Outotec® Cooling Towers Provide Higher Efficiency and Decreased Emissions

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Abstract

Outotec has developed revolutionary new cooling tower technology. It has three installations around the world, two of which are in operation. The new and highly refined tower design allows for higher cooling efficiency, lower emissions and streamlined maintenance. The result is a more cost effective solution for our clients in both investment and operational costs. Fewer towers and less ancillary equipment and civil construction are needed to achieve the required cooling target.

The Outotec® Solution Cooling Tower has been designed to operate in harsh conditions. Applications include, but are not limited to, spent electrolyte cooling, gypsum removal and chloride removal in the hydrometallurgical production of zinc. The development of the tower is based on CFD modeling to find the optimal structure and to estimate the cooling efficiency and behavior of the tower.

The only potential direct emission component of solution cooling towers is in the form of droplets escaping through the top of the tower. These droplets are captured using demisters. The conventional demister arrangement uses two layers of demisters: a coarse demister and fine demisters. The Outotec design adopts a new approach. Horizontal airflow allows optimal droplet separation in the demisters, resulting in unprecedented cooling efficiency combined with optimized drift loss. In addition, the new design allows more efficient maintenance, especially in the cleaning of the demisters. This is achieved by utilizing a patented structure for the cooling tower that enables the use of horizontal airflow demisters.
The first commissioning of the new Outotec® Solution Cooling Tower involved spent electrolyte cooling towers at Grupo Mexico’s zinc plant, Industrial Minera México (IMMSA) in San Luis Potosi, Mexico. During the commissioning, capacity and emission measurements were taken, and the results were found to be in accordance with calculated cooling results in similar conditions. The new demister arrangement combined with optimized airflow inside the cooling tower results in higher droplet separation efficiency compared to traditional towers, which was observed in the measurements taken during the commissioning.

1 Introduction

Outotec has developed a new forced draft solution cooling tower design. The development work began with the need to streamline the maintenance of the solution cooling tower while achieving improved cooling efficiency. Extensive measurements were initially taken of the conventional design of cooling towers supplied by Outotec. The measurements from the old towers were then used to develop and validate a computational fluid dynamics (CFD) model of spent electrolyte cooling. This model is not geometry-dependant and could thus be used to develop the geometry of the new cooling tower. The model enables the behavior of gas inside the tower, cooling efficiency, droplet behavior and the functioning of the tower in different weather conditions to be estimated. After CFD research the structural development commenced, concentrating on the optimized maintenance of cooling towers. This resulted in a structure that enables online maintenance of the tower demisters with minimum downtime during operation. Online maintenance can be realized and fully utilized after some period of operation, but it will not be discussed in this paper. (1)

At the time of writing (December 2012) Outotec has supplied three installations of the new tower type, two of which are running and a third is close to commissioning.
Solution cooling towers are used in cooling applications with zinc electrolyte solutions containing sulfuric acid, very fine solid particles and/or zinc sulfate at high concentrations causing scaling and other process problems inside the equipment. The towers represent a different type of equipment than the water cooling towers that are used in a wide range of industrial, residential and other applications. Applications in which the solution cooling towers are used include, but are not limited to, spent electrolyte (zinc electrolyte returning from electrowinning) cooling, gypsum removal and chloride removal.

Conventional solution cooling towers have vertical outflow demisters, i.e. the air out of the tower flows upwards from the top of the cooling tower. The airflow is produced by a fan or fans placed at the lower part of the cooling tower blowing air horizontally inside the tower. The hot solution is dispersed as droplets countercurrent to the air into the tower from the upper part of the tower, usually just below the demister layers. Dispersion is achieved by gravity-operated plate dispensers or pressure nozzles. The cooling of the solution inside the tower is based on the evaporation of the solution and the heat transfer between the droplet and cooling air inside the cooling tower.
Some of the droplets are caught in the airflow travelling upwards through the tower. As the airflow exits the tower, it travels through the demisters. Usually there are two layers of demisters: a coarse demister and a fine demister.

The quantity of droplets exiting the tower is called drift loss, which represents the direct pollution produced by the cooling tower. In solution cooling towers these droplets can contain multiple harmful components, such as H$_2$SO$_4$, ZnSO$_4$ and Cl. In addition to the emissions from the gas outlet, i.e. direct emissions, solution cooling towers produce indirect emissions, such as emissions caused by the production of the electricity needed to operate the equipment. This article does not estimate or discuss these non-direct emissions.

2 IMMSA Zinc Plant

The Industrial Minera México (IMMSA) zinc plant belongs to Grupo Mexico, the largest mining company in the country. The plant started operation in 1982 and currently has a production capacity of 107 thousand tons of cast zinc. The plant utilizes a conventional Roasting-Leaching-Electrowinning process. Zinc concentrates are received from three underground mines owned by Grupo Mexico. The concentrates mixture is fed to an 85-square-meter roaster, the sulfur dioxide is processed in a double contact sulfuric acid plant, and the zinc oxides are dissolved in several leaching steps. Iron is precipitated as jarosite, and the impure zinc solution is purified in two steps. The first step is a hot purification process with arsenic trioxide and zinc dust. The second step uses zinc dust and copper sulfate as reagents. The purified solution is conditioned and fed to the electrolysis circuit, where the zinc is reduced to metal. For this, there are two electric circuits containing twelve rows of sixteen concrete polymeric cells each. Each cell contains forty-five
anodes and forty-four 1.8-square-meter deposit area cathodes. The plating cycle is 24 hours, and after cathode stripping the zinc is melted in two electric furnaces and cast as ingots or one ton blocks.

2.1 Zinc Electrolyte Cooling Process

The purified zinc rich solution is cooled in two steps. The first step has two conventional square gravity feed cooling towers. The solution is cooled from 75 to 42 °C. The towers overflow to a thickener where gypsum is precipitated. The overflow goes to two storage tanks and a third cooling tower cools the solution from 42 to 34 °C. This cooled purified solution is mixed with the cooled spent electrolyte and fed by gravity to the electrolytic cells.

The spent electrolyte overflowing the electrolytic cells is collected in launders and directed to two one thousand-cubic-meter capacity storage tanks. From these tanks the hot spent electrolyte is sent to the spent electrolyte cooling towers. This cooling circuit uses ten conventional cooling towers identical to that for the purified solution mentioned above. Currently, as described above, there are two additional Outotec® Solution Cooling Towers in this circuit.

3 Emissions from the Solution Cooling Tower

The first commissioning of the Outotec® Solution Cooling Tower commenced at the IMMSA zinc plant in San Luis Potosi. The application was spent electrolyte cooling. The cooled solution in the zinc electrolyte process has a composition of $H_2SO_4$, $ZnSO_4$, Cl and other metallic components. (See Table 1 for generic solution compositions.) In some plants the concentrations can be much higher. Note: this is not the composition of the solution at the IMMSA plant, but a general example.
Table 1: Generic chemical components in cooled solutions in solution cooling towers

<table>
<thead>
<tr>
<th>Component</th>
<th>Gypsum removal</th>
<th>Spent electrolyte</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>H$_2$SO$_4$</td>
<td>pH 5</td>
<td>160-180</td>
<td>g/l</td>
</tr>
<tr>
<td>Cu</td>
<td>0.5</td>
<td></td>
<td>mg/l</td>
</tr>
<tr>
<td>Co</td>
<td>0.2</td>
<td></td>
<td>mg/l</td>
</tr>
<tr>
<td>Ni</td>
<td>0.2</td>
<td></td>
<td>mg/l</td>
</tr>
<tr>
<td>Cd</td>
<td>0.5</td>
<td></td>
<td>mg/l</td>
</tr>
<tr>
<td>As</td>
<td>0.05</td>
<td></td>
<td>mg/l</td>
</tr>
<tr>
<td>Cl</td>
<td>100-300</td>
<td>100-300</td>
<td>mg/l</td>
</tr>
<tr>
<td>Ca</td>
<td>400</td>
<td>300</td>
<td>mg/l</td>
</tr>
<tr>
<td>Mg</td>
<td>5-15</td>
<td>5-15</td>
<td>g/l</td>
</tr>
<tr>
<td>Mn</td>
<td>3-10</td>
<td>3-10</td>
<td>g/l</td>
</tr>
<tr>
<td>Zn</td>
<td>150</td>
<td>50-60</td>
<td>g/l</td>
</tr>
</tbody>
</table>

At the start of the development work, the emissions from conventional cooling towers were measured and found to be over 1500 kg/a of Zn and over 5000 kg/a of H$_2$SO$_4$. This represents a significant amount of acid and product losses, contributing to a detrimental effect on the environment, people and plant equipment around the cooling towers. Other metallic components are also released with the drift loss, as the amount of solution released is approximately 27 m$^3$/year.

Direct emissions from the solution cooling tower are the result of drift loss through the gas outlet, i.e. solution droplets exiting the tower. The tower outlet is equipped with demisters to remove the droplets, the most commonly used being vane-type demisters. The vane demister utilizes the momentum of the droplets in the gas flow, causing them to collide with the vanes and thus be removed from the gas flow. Mesh type demisters that are used in water cooling towers could offer higher efficiency, but they very difficult to clean and easily blocked.
There are usually two layers of demisters. The first one is a coarse layer for removing larger droplets, and the second one is a fine layer for removing smaller droplets with smaller spaces between the vanes. The larger caps in the first layer also allow the demister to be cleaned easily.

When air flows vertically through the demister out of the tower, the drainage of droplets out of the demisters is countercurrent to the gas flow as seen in Figure 3. With the vertical demisters used in the traditional cooling towers, the limiting gas velocity, i.e. the breakout point out of the cooling tower, is approximately 5-6 m/s (2). The breakdown point of the demister is a function of the gas and liquid flow rates into the demister.

With horizontal demisters, the velocity out of the cooling tower can be increased to as much as 8 m/s before the breakout point is reached, with some horizontal demister types reaching 10 m/s (3). In the horizontal demisters the drainage is perpendicular to the flow. In some research done with demisters, lower values are also given, but these seem to include extreme liquid flow rates and demisters not equipped with “hooks” that help prevent the liquid from re-entering.

In Figure 4 (below) the cut-out size of generic vertical and horizontal flow demister is shown. This states the largest particle that can get through each type of demister. In both cases the spacing between the vanes is the same. Figure 5 (below) presents the measurement results from Outotec’s internal measurements of a traditional cooling tower that shows the droplet size distribution before the demisters. These measurements are based on the measured droplet distribution after the demisters and then calculated backwards to obtain the distribution before the demisters. Due to the nature of the calculation, droplets over 38 micrometers in size are not shown here. As can be seen from the graph, the ability to drop the maximum droplet from 35 micrometers to or less than 20 micrometers has quite a substantial effect on the released emissions.
The removal efficiency of demisters tends to raise as the velocity of the gas through the demisters rises. The capacity of the demisters is usually set by the critical liquid and gas rates. If the demister operates above these limits, the efficiency of liquid removal begins to decrease. This gives cooling tower with horizontal demisters the following distinct advantages: the droplet separation efficiency is higher, and the cooling efficiency/demister area is higher due to the greater air/demister area.
In addition to the demister technology, the new cooling tower construction has also been developed to allow the airflow through the tower to be distributed as evenly as possible. This enables an evenly distributed gas flow to the demisters. In some traditional tower designs the gas flow can be quite unevenly distributed, leading to higher velocities in certain demisters and lower velocities in others. This causes the demisters to operate outside the optimal range.

4 Outotec® Solution Cooling Tower CFD model

During the development of the new cooling tower a three-dimensional computational fluid dynamics (CFD) model was developed. ANSYS Fluent software was used for the calculations to solve the three-dimensional calculation grid. The model has been validated to work in both a steady state and transitional mode. First a reference model was created and validated with measurement data from the site.

The model makes it possible to evaluate the cooling efficiency of the tower in different operating conditions. Depending on the required solution, the temperature gradient over the cooling tower and local atmospheric conditions, the amount of liquid can vary significantly in different cases. It is therefore very important to select the correct flow through the tower to avoid over or under dimensioning.

In addition to capacity estimates, it is possible to evaluate the flow patterns and droplet behavior inside the cooling tower. Currently the Outotec calculation model does not support the modeling of the film cooling of the solution at the cooling tower walls and curtain. For each case a series of calculations is performed to estimate the effect of ambient and operating conditions and fine the optimal cooling tower solution.

5 Testing Methods for the Solution Cooling Tower

To analyze the performance of the installed cooling tower, two factors are measured: the cooling efficiency of the cooling tower, and the amount of emissions from the cooling tower.

5.1 Testing the Cooling Efficiency

Testing the cooling efficiency of the cooling tower is straightforward. The environmental conditions are noted down along with the solution flow, fan speed, inflow temperature and outflow temperature of the solution. This data is then compared to the estimated cooling efficiency to confirm the accuracy of the estimate. In addition to the cooling efficiency, flow and temperature profiles were measured from accessible positions.
5.2 Measuring the Emissions from the Cooling Tower

Measuring the direct emissions from the cooling tower is more challenging. There are various ways to test the drift loss from the cooling tower. The methods used for the measurements are divided into two main groups: droplet size distribution measurement techniques, and total drift mass measurement techniques. (4)

In the tests relating to the Outotec cooling tower, the sensitive paper method (a droplet size distribution method) was used. This method was selected based on a literature review and time constraints that did not allow use of other testing methods. The articles reviewed suggested that the sensitive paper method is reasonably accurate compared to other methods. The literature study made by Lucas et al. (5) estimated that the sensitive paper method can be used to measure the drift loss from a water cooling tower and is especially useful in low water loading conditions, such as the cooling tower application measured here.

An added benefit of using droplet distribution techniques, such as the sensitive paper method, is that the droplet size distribution can be estimated. The droplet size measurements can also be used to validate that the demister can achieve the estimated droplet separation efficiency.

5.3 Test Results from First Commissioning

Cooling tower tests were carried out at Grupo Mexico’s IMMSA zinc plant site in San Luis Potosi. The tested cooling towers are used in spent electrolyte cooling. The model used is the Outotec Cooling Tower 6000.

5.3.1 Measured Cooling Efficiency

The cooling efficiency was found to be in good agreement with the CFD model used in the dimensioning. Some additional research work and dimensions are required to further enhance the estimate accuracy of the model. Below is presented the actual measured cooling efficiency of the electrolyte tower compared to the calculated efficiency with the calculation model. The average difference between outlet temperatures of the model and actual case was ±3.3 %. With higher fluid flows the model overestimated the cooling and with lower flow underestimated it. Figure 6 presents four different operational points for the cooling tower. Two different flow regimes were used, and two different environmental condition points were observed.
5.3.2 Comparing the Outotec Cooling Tower to Conventional Designs

The Outotec cooling tower was also compared to the locally used conventional cooling tower design. Actual site data was obtained, the conventional cooling tower was modeled, and authentic measurement results were compared.

The end result is that at the time of the comparison, the Outotec cooling tower was able to process 68 % larger flows than the conventional cooling tower while the fan was not working at full capacity, and the temperature gradient achieved with the tower was 82 % larger. With full fan power it is estimated that the Outotec cooling tower can achieve a temperature gradient over four times better than that achieved with the conventional design, while the flow is 68 % larger. Table 2 compares the cooling efficiency of three conventional towers to one Outotec cooling tower.
Table 2: The cooling efficiency of three conventional cooling towers compared to one Outotec cooling tower

<table>
<thead>
<tr>
<th>Item</th>
<th>Outotec</th>
<th>Traditional towers, IMMSA</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Towers</td>
<td>1</td>
<td>3</td>
<td>pcs</td>
</tr>
<tr>
<td>Cross sectional area (^2)</td>
<td>28.3</td>
<td>58.8</td>
<td>m(^2)</td>
</tr>
<tr>
<td>Solution feed</td>
<td>750</td>
<td>1370</td>
<td>m(^3)/h</td>
</tr>
<tr>
<td>Fan speed</td>
<td>62 %</td>
<td>67 %(^1)</td>
<td></td>
</tr>
<tr>
<td>(\Delta T)</td>
<td>4.2</td>
<td>3</td>
<td>°C</td>
</tr>
<tr>
<td>Cooling Power</td>
<td>4.55</td>
<td>5.93</td>
<td>MW</td>
</tr>
<tr>
<td>Cross sectional cooling efficiency</td>
<td>0.16</td>
<td>0.10</td>
<td>MW/m(^2)</td>
</tr>
<tr>
<td>Relative cooling potential 1vs1 (fan 100%)</td>
<td>249 %</td>
<td>100 %</td>
<td></td>
</tr>
</tbody>
</table>

**Notes**

1. One fan of the conventional towers was not operational, other 2 at 100 %
2. Cross sectional area is the free flow area inside tower horizontally

5.3.3 Measured Emissions from the Cooling Tower

During the cooling tower start-up, measurements using the sensitive paper method were made. Due to the time constraints, longer duration measurements with a larger sampling were not performed. During these preliminary measurements it was observed that, after the coarse demister, some droplets were visible in the paper, but after the fine demister no droplets were visible. This leads to the conclusion that the emission level of the Outotec cooling tower’s air discharge flow is below the detection limit of the applied measurement technique. Therefore, no further measurements were performed since a new measurement technique would need to be applied for testing the Outotec cooling tower.

However, comparative qualitative measurements were also made with the local conventional towers in which clearly detectable emissions levels were observed with the same exposure time. In addition, it was noted that the measured emission level of the conventional cooling tower is highly dependent on the measurement point. Due to the nature of the vertical demister package installation, gas flow tends to channel to the gaps between demister elements. Droplet emissions in channeling flows are so high that discharged droplets can be visually observed. The channeling flow is eliminated in the Outotec cooling tower due to the tight demister installation and large demister elements.
5.4 Performance of the New Cooling Towers at the IMMSA Plant

Before the start up of the new Outotec cooling towers, the flow rate fed to the cells was between 6.5 to 7 cubic meters per hour. The feed temperature to the cells used to be 36 to 38 °C and the outlet temperature between 40 to 44 °C. Most of the time nine towers were in operation and one was out for cleaning and maintenance.

Currently, the flow rate fed to each cell is between 8.5 to 9 cubic meters per hour with the two Outotec cooling towers and five old towers in operation. The inlet temperature to the cells is 31 to 33 °C and the outlet temperature is 34 to 36 °C. Several housekeeping tasks in the cell house activities are being done in parallel with the operation of the new cooling towers, so the quality and productivity of the electrolysis have improved in several aspects. The physical quality of the cathodes is better with a very smooth surface. The lead content in the melting furnaces has been reduced from an average of 28 ppm to currently 12 ppm. More time is needed to evaluate the improvement in performance of other important operational indicators.
One important aspect is that, after the first inspections inside the tower, the dynamic wall remains clean. This will represent an increase in the availability of the equipment and minimize the need for the time-consuming and risky activity of cleaning the walls.

6 Conclusions

The Outotec® Solution Cooling Tower design with horizontal gas outlets has been developed for the task of solution cooling. During the first commissioning at the IMMSA zinc plant in San Luis Potosi, Mexico, measurements were made of the new cooling tower type to validate the CFD modeling used in the development of the new tower type. Based on the results, the model gives estimates that are in close relation with the actual cooling results, but some additional work is still to be done with the model to enhance the accuracy of the estimation.

The new demister arrangement combined with optimized airflow inside the cooling tower achieves much higher droplet separation efficiency compared to traditional towers. This was also observed in measurements taken during commissioning. The effect on the emissions from the cooling tower installation can be considerable when compared to the traditional cooling tower installation with vertical outflow cooling towers.

With the first commissioning of the Outotec® Solution Cooling Tower 6000, vertical gas discharge and tangential gas feed were successfully applied for the first time to electrolyte cooling. The measured cooling efficiency and emission levels of this new cooling tower are superior compared to the conventional technology. In terms of sustainable development, the Outotec cooling tower should be considered the Best Available Technology (BAT) for cooling environmentally harmful solutions with direct contact between the cooling air and the solution.

References

[1] Internal Outotec Documentation