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# Repair of the Inner Shell of Natural Draft Cooling Towers

Assainissement de la surface intérieure des tours de refroidissement

Sanierung der Innenschalen von Naturkühltürmen

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## SUMMARY

First signs of degradation on the inner shells of RWE's natural draft cooling towers appeared in 1978. Some of the concrete surfaces revealed a high degree of scaling, resembling exposed aggregate concrete, and in some areas corroded reinforcement bars had broken off large pieces of concrete. Extensive studies of the towers were undertaken between 1978 and 1982 on the causes of the damage and on rehabilitation options. The resulting program and procedures have become well recognised for cooling tower upgrades and are being applied by many other cooling tower operators.

## RÉSUMÉ

Les premiers dégâts aux parois internes des tours de refroidissement sont apparus en 1978. La surface en béton a été attaquée et des phénomènes de corrosion ont provoqué un effet d'écaillage important produisant une surface similaire à celle du béton délavé. Entre 1978 et 1982, de vastes analyses portant sur la cause des dégâts, ainsi que sur les possibilités d'assainissement, ont été conduites. Le programme et la méthode d'assainissement qui en ont résulté, sont devenus une référence qui est appliquée maintenant à l'échelle internationale dans le domaine de l'assainissement des tours de refroidissement.

## ZUSAMMENFASSUNG

Erste Schäden an den Innenschalen von Naturkühltürmen des RWE traten 1978 auf. Die Betonoberfläche sandete stark ab, partiell ergab sich eine waschbetonähnliche Oberflächenstruktur, und korrodierte Bewehrungseisen sprengten Betonflächen ab. An Kühltürmen wurden zwischen 1978 und 1982 umfangreiche Untersuchungen über Schadensursache und Sanierungsmöglichkeiten durchgeführt. In Labortests und an Probeflächen in einem Kühlturm wurden die von verschiedenen Herstellern für diesen besonderen Anwendungsfall vorgeschlagenen Materialien erprobt. Das daraus entstandene Programm und die Vorgehensweise haben sich zum Standard der Kühlturmertüchtigung entwickelt und werden von vielen anderen Kühlturmbetreibern angewendet.

# 1. INTRODUCTION

Engineers always try to build concrete structures in an economical way by using as little concrete and steel as possible. In Europe, throughout the 70s, the use of newly developed calculation systems led to thinner and thinner steelreinforced concrete shells. A good example for this development are the shells of natural draft cooling towers. These constructions may be as high as 180 m (Chivaux, France), with a wall thickness of sometimes down to 16 cm. Considering a layer of crossed reinforcement on the outside and inside there is not much space left for the concrete coverage and the concrete itself.

The inner shells of RWE Energie's natural draft cooling towers built in the 70s showed first signs of degradation in 1978. The power station personnel detected huge amounts of sand filling the water basins. When searching for the cause, it was revealed that the surface of the inner side of the cooling tower shells was damaged in different ways. Sand particles were attached to the surface, corroded reinforcement became visible and great areas of coarse aggregates formed the surface, which implied that the surface of the shell as it had been after construction had deteriorated during the course of operation.

# 2. INSPECTION AND TESTING

## 2.1 Examining the concrete

The first step following the detection of the damage was a careful inspection of the cooling towers. The strength of the surface of the concrete was examined by cutting it with a sharp knife and measuring the depth of the cut. In some areas the knife cut several millimeters into the concrete, while it was impossible to perform cuts on normal concrete. The compressive strength of the concrete was tested and found to be equivalent to the design values. The amount of corroded reinforcement was counted and added up to several hundred meters.

However, the most important aspect investigated was the carbonation depth in relation to the concrete coverage of the reinforcement. The results were even worse than expected. The concrete coverage designed for 1.5 cm, in large areas appeared to be only between 0.5 cm and 1.0 cm, while the carbonation had already reached a depth of more than 1.5 cm in some areas and 1.0 cm on an average. [1]

This made a repair of the concrete shells a precondition for further operation.

## 2.2 Reasons for the damage

After having obtained these results, the reasons for the degradation were examined. The cooling towers inspected had all been built with the help of a climbing scaffolding, concreting every day on an average. So every ring of concrete had its own environmental influences throughout construction, i.e. rain and wind. Moreover, the treatment of the surface after having removed the scaffolding varied depending on how good it was done. Not enough attention had been paid to the concrete coverage of the reinforcement and to the sealing of the concrete surface. Since cooling tower shells are exposed to strong winds and great changes of temperature, small cracks can always be found in the surfaces.
In addition to the above-mentioned, operation also constituted an unexpected attack. During operation, treated water ran down the surface and washed out the cementitious matter. Measurements showed that the pH value of this water was at times as low as 4. Thus, this may be regarded as a chemical attack to the surface and explains the loosening of the surface and the wash-out effect. The water and the air accounted for the high carbonation of the concrete surface which, compared to today's standards, had undergone inadequate curing.

Moreover, effects of microbiology with organisms living on the surface and producing acid were revealed, as well as frost effects in the lower part. However, both proved to be of no great influence compared to the others. [2]

## 2.3 Materials testing

A main aspect in choosing the appropriate kind of repair system is the time available. Most of the cooling towers are connected to base-load power stations which implies that they are only shut down for six weeks every three years. Therefore, upgrading has to fit into this six-week maintenance period.

A wide range of concrete coating materials were available for the upgrading process. But as stated above, there were certain requirements for the material to be used. After discussing the subjects with experts from universities and production companies, a laboratory test series was set up for testing proposed materials with regard to

- resistance to $CO_2$, $S_d (CO_2) > 50$ m
- resistance to $H_2O$ vapor, $S_d (CO_2) > 10$ m
- changing temperatures
- swelling behavior
- adhesive strength
- reapplying layers of coating

The materials showing a good results were then applied as test areas to the concrete surface inside one of the cooling towers. After all the tests, two materials of different companies based on equivalent materials proved to be the best. These are specially designed epoxy-resin coatings.

## 3. UPGRADING MEASURES

### 3.1 Access equipment

For the treatment of the concrete surface, access to all areas of the cooling tower shell must be possible. This is achieved by travelling working platforms fixed with steel cables suspended from the cornice. The basic equipment is predominantly used for the maintenance of the facades of huge buildings. In order to use the system in cooling towers it was necessary to develop travelling catheads for the cooling tower cornice which are remote-controlled so that they are able to travel horizontally on demand. The up and down movements are controlled by winches installed on the platforms. By using this equipment, it is possible to reach every spot on the shell.
Due to the hyperbolic shape of the shell it is necessary to prestress the cables since otherwise the lower part of the shell would be out of reach. On the other hand, it is necessary to install rolling spacers in the upper part to prevent damage caused by the ropes and to the ropes moving on the surface.

All the equipment, particularly the working platforms, have to be examined, tested and approved by the German labour protection authorities. There has been no major accident during the upgrading of cooling towers throughout the last 15 years.

### 3.2 Surface treatment

For the upgrading of concrete, surface treatment is most important. Due to the limited time available it was not possible to do the blasting of the concrete by hand either with water or sand. Therefore, the company, which secured the order from RWE Energie, built unmanned high-pressure water-jet cleaning devices. The moving construction is similar to the one mentioned above.

The construction consists of a steel or aluminum structure in which three of four rotors are installed. These rotors have a diameter of about 60 cm and are mounted in such a way that the areas reached by each one overlap. Inside each of the rotors are four water-jet nozzles which are slightly tilted, thus rotating by the water pressure alone. The pressure is adjustable up to 800 bar, while the normal pressure required is about 400 bar. The water-jet nozzles clean an area with a width of 1.5 m and travel at a speed of 9 m per minute. Consequently, they are able to prepare an area of about 800 m² in an hour. For an area of 26,000 m² it takes about 5 days, including all interruptions and adjustments.

### 3.3 Upgrading the concrete

The concrete treated according to this method is examined carefully and the adhesive strength is tested. It has to be 1.5 N/mm² on average. Afterwards, the reinforcement bars as well as possible weak concrete areas which have been detected are sandblasted by hand. Before being double coated with a thickness of 1,000 $\mu$m they have to be cleaned according to SA 2 1/2 of the DIN standard. In general, there is no reprofiling of the reinforcement with mortar due to the lack of time. The average amount of reinforcement to be treated is about 3,000 m with a maximum of up to 5,500 m. The treatment of the reinforcement is the most time-consuming work.

The coating is applied in two layers by using airless spraying systems. While the primer is an unpigmented surface-penetrating system, the top coat is of gray colour. It has to be applied to a thickness of 200 $\mu$m measured after drying. Therefore, an amount of 500 gr/m² for the primer and 600 gr/m² for the final coat is used.

## 4. COOLING TOWERS WITH CLEANED FLUE-GAS DISCHARGE.

### 4.1 Additional attack

During the upgrading of the damaged cooling tower in the above-mentioned way, a new environmental law was released in Germany. For meeting its requirements, desulphurisation plants had to be built for almost every power station running on lignite coal. After careful investigations, the general management of RWE Energie AG decided to lead the cleaned flue gases into the cooling towers and to discharge them together with the vapor. The reasons for this decision were, besides environmental reasons, i.e. a lower impact on the surrounding, that this method would not require the reheating of the gases cooled down by the washing procedure as well as the building of new stacks. [3]

Consequently, the coating systems applied as well as new ones underwent a new series of laboratory testing procedures. The temperature and the acid content were the important factors for these tests which proved that the materials already applied remained to be the best choice. The retrofitted cooling towers for flue gases are also coated with epoxy resin, but at least a total of 1.2 kg/m² are used which amounts to 350 $\mu$m of dry thickness.

### 4.2 Outside

Since there now was an acid content in the vapor which got in touch with the outside of the shell, a protection had to be created for the outside, too. As for the coating, an acrylic coating was chosen in order to let remaining moisture out of the concrete. Due to the fact that it was possible to do all the work while the cooling tower was in operation, time was not that important anymore. Therefore, all the reinforcement bars were reprofiled before coating the complete concrete surface.

### 4.3 Repairing the coating

Since some of the cooling towers which are used for the discharge of the cleaned flue gases had not received the three layers of coating with the necessary thickness, some repair work meanwhile had to be carried out on the coating. Thus, new methods of surface treatment were required. Since it is not possible to remove the remaining and destroyed coating by high-pressure water without causing further substantial damage to the concrete, sand blasting was the only viable solution. However, due to all the plastic fillings, the sand and removed coating and concrete could no longer be dropped to the basin.
In order to save time and money an automatic sand-blasting device, similar to the water system, was developed. In addition, a screen consisting of brooms was attached to the sand-blasting device, and the dust and sand were collected with a type of oversized vacuum cleaner. After some testing periods, two different methods emerged which work almost dustfree so that they fulfill the requirements.

## 5. RESULTS AND OUTLOOK

Throughout the last 15 years, 18 cooling towers have been upgraded by RWE Energie AG. The coatings on the cooling towers which are not involved with the discharge of cleaned flue gases are in good condition, even after 15 years of operation. The others, with a coating that complies with the quality assurance system developed in the past years, are also in a good condition which proves the system's worth.

The above-mentioned method of upgrading cooling tower shells has been used in about 30 other cooling towers in Israel, the Czech Republic, Slovenia, France, Poland, Belgium and Spain, to mention a few countries.

New cooling towers which are to be built and which must cope with the discharge of flue gases - as planned in Germany - should have a concrete design which no longer requires an additional protective coating.

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