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Evaluation of drift and salt deposition from a natural draft seawater cooling tower. Part II: Field monitoring

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ABSTRACT

In the present paper, environmental impact of drift and salt deposition from an oversize hyperbolic natural draft seawater cooling tower in a power plant was conducted by field monitoring. This seawater cooling tower was in a closed-cycle cooling system which has high salt concentration about 1.5–2.0 times original sea water salinity. Considering the impact of regional scope, suitable field monitoring positions with wet deposition field monitoring method was set according to early SACTI analytical research results. 3-D salt deposition contour map of four seasons was drawn according to monitoring results. In most area of the plant, salt deposition flux is more than 1 g/(m^2 month), where most plant leaves in growing period will hurt, and the maximum salt deposition flux is more than 14.71 g/(m^2 month) forming potential environmental hazards. Necessary measures should be taken such as changing efficient eliminator or reducing salt concentration of circulating seawater. Therefore, a drift salt deposition analysis before design is necessary for choosing a suitable eliminator to meet environmental requirement.

Keywords: Seawater cooling tower; Closed-cycle cooling; Salt deposition; Field monitoring; Wet deposition

1. Introduction

Natural draft cooling towers constitute an energy-efficient solution for the dissipation of waste heat from power plants, air conditioning and industrial processes by means of water evaporation. Since 1970s, seawater cooling tower has been used in coastal facilities across the globe for saving fresh water. Seawater goes through cooling tower once or recycled, namely once-through cooling and closed-cycle cooling. Once-through cooling requires a significantly greater amount of water than closed-cycle cooling to be withdrawn from a water body, passed once through the power plant to capture waste heat and then discharged back into a water body [1]. As the growing demands for electricity plant cooling water and potential regulatory [2] developments, closed-cycle cooling with seawater cooling tower has become a promising technology for saving fresh water and protecting marine ecological environment. However, droplets, entrained along the vaporing water plume from seawater cooling tower in closed-cycle cooling system which has 1.5–2.0 original sea water salt concentration, is objectionable for several reasons [3]. Salt deposition around the cooling tower is major concern for high salt concentration seawater in closed-cycle cooling system especially oversize hyperbolic natural draft seawater cooling tower. The salt deposition condition of natural draft seawater cooling towers can be investigated by computational fluid dynamics (CFD) simulation, analytical mathematical model such as the seasonal/annual cooling tower impact (SACTI) model and full-scale field monitoring. Due to recent development in CFD techniques, environmental assessment of cooling tower salt deposition [4–7] has been carried out using CFD method, yielding predictions of more detailed accurate plume behaviors. Although CFD simulation has many advantages, it also suffers from high professional requirements and verifying difficulties, still in the

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exploratory stage of drift salt deposition research. The SACTI model has been calibrated and validated using an extensive US and European database on cooling tower plumes and drift by Policastro et al. [8]. It has been widely used in developing environmental reports required for combined construction and operation licensing application of power plants due to its low cost for the analysis and conservative results for licensing [9–11]. However, the SACTI model assume that the impact is conducted only at ground level; the topography of the site is flat; applied to an area near cooling towers; and the exit ports of the cooling towers have the same height. Obviously, there are no plant accords with assumption, which restricted the accuracy of SACTI model. Though has expensive cost, field monitoring for predicting the drift and salt deposition is the most accurate and reliable method. Jallouk et al. [12] investigate drift and deposition condition of K-31 and K-33 mechanical draft cooling tower at the Oak Ridge Gaseous Diffusion Plant (ORGDP) by introducing chemicals in circulating water system. The results show that drift and deposition are not causing any adverse effect on the native vegetation surrounding ORGDP under that operating conditions. Davis [13] investigates the drift and deposition of a natural draft cooling tower of Potomac Electric Power Company's generating station at Chalk Point, Maryland, by field monitoring. The natural draft cooling towers were in use saline water once-through cooling system. The final report concludes that effects of drift salt loading on soils and crops are expected to be negligible at off-site locations. These two projects provide valuable validate data for most simulated models. Nevertheless, these field monitoring experiments were conducted in the 1970s, the natural draft seawater cooling tower become larger and larger, need is urgent for the environmental impact of salt deposition of oversize natural draft seawater cooling tower. Few efforts were made to understand the drift and salt deposition of oversize hyperbolic natural draft seawater cooling tower in closed-cycle cooling system with higher salt concentration.

In the present study, environmental impact of drift and salt deposition from an oversize hyperbolic natural draft seawater cooling tower cooling in closed-cycle cooling system was evaluated by field monitoring. The study was conducted in a power plant in eastern China. Considering the impact of regional scope, suitable field monitoring positions with wet deposition method were chosen according to early SACTI analytical research results. 3-D salt deposition contour map of four seasons was drawn according to monitoring results. The results were analyzed and compared with NUREG-1555 [14].

2. Field monitoring setup and procedures

The natural draft seawater cooling tower located in gulf of eastern China. The surroundings and terrain are shown in Figs. 1 and 2. The parameters of cooling tower are shown in Table 1. A grid type eliminator was set upon the water distribution system. For the cooling tower located in an area with different seasonal weather conditions which vary greatly, typical month of each season such as April (spring), July (summer), October (fall), December (winter) were chosen during monitoring process.

11 field monitor positions were set in wet deposition method to evaluate the drift salt deposition distribution. Fig. 3 shows the salt deposition field monitoring positions of fall. Field monitoring positions were set according to SACTI analysis results with a blank monitoring position (11#) 15 km away from the cooling tower shown in Fig. 4. More positions were set in the areas of severe salt deposition and the predominant wind direction to understand the attenuation of salt deposition. Distance between seawater cooling tower and monitoring positions range from 0.5 to 10 km. Similar field monitoring method was adopted considering both field situation and SACTI results in the other field monitoring. Three PE circular plastic buckets with a diameter of 0.3 m and height of 0.3 m, having 1 L distilled water, were used in a field monitoring position to collect drift salt for 15 d. Meanwhile, distilled water was replenished whenever the distilled water height below 1.0 cm. PE plastic buckets, maintained level,

Fig. 1. Surrounding terrain of the cooling tower.

Fig. 2. Cooling tower and surroundings.

Table 1
Parameters of seawater cooling tower

Parameter	Value
Fill area (m^2)	13,000
Cooling tower height (m)	177.2
Outlet diameter (m)	79
Heat dissipation rate (MW)	2,404.8
Circulating water flow (t/h)	100,000
Total air flow rate (kg/s)	30,720
Salt concentration of cooling water (‰)	46

were placed at an open and unsheltered platform, with the top distance of 1.5 m away from the ground. Inspection of distilled water was made to get chloride concentration at the end of field monitoring. Three titrations were made for each sample to reduce the analytical error. The value of salt deposition was calculated by chloride concentration multiplied by deionized water volume, characterized by salt deposition value per square meter per month.

To measure the ambient conditions during the field monitoring, a 40 m tall meteorological tower located in open area of the plant is used. During the monitoring time, the meteorological data (wind direction, velocity, temperature and relative humidity) is under collection. The meteorological tower is equipped with three wind anemometers, three wind vanes and three thermo hygrometers located at two different heights, 25 and 40 m. Consequently, forecast sources are used to select the most suitable period to carry out the field monitor and avoid extreme weather such as typhoon and rain. The meteorological conditions during the four test periods are shown in Table 2.

3. Results and discussion

3.1. Comparison between SACTI and field monitoring

Fig. 5 presents the results from field monitor and SACTI model of four seasons. It is remarkable to note that the simulated salt deposition is in good agreement between the field monitoring and SACTI data. There are deviations between most field monitoring positions. This is because the monitor positions located local complex airflow field formed by some huge buildings and mountains, drift droplets were affected greatly by the airflow field. Therefore, SACTI codes are less suitable when taller structures and buildings influence significantly. These errors show that the plate flat assumption of SACTI model restricts the accuracy of salt deposition in complex terrain plant. Field monitoring for predicting the drift and salt deposition is still the most accurate and reliable method.

3.2. Field monitor salt deposition distribution

The two cooling tower centers were set as origin of coordinates, and relative longitude as abscissa, relative latitude as ordinate. Salt deposition contour maps were made according to field monitor results.

Fig. 6 presents the salt deposition distribution of seawater cooling tower of spring. It can been seen that the monthly salt deposition of all monitor points is larger than

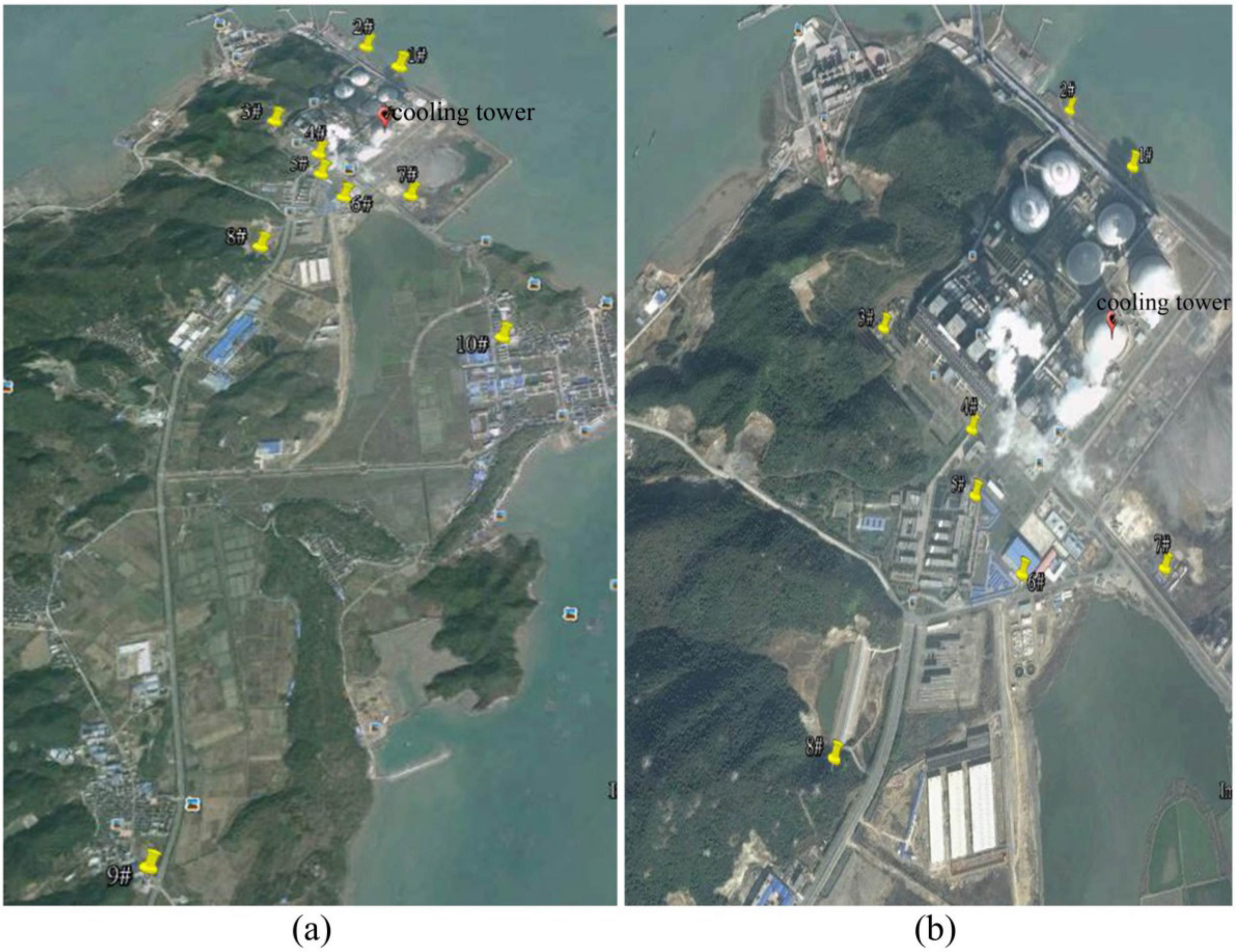

Fig. 3. Field monitoring positions of fall (a) original map and (b) local magnifying map.

1 g/(m^2 month). Salt deposition distribution shows a slowly rising slope shape, as wind direction focus on one direction and wind speed distributed uniformly. The maximum monitor point located 532 m away from the cooling tower in the north direction with a value of 12.58 g/(m^2 month). Moreover, the salt deposition value increases as the distance from the cooling tower increase in north direction. However, it shows opposite trend in southern direction. This is because the predominant wind direction in the southern direction of spring, and drift droplet was blow to north by wind with the plume. Drift droplets drop off gradually to the ground from hundreds of meters sky. Therefore, the salt deposition in the north of the cooling tower will have a maximum value in a certain range. The average salt deposition value of the plant is 5.23 g/(m^2 month). The salt deposition mostly distributes in the north area of the seawater cooling tower, and the value of southern area is smaller.

Fig. 7 presents the salt deposition distribution of seawater cooling tower of summer. As it can be seen that, the severe salt deposition area is mostly located in NNW direction as the predominant wind direction is S. The maximum value of salt deposition in north direction is 8.12 g/(m^2 month) with a distance of 733 m. The average salt deposition value of the plant is 2.1 g/(m^2 month). Both the average salt deposition value around the plant and maximum value of salt deposition of summer are lower than spring. Moreover, the maximum salt deposition monitor position is far away from cooling tower. It can conclude that with a higher ambient temperature, ground deposition was lower as was also the zone affected by the cooling tower. A high level of ambient absolute humidity increased ground water deposition and the radius of the drift dispersion area. Regarding the last variable, a high level of droplet output temperature decreased ground water deposition but increased the size of the zone affected by the cooling tower because droplets with a higher temperature at the tower exit arrived at the wet bulb temperature with a smaller size, which made them travel further. These phenomena were also revealed in a study by Lucas et.al. [3] CFD mathematical model research.

Salt deposition distribution of fall is shown in Fig. 8. The severe salt deposit area is mostly located in south direction as the predominant wind direction is NNW. The maximum salt deposition value at the most impacted point about 620 m SSE direction of the tower is 9.70 g/(m^2 month). Salt deposition is more concentrated in a center area as the "peak" of map is sharper. The value of salt deposition decreased significantly, five monitoring positions was less than 1 g/(m^2 month). The average value of salt deposition in fall was 1.5 g/(m^2 month).

Fig. 4. Blank field monitoring position 11#.

Table 2
Meteorological condition during field monitoring

Season	Average temperature (°C)	Average humidity (%)	Predominant wind direction	Average wind speed (m/s)
Spring	17.60	50	SSW (191.26°–213.75°)	4.8
Summer	27.60	70	S (168.76°–191.25°)	4.5
Fall	22.30	57	NNW (326.26°–348.75°)	4.9
Winter	7.90	74	NNW (326.26°–348.75°)	6.0

Fig. 9 presents the salt deposition distribution of seawater cooling tower of winter. The severe salt deposition positions mainly concentrated in the SSW direction, which is mainly due to prevailing northerly winds in winter, carrying the drift also landed in the south direction. The maximum value is 14.7 g/(m^2 month) with a distance of 620 m in the SSE direction. Salt deposition mostly distributed in plant zone. Although, salt deposition in the southeast direction is large, the salt deposition decreased with the increase of the distance, the value of salt deposition is nearly zero as the distance more than 5 km.

3.3. Salt deposition comparison of different seasons

Comparing these four salt deposition contour maps, it can be seen that the salt deposition is closely related to the wind condition, thus the severe salt deposition area is located in the predominant downwind direction. In spring and summer, southerly wind results in droplet drift in the north parts of the cooling tower. On the contrary, severe salt deposition areas of fall and winter concentrate in south direction. The values of average and maximum salt deposition of four seasons are shown in Table 3. The maximum salt deposition value appears in winter and the maximum salt deposition position is closest to the cooling tower. As both wind frequency and speed of winter is more centrally distributed. Salt deposition mostly falls to one area along drift with the combined effect of higher humidity and lower temperature. Drift droplet diameter was influenced by evaporation, furthermore influence the fall distance. Thus, maximum salt deposition position distance of summer and winter is close as the combine effect of similar humidity and speed.

According to Standard Review Plans for Environmental Reviews for Nuclear Power Plants: Environmental Standard Review Plan (NUREG-1555) from United States Nuclear Regulatory commission:

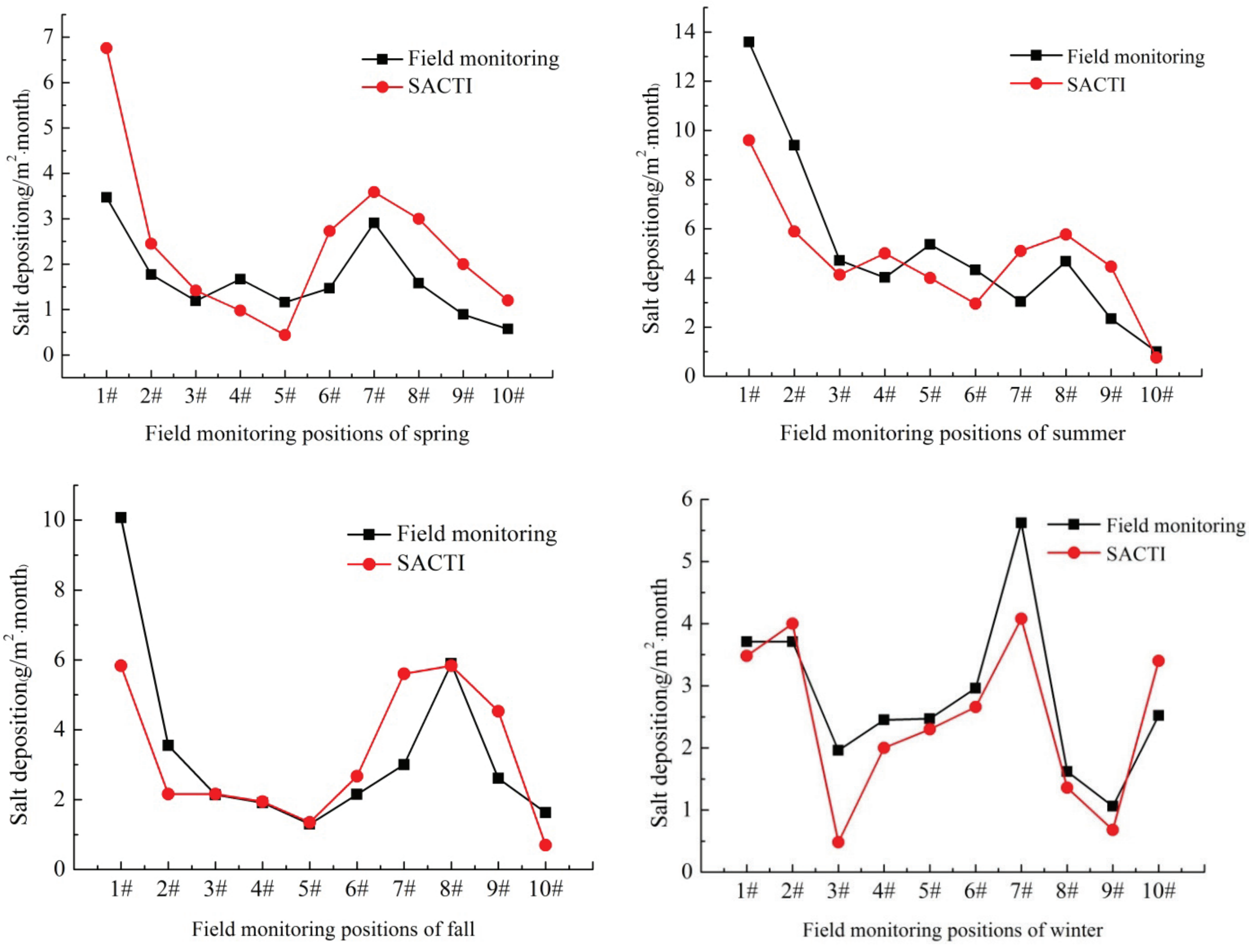

Fig. 5. Result comparison between the field monitoring and SACTI.

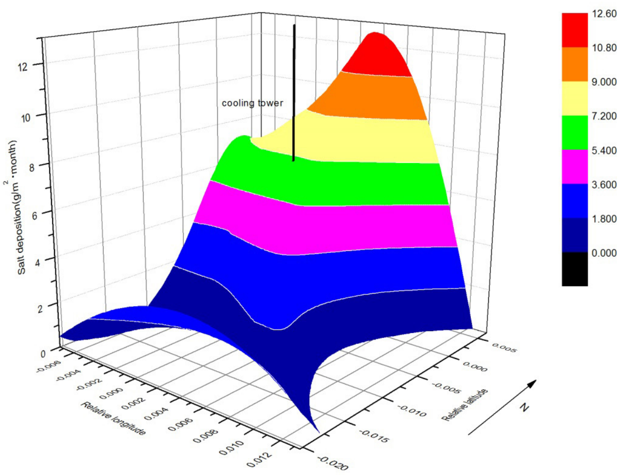

Fig. 6. 3-D salt deposition contour map of spring.

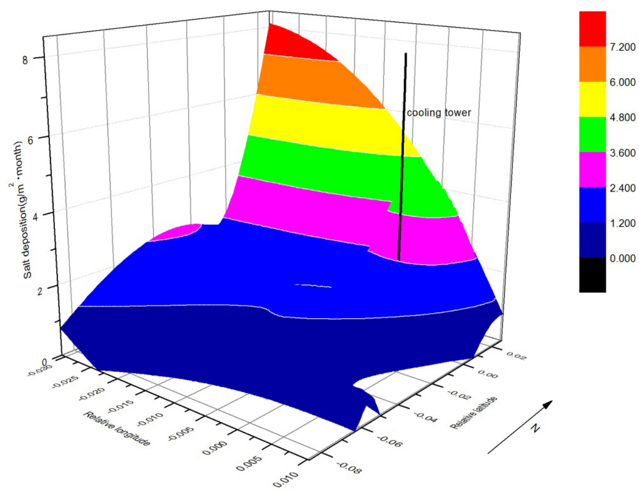

Fig. 7. 3-D salt deposition contour map of summer.

When salt deposition flux is 0.1–0.2 g/(m^2 month), plant will growth normally;

When salt deposition flux is close to or more than 1 g/(m^2 month), most plant leaves in growing period were hurt;

When salt deposition flux is more than 10 g/(m^2 month), with the combine consideration of ecosystem and equipment corrosion, either reduce salt concentration of circulating water or change tower design should be done.

As shown in Table 3, average salt deposition flux of all seasons is more than 1 g/(m^2 month), where most plant leaves in growing period were hurt. Meanwhile, the maximum salt deposition flux of winter is more than 14.71 g/(m^2 month) forming potential environmental hazards. Necessary measures should be taken such as changing efficient eliminator and reduce salt concentration of circulating water.

The seawater cooling tower gas flux and drift change by temperature difference inside and outside cooling tower. As the severe of temperature difference the greater the gas flow rate and entrained liquid droplets. The drift droplets freely fall with the wind at the combined influence of evaporation and cooling, consequently causing droplet volume change, which influence the distance of salt deposition

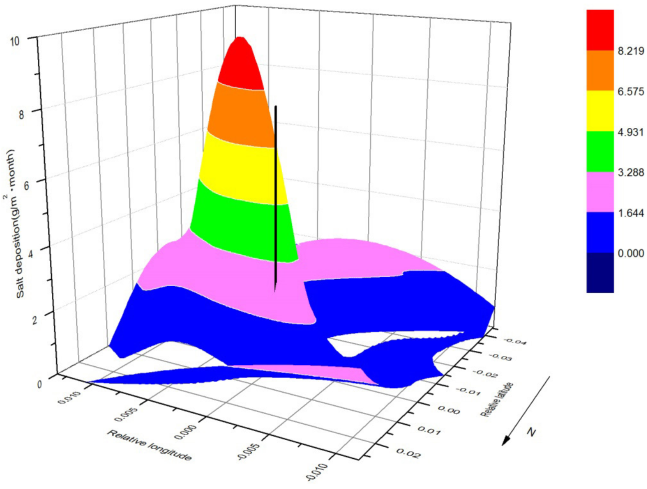

Fig. 8. 3-D salt deposition contour map of fall.

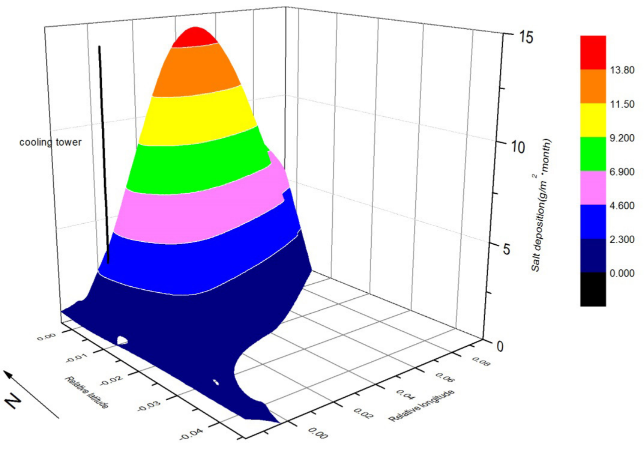

Fig. 9. 3-D salt deposition contour map of winter.

area. The larger droplets fall more rapidly causing a larger deposition rate. Besides, wind distribution around big building is not the same as usual, wind speed is always severe at top and side, making salt deposition hard, resulting in lower salt deposition value.

Cooling tower drift is restricted to a certain value in actual application without consideration of wind direction and speed. However, the salt deposition environmental influence always concentrates in areas where drift droplets fall down with wind causing salt deposition problem. Thus, a general wind and local gas flow around big building analysis is urgent before cooling tower design. An efficient drift eliminator should be chosen when either the wind direction focus or the speed is similar. On the contrary, a usual drift eliminator should be adopted to reduce pressure drop.

4. Conclusion

In this work, salt deposition characteristics of an oversize hyperbolic natural draft seawater cooling tower in closed-cycle cooling system was studied by means of field monitoring. Field monitoring positions were set according to early SACTI analysis results with a blank monitoring position. It is remarkable to note that the simulated salt deposition trends was in good agreement between the field monitor and simulated data, but limited absolute value accuracy. According to monitor results, contour maps of salt deposition of four seasons were drawn. Comparing these four salt deposition contour maps, the salt deposition is closely related to the wind direction, and the severe salt deposition area is located in the predominant downwind direction. The maximum monitoring results located in a certain distance of downwind direction, as drift droplet come from the top of cooling tower, they were blown away with plume by wind, eventually landing to the ground. In most area of plant, salt deposition flux of all positions are more than 1 g/(m^2 month), where most plant leaves in growing period were hurt, and the maximum salt deposition flux is more than 14.71 g/(m^2 month) forming potential environmental hazards. Necessary measures should be taken such as changing efficient eliminator and reduce salt concentration of circulating water. A drift salt deposition analysis before design is necessary for choosing a suitable eliminator satisfying environmental requirement and reducing operation cost. The calculation and field monitoring results provide valuable guidance for further application of seawater cooling tower.

Table 3
Comparison of salt deposition of four seasons

Season	Average salt deposition flux g/(m^2 month)	Maximum salt deposition flux g/(m^2 month)	Maximum deposition position relative coordinates	Maximum deposition position relative distance
Spring	4.85	12.58	(0.003310, 0.006510)	0.0073
Summer	1.54	8.12	(–0.03073, 0.02704)	0.041
Fall	1.50	9.70	(0.004436, –0.008918)	0.0099
Winter	1.15	14.71	(0.03629, –0.004420)	0.036

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