structures, but this requires combined measurements of both relative humidity and temperature during the condition assessment.

In the present paper, current experience with relative humidity measurements for assessing moisture conditions in concrete structures is reported. During field investigations of repaired concrete structures, it was observed that the degree of pore saturation was almost constant, even when the relative humidity in the concrete varied between wide limits due to diurnal and seasonal temperature variations.

1 INTRODUCTION

The moisture conditions in concrete always play an important role in the physical and chemical deterioration of concrete structures. Deterioration both due to frost action and alkali-silica reaction needs a certain amount of moisture in order to represent a problem. For corrosion of embedded steel, the level of moisture content both affects the rates of carbonation and chloride penetration as well as electrical resistivity and availability of oxygen.

There are a number of methods for assessing the moisture conditions in concrete based upon a number of different techniques such as destructive sampling, electrical resistivity, dielectric properties, thermal properties, infrared absorption and neutron scattering. The most common method, however, is measurements of relative humidity. Since such measurements only are an indirect way of testing the moisture conditions, the interpretation of such measurements requires a good basic knowledge of thermodynamics in order to make a correct assessment of the moisture conditions. In order to assess the moisture conditions by use of relative humidity measurements in existing concrete structures, field measurements were carried out over a certain period of time as reported and discussed in the following.

2 EXPERIMENTAL

All field measurements were carried out as part of a more general following-up of number concrete structures which had been repaired due to corrosion of embedded steel. These measurements primarily included combined observations of relative humidity (RH) and temperature (T) over periods of up to several years (Pruckner 2002). Most of the concrete structures included parking garages, where the repaired concrete decks also had been protected by an approximately 5 mm thick polyurethane top coating, but some of the structures had also been repaired without any additional surface coating.

Before the repairs of the concrete structures, 50 mm deep holes were drilled with a cavity-volume of approximately 3 cm^3. In each hole, measurements were carried out by use of a commercial hygrometric sensor, which continuously recorded the two variables RH and T at one-hour intervals. The sensing element of the humidity probe was made of a hygroscopic material, in which the dielectric properties were changing with the ambient RH.

In the following, some typical results from the field measurements in the concrete decks of two of the parking garages are presented. These measurements were made in one location in Parking Deck A and three locations in Parking Deck B. In addition, some similar field measurements from the inside of a repaired concrete wall of a fertilizer silo are also presented. After the repair, this concrete wall was not protected by any surface coating. All field measurements were carried out over a period of approximately four years, and all data were used for calculating the variation in degree of water saturation in the concrete.

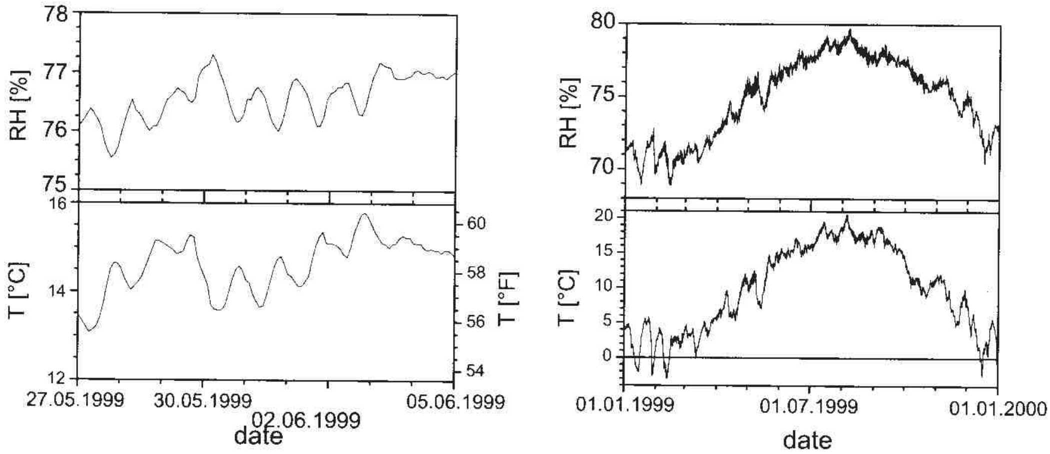
3 RESULTS AND DISCUSSION

During the collection of all data both from the parking garages and the fertilizer silo, it very soon became clear that not only the moisture variation but also the temperature variation of the ambient atmosphere very much affected the RH measurements in the concrete. Especially for the surface protected concrete decks in the parking garages, it was not likely that the variation in ambient RH should affect the RH inside the concrete. From Figures 1a and 1b it can be seen that both the observed short-term and the long-term variations of RH in the Concrete Deck A to a great extent followed the observed variation of temperature.

Since the viscosity of water is strongly affected by temperature (T), the observed RH in the concrete must also be affected by the temperature. It was convenient, therefore, to transform all the observed RH values in the concrete to a standard temperature of 25°C (298 K) according to the following equation (Pruckner 2002):

$$\mathrm{RH}(298\ \mathrm{K}) = 100 \cdot \exp\left[\ln\left(\frac{\mathrm{RH}(\mathrm{T})}{100}\right) \cdot \frac{\left(\dfrac{1}{298\ \mathrm{K}} - \dfrac{1}{\mathrm{T}_\chi}\right)}{\left(\dfrac{1}{\mathrm{T}} - \dfrac{1}{\mathrm{T}_\chi}\right)}\right] \tag{1}$$

where $T_\chi = 350$ K.



Figures 1a and 1b. Short-term and long-term variation of RH versus temperature in Parking Deck A.

Based on both the observed RH (T) and the adjusted RH (298 K) values, the variations in the degree of water saturation (SD) could also be calculated by applying an adsorption isotherm with the following equation (Pruckner 2002):

$$SD = \frac{1 - \ln\left|\frac{RT\ln\left(\frac{p}{p_s}\right)}{\Delta\mu_{mono}}\right|}{1 - \ln\left|\frac{RT\ln(0.999)}{\Delta\mu_{mono}}\right|} \tag{2}$$

where:

R gas constant [J/Kmol].

p water vapor pressure [Pa].

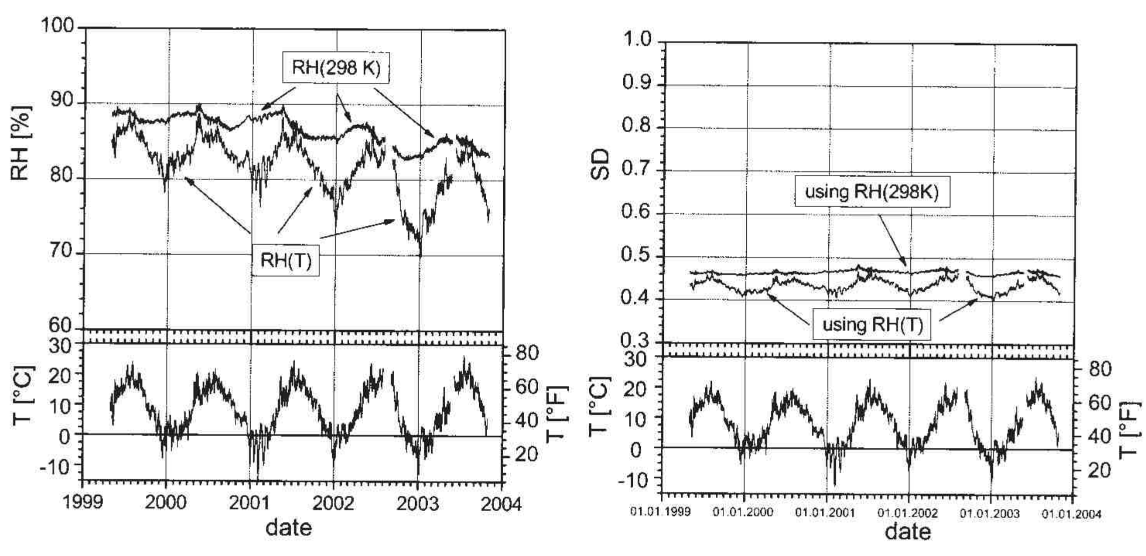
p_s water vapor pressure at saturation [Pa].

$\Delta\mu_{mon}$ change of chemical potential at monolayer coverage.

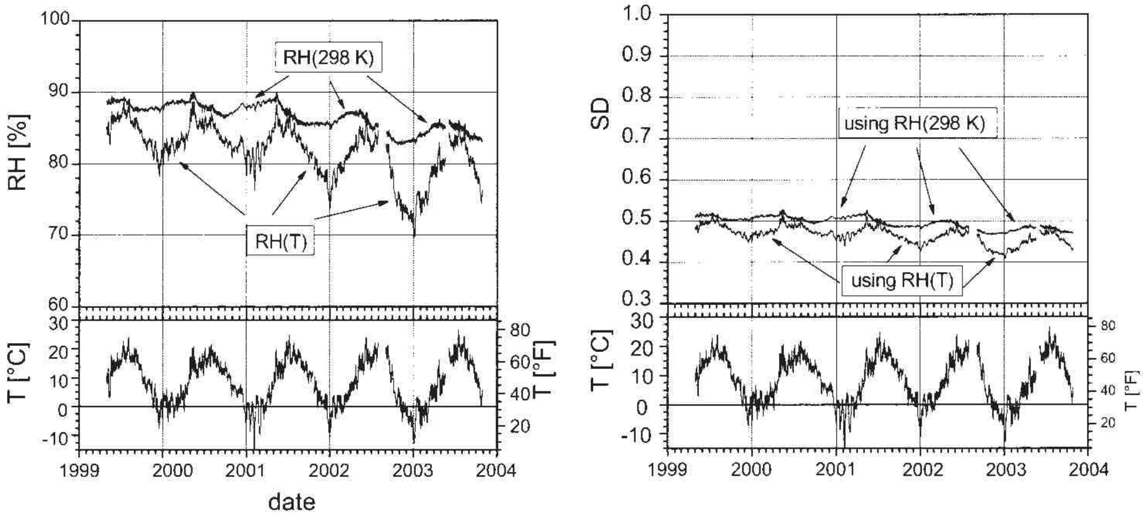
In the following, some typical variations in both the observed and calculated values for the moisture conditions in the concrete are presented.

For the Parking Deck B, the concrete deck was covered with an air-and water-tight polyurethane layer on the top-side and an acrylic thick-film membrane on the soffit side. For this particular structure, therefore, it was assumed that the observed variations of RH were mostly caused by variations in the concrete temperature. After the adjustments of the observed values of RH (T) to the standardized temperature RH (298 K), it can be seen that both the relative humidity (Fig. 2a) and the degree of water saturation (Fig. 2b) were quite constant during the whole four year observation period.

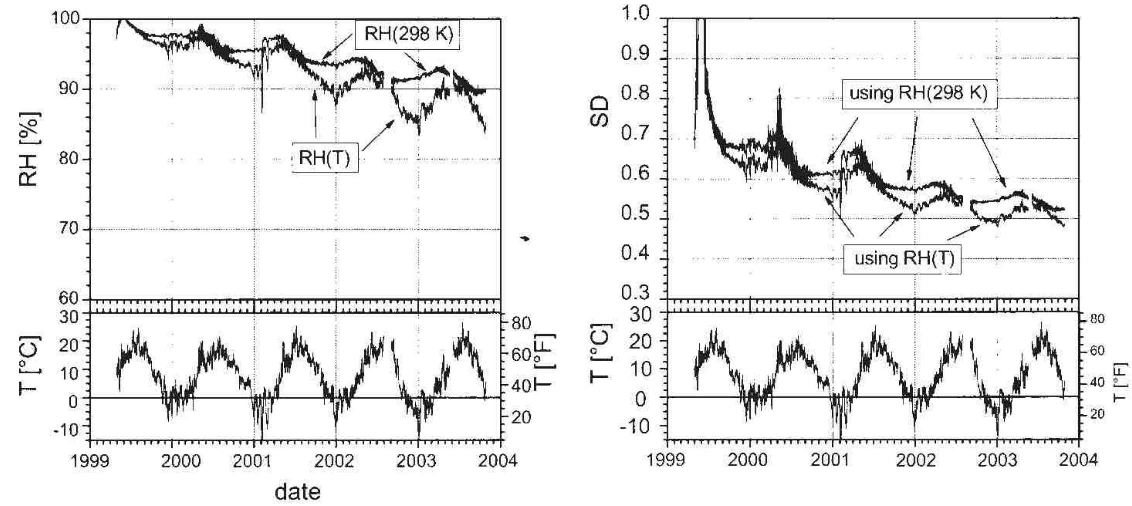
For Locations 2 and 3 in Parking Deck B, the situation was quite similar. For Location 2, however, a slight tendency of drying-out of the concrete was noticeable, as the standardized relative humidity decreased from approximately 88 to 85%. For this location, the seasonal variations were more pronounced, since in the middle of May, RH (298 K) typically approached the annual maximum. From this date the moisture content decreased until October, while it remained more or less constant until the beginning of January. After that, the moisture content increased again. Also in Location 3, the relative humidity RH (298 K) in the concrete decreased from 100% to 90% over the four year observation period. This decrease was again



Figures 2a and 2b. Variation of RH(T), RH(298 K) and saturation degree (SD) with time for Location 1 in Parking Deck B.



Figures 3a and 3b. Variation of RH(T), RH(298 K) and saturation degree (SD) with time for location 2 in Parking Deck B.

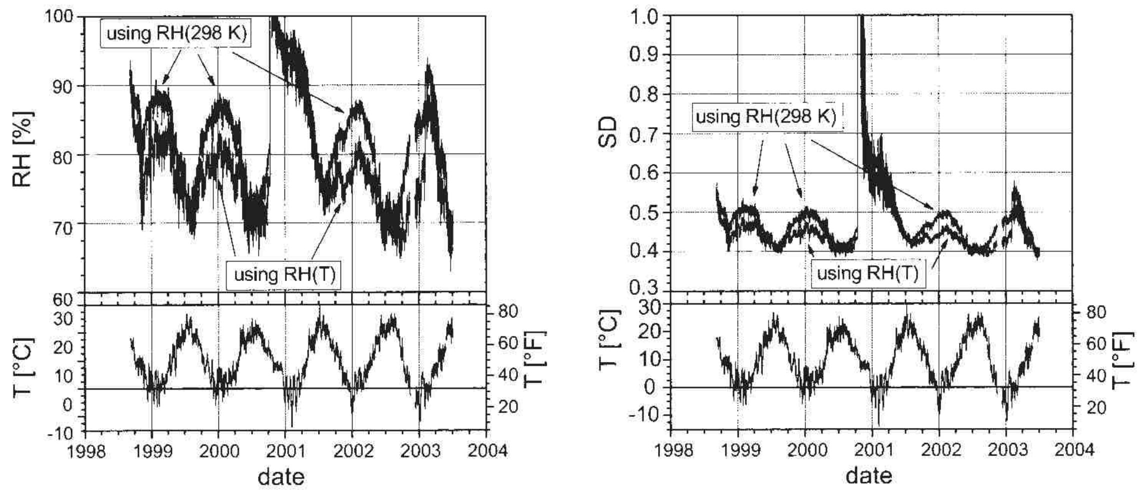


Figures 4a and 4b. Variation of RH(T), RH(298 K) and saturation degree (SD) with time for location 3 in Parking Deck B.

overlaid by a seasonal pattern, where the maximum appeared in the middle of May and a flat minimum between October and January.

For the concrete wall inside the silo of the fertilizer plant, it was expected that the RH in the drilled cavity of the concrete would be in a more close equilibrium with the RH of the ambient environment, following the outside relative humidity. From Figures 5a and b it can be seen that both the standardized relative humidity and the degree of water saturation in the concrete typically varied in accordance with the annual course of the outdoor relative humidity in the local region, which is shown in Figure 6. This figure shows the average values of both the monthly relative humidity and the temperature recorded over a 21 year period in the Oslo region.

From the results shown in Figures 5a and b, it should be noted that the instantaneous increase in the observed relative humidity in the concrete on October 12, 2000, was caused by a cleaning with water of the inside of the concrete silo. After this incident, it can be seen that it took more then half a year before the saturation degree reached equilibrium again with the relative humidity of the ambient atmosphere.



Figures 5a and 5b. Variation of RH(T), RH(298 K) and saturation degree (SD) with time for the concrete wall.

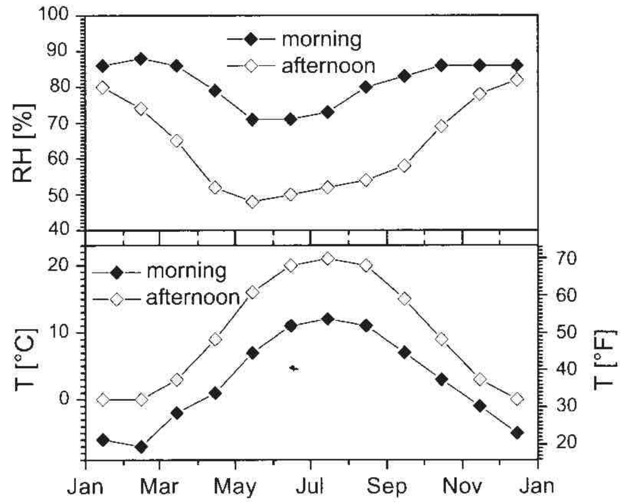


Figure 6. Average values of RH and T over a 21 year period for the outdoor environment in the Oslo area (Washington Post).

For the field investigations carried out of both the surface protected and the unprotected concrete structures, the above results and trends appear to be in well agreement with other results reported in the literature (Nilsson 1988, 1997, Sellevold 1997, Paroll & Nykänen 1998).

4 CONCLUSIONS

For assessment of the moisture conditions in concrete structures, measurements of relative humidity are often applied. Since such measurements are only an indirect way of testing the moisture conditions, however, proper interpretation of such measurements requires a good basic knowledge of thermodynamics in order to make a correct assessment of the moisture conditions. Based on the results reported in the present paper, the following conclusions appear to be warranted:

1. The relative humidity in concrete strongly depends on the ambient temperature. Measurements of relative humidity in concrete should therefore always be combined with temperature measurements. Basic thermodynamic relationships can then be applied for obtaining more useful information about the moisture conditions in the concrete.

2. By converting all humidity measurements in the investigated concrete structures to a stan-dardized temperature, it was possible to obtain information about the saturation degree by applying an adsorption isotherm. Data about the saturation degree could then be obtained from the combined measurements of relative humidity and temperature.
3. For the surface treated concrete structures, it was observed that the degree of water saturation in the concrete was almost constant, even when the measured relative humidity varied within wide limits due to diurnal and seasonal temperature variations.
4. For the sheltered but non-surface treated concrete structure, the degree of water saturation in the concrete typically varied in accordance with the variation of the outdoor relative humidity in the local region.

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