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Development of Efficient Process Cooling Water Treatment Technology

YING-CHIEH LIU and MAO-SUNG YEH

Green Energy & System Integration Research & Development Department
China Steel Corporation

China Steel Corporation (CSC) and Dragon Steel Corporation (DSC) are integrated steelmakers. High-temperature equipment of the integrated steel mills requires a large amount of process water for cooling and removal of dust and rust. To ensure water safety and smooth production, the development of process cooling water treatment technology is necessary. It requires the formulation of improvement strategies and the establishment of operational guidelines based on specific cooling issues at different sites using key technologies. The R&D team has developed key technologies such as descaling, scale prevention, sterilization, and oil removal. The technologies are tailored to the specific needs of the production lines for important processes such as blast furnaces, converters, billets, and electric furnace steel plants. Through field testing and verification, significant improvements have been achieved and gained on-site approval, thereby achieving the goal of cost reduction.

Keywords: De-scaling, Scaling prevention, Sterilization, Oil removal

1. INTRODUCTION

CSC and DSC are integrated steelmakers. High-temperature equipment requires a large amount of process water for cooling, dust removal, and rust prevention. Processes such as blast furnaces, converters, billets, and electric furnace steel plants are critical, and any abnormalities significantly impact production.

The three major challenges often encountered in process cooling water treatment are scaling, corrosion, and algae growth. Scale deposition causes many technical and economic problems in industrial plants because of the poor efficiency of equipment. The use of chemical agents is low-cost and easier to gain access to surfaces or places beyond the reach of physical removal methods[1,2,3]. Corrosion can lead to critical equipment or pipeline damage. Algae growth causes many serious problems in industrial plants by blocking the flow of water on nozzles or cooling facilities.

At CSC there were scaling problems on the Top Gas Pressure Recovery Turbine Fans (TRT fans) in the No.2 Blast Furnace (BF) facility and the Induced Draft Fans (ID fans) in the No.2 Blast Oxygen Furnace (BOF) facility[4,5,6]. The TRT fans and ID fans were not efficient due to scale deposition. At BF, the TRT equipment used for gas recovery and power generation required a vibration level below 100 μm within 3 years to prevent damage. However, the field vibration level increased from 15 μm to 90 μm within a year by cleaning blades with spraying water and needed off-line cleaning, thereby affecting power generation. The scale deposition was analyzed, and a more suitable scaling inhibitor from Cinyea DP201 was selected. The dosing concentration needed to be increased from 14 to 20 mg/L for better effects. For reducing blade fouling, the suspension solid (SS) concentration in spraying water needed to be reduced from 20 to less than 1 mg/L. With the application of the two approaches, the vibration level of TRT fans could be reduced.

The ID fans at the BOF facility are important equipment for generating power. They also had scale problems even with the use of a scaling inhibitor from GE. The scale problems of ID fans led to increasing vibration levels from 10 μm to 60 μm within 2 months of operation and needed an 8-hour sandblasting treatment, thereby making the ID fans consume more operating power. The scale deposition was analyzed, and a more suitable scaling inhibitor from Ecotek T-221 was selected. On the other hand, the three ID fans with 3D-type blade structures at the BOF plant were prone to fouling. After switching to the 2D-type planar blade structure, anti-scaling dispersants could fully exert their dispersing effects, thereby preventing scale problems. Furthermore, for reducing blade fouling, the suspension solid (SS) concentration in spraying water could be reduced from 50 to less than 25 mg/L by dosing cationic polymer

0.5~1.0 mg/L in a sedimentation tank. After using a new scaling inhibitor and improving the spraying water quality, the maintenance frequency was reduced from 6 times to 2 times per year.

At BF, the closed-loop cooling water used soft water (SW) to cool production equipment such as tuyeres, blowpipes, hot blast valves, and cooling plates. BAC coolers are the main equipment for reducing the temperature of SW. At No. 2 Blast Furnace, most of the BAC coolers had scale problems and heavy algae and microbial growth on the tubes, thereby leading to poor cooling efficiency[(7)], especially models #2 and #3. Therefore, adopting a strategy of adding 200 kg of chlorine tablets for algae eradication and disinfection is necessary. The scale component was analyzed, and a more suitable de-scaling agent from Ecotek CT-89 600 kg was selected. With the application of the two approaches, the heat exchange efficiency could be enhanced.

The continuous casting machine for flat steel billets used a large filter screen (strainer) to clean the process cooling water, preventing blockages in production machinery, and ensuring smooth operation. The target flow rate of process cooling water is required to be 450 liters/min for production. Severe clogging problems of the large strainer led to the flow rate below 100 liters/min. As a result, the frequency of maintenance escalated to 1 month abnormally from 6 months, which required shutdowns for repair. Additionally, nozzles in the secondary cooling zone also had severe clogging problems, which led to uneven water curtains, significantly impacting the thermal transfer efficiency of the slab. The two factors could adversely affect both the production output and quality of the slab. The analysis of the clogging material revealed that the component included 70% of organic matter and 30% of inorganic matter. The organic matter consisted of microbial slime, whereas the inorganic matter resulted from the overflow of filter media in the upstream sand filters. Both are the main causes of the insufficient spraying water volume in the continuous casting machines. The filter media leaking from the damage of the sand filter needed to be promptly shut down for repair. Subsequent testing of the water quality from the remaining 11 normal units of sand filters revealed that the suspension solid (SS) of supply water decreased from 50 mg/L to 1.2 mg/L, meeting the regulatory standard of 15 mg/L. The clogging material was analyzed, a more suitable Sodium hypochlorite (NaOCl) was selected as a water disinfectant, and the dose concentration from supply water needed to be increased from 0.1~0.3 to 0.5~0.6 mg/L for better effects. At the secondary cooling zone, applying an efficient bactericide strategy of the Ecotek CN50 50 mg/L could resolve the blockage of the filter and nozzles. As a result, the spraying water flow rate increased from 100 L/min to 450 L/min.

DSC Electric Furnace Steel Plant produced 1,200 tons of iron oxide scale annually but sold it at a low price. However, 0.4% of the oil content could not be accepted for external sales. To prevent iron oxide scale from stocking up in the plant, there was an urgent need to establish treatment technology for skimming floating oil from scale pits. Therefore, the selection of suitable oil skimming equipment was crucial[(8)]. After evaluation, the mop-type oil skimmer was found to be the most suitable online equipment. With off-line TW circulation washing technology, the oil content could be stabilized and reduced to less than 0.1%. After improvement, the iron oxide scale could be returned to the sintering plant for recycling and disposal.

2. EXPERIMENTAL METHOD

2.1 Scale Deposition Analysis and Scaling Inhibitor Selection

X-ray fluorescence (XFR) analysis was used to determine the component of scale deposition. Scaling inhibitors were selected from three commercial products based on the scale composition. A jar test was performed to determine the best scaling inhibitors from the selected candidates and the best dosing concentration. The scale deposition was filtered by the 35-mesh filter. 0.2 g of filtered scale powder was poured into a beaker. Each beaker was filled with 1,000 mL of distilled water. Selected scaling inhibitors with different dosing concentrations were added respectively into each beaker and stirred at 300 RPM for 5 minutes. The mixed solution was settled for 30 minutes, and the Zn concentration or turbidity was measured. The one that produced the highest Zn or turbidity after settlement was the most suitable scaling inhibitor and best dosing concentration.

2.2 Scale Deposition Analysis and De-Scaling Agent Selection

X-ray fluorescence (XFR) analysis was used to determine the composition of scale deposition. De-scaling agents were selected based on the composition of scale deposition. A jar test was performed to determine the best de-scaling agents from the selected candidates and the best dose concentration. 5.0 g of scale deposition was poured into a beaker. Each beaker was filled with 1,000 mL of distilled water. Selected de-scaling agents with different dosing concentrations were added respectively into each beaker and stirred at 100 RPM for 7 days. The mixed solution was settled for 30 minutes, and the calcium hardness was measured. The one that produced the highest calcium hardness after settlement was the most suitable de-scaling agent and the best dosing concentration.

2.3 Clogging Component Analysis and Efficient Disinfectant Selection

The 550°C high-temperature combustion method was used to determine the organic content of microbial biofilms on the larger strainer. X-ray fluorescence (XFR) analysis was used to determine the components of inorganic material. Disinfectants were selected from commercial agents. Based on practical experience in cooling water treatment, sodium hypochlorite (NaOCl) could be added at the supply water end to increase residual chlorine from 0.1~0.3 to 0.5-0.6 mg/L. This helps maintain residual chlorine levels of 0.1~0.3 mg/L when the cooling water reaches the large strainer and will be able to reduce bacterial counts and resolve the blockage issues. Besides, adding 10 mg/L of non-oxidizing biocide of Ecotek CN-50 in the secondary cooling zone prevents microbial growth on the surface of the filter and increases the spraying water volume.

2.4 Oil Content Analysis and Oil Skimmer Selection

The oil concentration in the water could be measured by solvent extraction method. A floating oil skimmer is a device that removes oil from the water surface. It uses a floating mechanism with an oil-attracting material to collect the oil, which is then scraped into a container separating it from the water. Commercial floating oil skimmers include disc-type, drum-type, belt-type, tube-type, brush-type, weir-type, and mop-type. Based on practical experience in water treatment, the mop-type skimmers with an oil removal capacity of 0.21 tons per hour are considered the best equipment due to their relatively low cost, as well as low operating and maintenance costs. Oil skimmers not only prevent the re-emulsification of floating oil into the water phase but also contribute to reducing the oil content of the iron oxide scale.

2.5 Field Test Assessments

The criterion to assess the scaling level of TRT fans was the vibration level that was required to be less than 100 um within 3 years. There were two criteria to assess the scaling level of ID fans including the vibration level and maintenance frequency of ID fans. The limitation of vibration level was 60 um, and the frequency of maintenance should be less than 3 times per year. The criterion to assess the de-scaling level of the BAC cooler was the cooling efficiency which was required to be higher than 70%. The criterion to assess the disinfection level of the filter screens was the clogging level that was required to be no microbial proliferation anymore. The criterion to assess the oil removal of iron oxide scale was the oil content level that was required to be less than 0.1%.

3. RESULTS AND DISCUSSION

3.1 Scaling Level Reduction of TRT Fans in No. 2 Blast Furnace Facility

To keep the vibration level of TRT fans below 100 μm within the 3-year limit, the scaling problems needed to be solved. XRF analysis showed that the main components of scale deposition were 71.81% of ZnO and 5.35% of Fe_2O_3 in Fig.1 and Table 1. Three commercial anti-scaling inhibitors were tested by the jar test method and Cinyea DP201 was found optimal with a dosing concentration of 20 mg/L. Two strategies were used to improve the vibration level of ID fans. First, the water pipeline was drained for 30 seconds every day to reduce clogging. After this improvement, the SS concentration in spraying water was reduced from 15~20 to less than 1 mg/L. Secondly, the concentration of Cinyea DP20 was increased from 14 to 20 mg/L. The effective dispersion of TRT fans could be assessed by monitoring the change of Zn and Fe concentration in the water after spraying.

Field tests showed that the vibration level increased

Fig.1. Scaling of TRT fans in No.2 Blast Furnace Facility.

Table 1 XRF analysis results of scaling on TRT fans and ID fans.

Scaling items	XRF analysis results
TRT fans	71.81% ZnO、5.35% Fe_2O_3、0.74% P_2O_5、0.19% CaO、0.11% SiO_2、0.06% TiO_2、0.05% MnO
#5 ID fans	88.5% Fe_2O_3、3.1% MgO、2.9% SiO_2、2.0% CaO

at a slower rate when the anti-scale inhibitor was switched to DP201 with a dose concentration of 20 mg/L. After improvement, the vibration level increased by less than 2 μm per year. The annual benefits from increased power generation exceeded ＄9.4 million NTD.

3.2 Scaling Level Reduction of #5 ID Fan in Blast Oxygen Furnace Facility

The higher vibration level caused the ID fans to turn at high speed, thereby consuming more operating power during the production of molten steel. To keep the vibration level of ID fans below the 60 μm limit, the scale problems needed to be solved. XRF analysis showed that the main components of scale deposition were 88.5% of Fe_2O_3, 3.1% of MgO, 2.9% of SiO_2, and 2.0% of CaO in Table 1. The jar test determined that Ecotek T-221 was the best dispersant for Fe_2O_3 powder from three selected candidates with a dosing concentration of 20 mg/L. Three strategies were used to improve the vibration level of ID fans. The 3D-type blades of the #5 ID fan were first replaced with 2D-type blades in Fig.2. Secondly, the concentration of Ecotek T-221 was increased from 15 to 20 mg/L. Thirdly, the SS concentration in spraying water was reduced from 50 to less than 25 mg/L.

Field tests showed that the vibration level was below 19 μm steadily and the uptime extended from 2 months to 6 months, thereby significantly enhancing steel production and increasing gas recovery. Afterward, the blades of #4 and #6 ID Fans were also replaced with 2D-type blades in 2021 and 2022 respectively. The annual benefits exceeded ＄10 million NTD.

3.3 Enhancing Cooling Efficiency of BAC Cooler in No.2 Blast Furnace

The BAC coolers had scale problems in Fig.3. The #3 BAC cooler had 34% of cooling efficiency, while the #2 BAC cooler had 43% of cooling efficiency. XRF analysis showed that the main components of scale deposition for the #3 BAC cooler were 85.2% of $CaCO_3$, 12.3% of Fe_2O_3, and 2.5% of $ZnSO_4$ in Table 2. After selecting three de-scaling agents for the test, the result showed that the de-scaling agents from Ecotek CT-89 were the best candidates for good dissolution of $CaCO_3$. Furthermore, the proliferation of algae and microorganisms on the nozzle was another critical factor that affected the cooling efficiency of the cooler. Therefore, it was necessary to add chlorine tablets first for algaecide and sterilization purposes before descaling operations in the Field. The best strategies were used to improve the cooling efficiency of the BAC cooler by adding 200 kg of chlorine tablets for algae removal and 600 kg of CT-89 for scale removal.

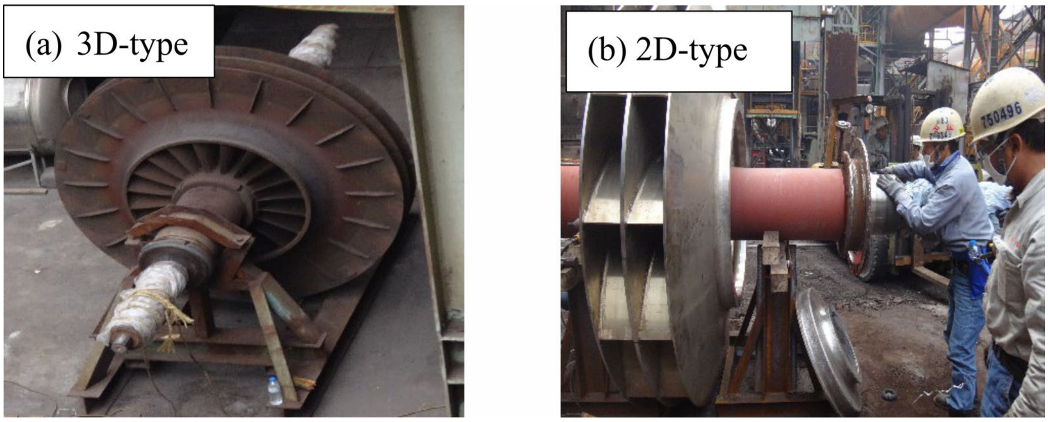

Fig.2. Comparison of 3D-type and 2D-type blade structure of #5 ID Fans.

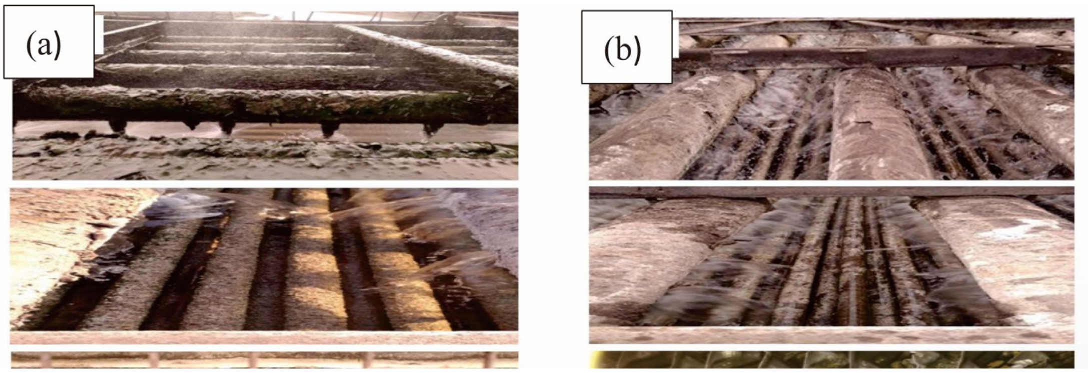

Fig.3. (a) Algal bloom and scaling on BAC cooler before and (b) after improvement.

Table 2 XRF analysis results of scaling on #3 BAC cooler.

Scaling items	XRF analysis results
#3 BAC cooler	85.2% $CaCO_3$、12.3% Fe_2O_3、2.5% $ZnSO_4$

The field test showed that the temperature differentials between inlet and outlet of soft water increased from 2.2℃ to 5.0℃, boosting the cooling efficiency of #3 BAC from 34% to 72%. Subsequent validation with the #2 BAC cooler yielded similar results. The annual electricity savings amounted to 210,000 kWh after improvement. The annual benefits exceeded ＄520,000 NTD.

3.4 Improving Sterilization Efficiency of Filter in Slab Continuous Casting Machine

The 550°C high-temperature combustion method and XRF analysis showed that the main organic matter constituted 70% and inorganic matter (SiO_2) constituted 30% of the large strainer. The organic matter was identified as bio-slime in Fig.4, while the inorganic matter was produced due to the overflow of filter media from the sand filter. Three strategies were used to prevent microbial growth. The first one was repairing the damaged sand filter to prevent continued leakage of internal filter media. Therefore, the SS concentration of supply water was reduced from 25 to less than 15 mg/L. The second one was increasing residual chlorine from 0.1~0.3 mg/L to 0.5-0.6 mg/L by adding sodium hypochlorite (NaOCl) at the supply water end. This helped maintain residual chlorine levels of 0.1-0.3 mg/L when the cooling water reached the large strainer, reducing bacterial counts and addressing blockage issues. The third one was adding 10 mg/L of non-oxidizing biocide CN50 in the secondary cooling zone to prevent microbial growth on safety filters and nozzles in Fig.5.

Field tests showed that the spraying water volume

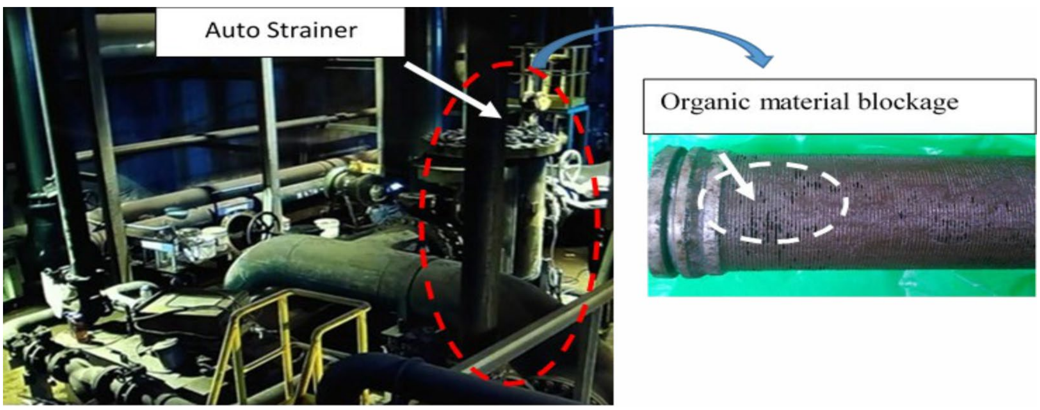

Fig.4. Appearance of Large Strainer and Organic Material Blockage.

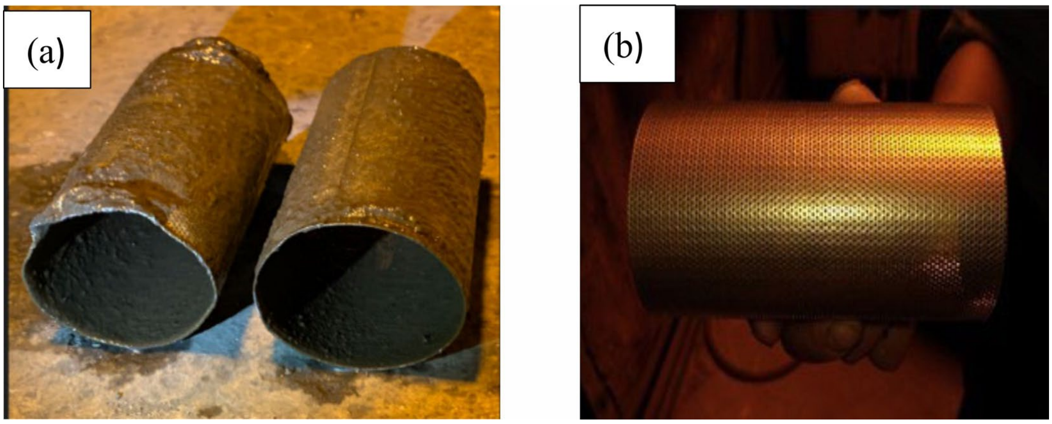

Fig.5. (a) Bio-slime on Safety Filter before and (b) after improvement.

for SCC machines increased from 100 to 450 L/min, meeting requirements for cooling low, medium, and high carbon steels. The frequency of maintenance could be improved from 1 month to 6 months and reduced downtime and losses. The annual benefits were approximately ＄1.35 million NTD.

3.5 Decreasing Oil Content of Mill Scale in Electric Furnace Steel Plant

Reducing the oil content of the iron oxide scale is closely related to recycling and reuse. Therefore, selecting an oil skimmer with high oil removal efficiency was a crucial part of this process. Two strategies were used to improve the oil content of the iron oxide scale. First, the mop-type oil skimmer with an oil removal capacity of 0.21 tons per hour was determined as the optimal online equipment. By skimming for 4 hours weekly in the scale pit, the iron oxide scale dug up no longer adheres to heavy floating oil. Secondly, the off-line treatment with TW circulating and washing for 1 hour further reduced oil content.

Field tests showed that the oil content of iron oxide scales for the electric furnace plant decreased from 0.44% to less than 0.07%, meeting the sintering acceptance standard of 0.1%. Annually, all 1,200 tons were fully reused to the sintering plant. This technology also had been deployed to the hot rolling plant, where 7,130 tons of iron oxide scale were also entirely recycled to the sintering plant in 2022. The annual benefits were approximately ＄6.18 million NTD by substituting mill scale for iron ore fines.

4. CONCLUSIONS

This study has successfully developed key technologies including scale removal, scale prevention, sterilization, and oil removal. The on-site implementation of this research has effectively resolved longstanding production challenges. Most importantly, the research team has established technical capabilities for comprehensive solutions and ensures smooth production. Future efforts will focus on advancing cooling water treatment technologies to reduce costs continuously.

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