Application of Anti-wear Technology for Water-cooled Wall of CFB Boilers

Changyu Zhao, Dongsheng Chen, Qiujia Wu, Wei Wang, Zichen Zhao, Xindong Liu *

Chifeng Thermal Power Plant, Chifeng, China

* Corresponding Author Email: 1215534401@qq.com

Abstract. Because of its high efficiency, low pollution, energy saving and other technical advantages, CFB boiler has been rapidly promoted commercially in recent decades. However, because of its special combustion mode and high material concentration, the gas-solid two-phase flow is more complex and the wear is more serious. No matter in theoretical research or engineering practice, the problem of serious wear and tear of CFB boiler has not been completely solved. Wear is the main reason that restricts the further development of CFB boilers. The main purpose of this paper is to study the application of anti-wear technology of water-cooled wall of CFB boiler. Therefore, this paper makes a systematic study on the serious wear problem of CFB boiler, makes an accurate prediction of the serious wear area, and puts forward comprehensive anti-wear measures to slow down the wear rate and prolong the service life. Through experiment, numerical simulation and comparison with the field practice, the study shows that the wear of water wall is mainly divided into erosion wear, friction wear and high temperature atmosphere corrosion wear. Among them, the wear of water-cooled wall (WCW) is mainly erosion and friction wear, while the corrosion wear of high temperature atmosphere accelerates the speed of these two kinds of wear.

Keywords: CFB Boiler, Water-cooled Wall, Wear Mechanism, Anti-wear Technology.

1. Introduction

CFB boiler wear is a long-standing engineering problem that plagues the safe and economic operation of boilers. The concentration of gas and solid phases in circulating fluidized bed boilers is high and unevenly distributed, and the concentration in the dilute phase area is much higher than the concentration of gas and solid phases in pulverized coal boilers, so the wear of the entire flue air system process in CFB boilers is more serious. And if a failure leakage accident occurs, it will increase the workload of temporary maintenance and overhaul of fluidized bed boilers, resulting in serious economic losses [1-2].

In a related study, Benjamin put forward the deformation wear theory from the energy balance consideration, and divided the impact wear in the process of erosion wear into cutting and scouring wear [3]. This theory believes that cutting wear mainly occurs in ideal plastic materials and deformation wear mainly occurs in ideal brittle materials. In engineering practice, ideal materials do not exist, so metal wear is a combination of both types of wear. Isabel's theory of secondary erosion wear clearly explains the wear of brittle particles that erode the surface of a material at a large angle [4]. The theory shows that the particles will secondarily erode the surface of the material after fragmentation and that the degree of fragmentation is related to the kinetic energy of the particles, the impact angle and other influencing factors. In the analysis of secondary erosion wear is not considered together with primary erosion, but is studied separately so that the analysis is more simplified.

In this paper, the key wear areas of the external circulation system of circulating fluidised bed boilers are obtained by combining the summarised wear rate calculation formulae for different wear damage modes and verifying them with the numerical simulation results of the experimental bench model, selecting suitable simulation parameters and models and using the simulation to expand the experimental working conditions. The numerical simulation is also used to simulate the wear rate of the fork and downstream tube bundles arranged in a limited space. By comparing the data obtained from the experiments and simulations with the wear data of the full-size CFB boiler, the key wear

areas of the CFB boiler are analysed comprehensively and the main wear areas of the boiler are predicted. By analysing the areas with severe wear damage in CFB boilers, corresponding comprehensive AW measures are proposed to slow down the wear rate.

2. Design Research

2.1. WCW Wear Mitigation Measures

In recent years, due to the CFB boiler development trend began to high parameters of large-scale development, in order to ensure the normal operation of the boiler, the boiler operating conditions have been greatly improved. In the improved working conditions at the same time, the boiler heating surface wear is also becoming more and more serious, for CFB boiler heating surface wear serious problems, now a large number of researchers engaged in AW research, summed up a lot of AW measures with good AW effect [5-6].

CFB boiler WCW wear is a serious cause of "non-stop" one of the main reasons, WCW wear is mainly due to its special combustion mode, high concentration of material inside the furnace, particle size and speed is the cause of wear factors [7-8], the current measures taken to alleviate the wear rate of the WCW are mainly.

(1) Tube yielding technology, boiler internal circulation of material against the wall downward flow, the WCW tube and wear-resistant refractory castable junction smooth over, reduce the scouring of the heated surface, AW.

(2) Spraying technology, spraying wear-resistant refractory metal or non-metallic material on the surface of the tube bundle of the heated surface that leaks outside, so that the hardness of the tube wall surface is increased and the particles are less likely to wear out the tube bundle of the heated surface when scouring the tube wall.

(3) Active multi-step AW technology, mainly the tabs are fixed to the WCW bundle with pins to reduce the speed and concentration of downward material for AW. Convective heating surface due to the high concentration of particles in the flue gas, in the process of flue gas flow, the heating surface tube bundle caused serious wear, the current AW measures for the convective heating surface is mainly through the flue gas at the turn to add a guide plate to make the concentration and speed of fly ash as low as possible, and in the formation of the flue gas corridor parts to add comb pipe and AW tile, reduce the lateral flow of flue gas and the speed here [9-10].

Cyclone wear is mainly caused by the flue gas carrying out gas-solid separation process, a large number of fly ash particles in the flue gas hitting the separator wall, resulting in wear-resistant castings falling off and causing wear. The widely used AW measure is the reasonable selection of wear-resistant refractory high-temperature wear bricks and the layered arrangement to prevent wear.

The lower part of the furnace chamber wears mainly because the wear-resistant castables are easy to fall off, exposing the WCW and causing wear. For the area where the wear-resistant castables tend to fall off, pins are placed on the side of the worn tube bundle to prevent the wear-resistant castables from falling off. Pins should also be welded on the heat-resistant pipes of the secondary air outlet and coal feed outlet to fix the wear-resistant castables and prevent them from falling off [11-12].

2.2. Problems

Although the AW measures mentioned above are widely used in engineering practice and have achieved good AW effects, there are still certain technical problems in the operation of the boiler, making the wear relatively serious. In actual operation the following problems mainly exist.

(1) Wear is composed of different wear theories and many influencing factors, so it is difficult to take all influencing factors into account in the research and optimisation of AW measures, resulting in many problems still existing in the formed AW measures, and although the wear situation has been improved to a certain extent, it has not been solved fundamentally.

(2) When AW measures are applied, due to their own defects and the restrictions of on-site construction, the AW devices cannot cover the entire heating surface, and some areas with serious wear still cannot be effectively AW.

(3) Some AW measures have been in operation for a short period of time, and play a certain AW effect in the beginning of operation, but after a period of operation the AW device begins to fail, and the heating surface is seriously worn. Frequent furnace shutdowns and repairs also cause serious economic losses.

(4) CFB boiler working condition regulation affects the concentration of material in the furnace chamber, flue gas flow rate, ash particle concentration and heat transfer efficiency of the boiler. If only the efficiency of the boiler is considered, it will cause serious wear on the heating surface. If only wear is considered, heat transfer will be affected. These issues need to be further optimised in future studies to determine the optimum operating conditions [13-14].

2.3. Wear Mechanisms

2.3.1 Abrasive wear

According to the different working conditions it can be divided into two-body wear and three-body wear. The wear rate w is calculated as follows:

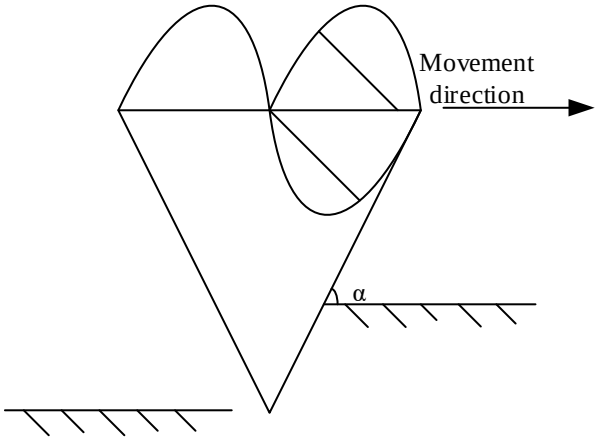


Figure 1. Abrasion of abrasive particles

$$w = \frac{2tg\alpha}{\pi} \cdot \frac{N}{\sigma_b} = k_\alpha \cdot \frac{N}{\sigma_b} \tag{1}$$

Where: α is the angle of clamping, °; σb is the hardness, σb ≈ H/3, H is the Brinell hardness; N is the normal load (pressure), N; ka is the abrasive wear coefficient.

Abrasion.

$$Q = w \times L \tag{2}$$

Where: L is the sliding length, m; Q is the wear volume, mm.

2.3.2 Adhesive wear

Calculation of the wear rate w based on Archard's theory.

$$w = \frac{Q}{L} = \frac{k}{L}\frac{N}{\sigma_b} \tag{3}$$

Where: Q is the total wear; N is the normal load, N; L is the sliding distance, m; σb is the material hardness, σb ≈ H/3 for elastic materials.

The wear coefficient k and the hardness σb of the friction substrate are constants in formula (3).

$$w = \frac{Q}{L} = \frac{k(T)}{3} \frac{N}{\sigma_b(T)} \tag{4}$$

k(T) and σb(T) ≈ H(T)/3 as a function of temperature.

3. Experimental Study

3.1. WCW Wear Area and Mechanism

In the process of circulating fluidized bed boiler operation, due to the more violent gas-solid flow in the furnace, the WCW surface is covered by a thick wall of falling flow, far beyond the concentration of particles and the speed of ordinary pulverized coal furnace, the speed of wear, in the long run, the wall surface will inevitably lead to downtime due to wear and maintenance. CFB boiler dense phase area is generally laid with refractory materials, compared to the thin phase area wall surface is more prone to wear, of which the following Four areas are the main areas of wear on the WCWs of the furnace.

(1) Refractory transition zone
(2) Corner areas of the furnace chamber
(3) Irregular areas
(4) General WCW tubes

Refractory transition zone wear is more typical of the WCW wear, the degree of wear is heavy on the lower light. The main reason for this is that the falling flow of the wall here and the rising fusion in one place to produce vortex, changing its original flow direction, increasing the wear and tear on the WCW.

The general wear and tear of the WCW tube is the extensive wear and tear of the upper part of the furnace chamber in the thin phase area. The reason for the wear is the above-mentioned wide range of downward flow against the wall of the WCW of a long time scouring abrasion. This is dominated by the frictional wear of tiny particles, which can be seen in the wear marks and a few small impact craters, although the wear rate of this type of wear is slow, but the large range is still not negligible.

In summary, the four wear areas are basically closely related to the wall-falling flow, so it is important to study the gas-solid flow characteristics of the wall-falling flow.

Research shows that the wear of the WCW is mainly divided into erosion wear, friction wear, high-temperature atmosphere corrosion wear. The wear of the WCW surface is mainly based on erosion and frictional wear, while the role of high-temperature atmosphere corrosion wear accelerates the speed of these two types of wear.

3.2. AW Project Implementation Plan

(1) AW plate welded on the WCW fins, and WCW tubes to retain a certain expansion gap, the installation process horizontal and vertical, the entire furnace chamber horizontal plate must maintain a unified a lap direction (keep clockwise direction under the lap on the installation) connected in the same direction, the seam is tight, uniform heat expansion free consistent and orderly. Vertical plate welding according to the furnace area different wind direction different lap direction.

(2) welding rod using special stainless steel welding rod, is to ensure that no higher than three ten thousandths of the rate of falling pieces of force guarantee, and anti-friction plate and fin material perfect fusion, high temperature does not fall off.

(3) Adding anti-friction plate area to ensure that all welded anti-friction plate in a horizontal line, forming a free shrinkage, the installation gap is not more than 1.2mm. different anti-friction area using different welding technology: spot welding, full welding, single-sided welding, welding. After the overall addition of the heat guide plate, the thermal efficiency of the furnace chamber is affected by no more than 1%. In order to ensure the welding process, no bubbles, cracks, welding rod welding before the need for 200-250°C drying 1h, in 100-150°C insulation barrel insulation, with the use of the welding current control at 100-130A. For the furnace chamber to protect the area, the welding

position polishing treatment, remove the spray layer, to ensure the flatness and solidity of the AW plate welding.

(4) The use of high thermal conductivity, high wear resistance, high temperature resistant rare earth alloy casting products, no deformation, no shedding, no corrosion; professional construction team, mature construction technology, reliable quality, safety, solid installation, long life;

(5) Construction personnel are licensed to work, wear labour protection equipment and tools, and strictly comply with site safety management norms. The professional construction tools used in the construction (such as welding machines, wires and cables, etc.) comply with the national inspection standards.

3.3. Benefit Transformation and Forecast

3.3.1 Overall objectives

To ensure that the boiler stops as planned, no leaks due to WCW wear and tear, and to reduce direct losses and indirect losses caused by non-stopping.

3.3.2 Output indicators

No unscheduled shutdown due to boiler wear and tear that brings about insufficient steam production or emergency shutdown resulting in supply cut-off. Avoid direct losses and greatly reduce the cost of maintenance and repair of the WCW during a shutdown. The boiler is scheduled to be shut down for maintenance, which can effectively ensure that the hourly gas production reaches the planned requirements, and can effectively deploy the maintenance plan and switchover boiler plan.

3.3.3 Benefit indicators

(1) Long-cycle safe operation of the boiler can ensure that steam is deployed as required and that gas and heat supply is carried out in an orderly manner. No more unplanned furnace shutdowns for maintenance will occur throughout the heating season, ensuring an orderly supply of gas and more secure heating for residents.

(2) Because the WCW heating surface area is large, the installation of the deflector plate can greatly reduce the maintenance staff to overhaul the WCW labour intensity. Adding a guide plate AW can increase the service life of the WCW, avoiding wear and tear replacement and large area replacement at the end of service life, thus saving the cost of maintenance and replacement, bringing more capacity.

In summary, the transformation can make the boiler long cycle of safe operation, a single boiler can save each year due to non-accountable stop care. Caused by the maintenance, main materials, auxiliary materials, consumables manpower and other comprehensive fees. As well as avoiding a series of livelihood problems caused, etc. Service life of more than 5 years, a single pot care can save costs of 1 million yuan.

3.4. WCW Damage and Optimization

3.4.1 WCW damage mechanism

Particles in the fluidized wind under the influence of upward movement, when the movement to a certain height, under the action of gravity, and then downward to do accelerated movement, due to the high concentration of particles in the CFB boiler furnace, so the concentration of particles flowing downward is also higher and faster flow rate. Particles in the process of falling when encountering obstacles, particles in the local formation of vortex, local wear and tear serious. The CFB boilers now in operation use more membrane WCWs, which are less likely to form local vortices when the particles flow through the WCWs due to their structural characteristics, thus alleviating wear. WCW wear serious areas appear in the junction with the refractory castings, when burning poor quality coal, where the wear is more serious.

3.4.2 WCW AW measures to optimise

The serious wear of the WCW bundle inside the furnace chamber is mainly due to the influence of gravity, the material flows downwards with high concentration and fast flow rate, and once it meets the obstacle in the flow process, it is easy to produce eddy currents causing wear. Most CFB boilers use a membrane WCW, as the upper part of the furnace chamber has fewer raised parts, particles in the near-wall area is less likely to occur vortex phenomenon. When burning poor quality coal, these parts of the wear and tear more serious. At present, this problem is mainly to take active multi-step AW technology, tube yielding technology and spraying technology combined with the comprehensive AW measures. Active multi-step AW technology is aimed at reducing the speed and concentration of the furnace wall flow particles, so that the material in the internal circulation to reduce the erosion of the WCW heating surface abrasion; tube yielding technology is mainly to make the refractory and WCW tube bundle junction play a smooth over, the material in the process of falling, to alleviate the serious local wear; spraying technology construction is more convenient, not limited by space, can be used in the corner area.

4. Experiment Analysis

4.1. Furnace WCW Wear Problem Analysis

At present, the wear and tear of the WCW of the furnace is one of the major problems that lead to the shutdown of many large circulating fluidized beds during normal operation. This fluidized bed boiler common problem, although there have been some methods to improve the furnace WCW wear, but still can not be completely counted to solve, and some methods are used improperly, will cause the boiler bursts frequently, which has become the use of boiler manufacturers one of the most difficult problems. Table 1 shows the statistics of some circulating fluidised bed boilers that have been shut down due to WCW wear and burst tubes.

Table 1. Circulating fluidized bed boilers due to WCW wear resulting in furnace shutdown

Unit	Coal quality parameters		Number of furnace shutdowns per year due to WCW wear	Number of days per year due to WCW wear	Direct loss due to furnace shutdown	
	Coal type	Calorific value			Million/day	Million yuan/year
	/	kcal/kg	Times	Days		
2×25MW	Washed medium coal	~3500	6	30	6	180
2×50MW	Blended Coal	~2500	6	30	13	390
2×50MW	Blended coal	~4000	7	35	13	455
2×50MW	Washed medium coal	~3200	8	40	13	520
2×150MW	Poor coal	/	6	30	35	1050
2×135MW	Poor coal	~4500	6	30	30	900
2×300MW	Blended Coal	~3800	3	30	70	2100

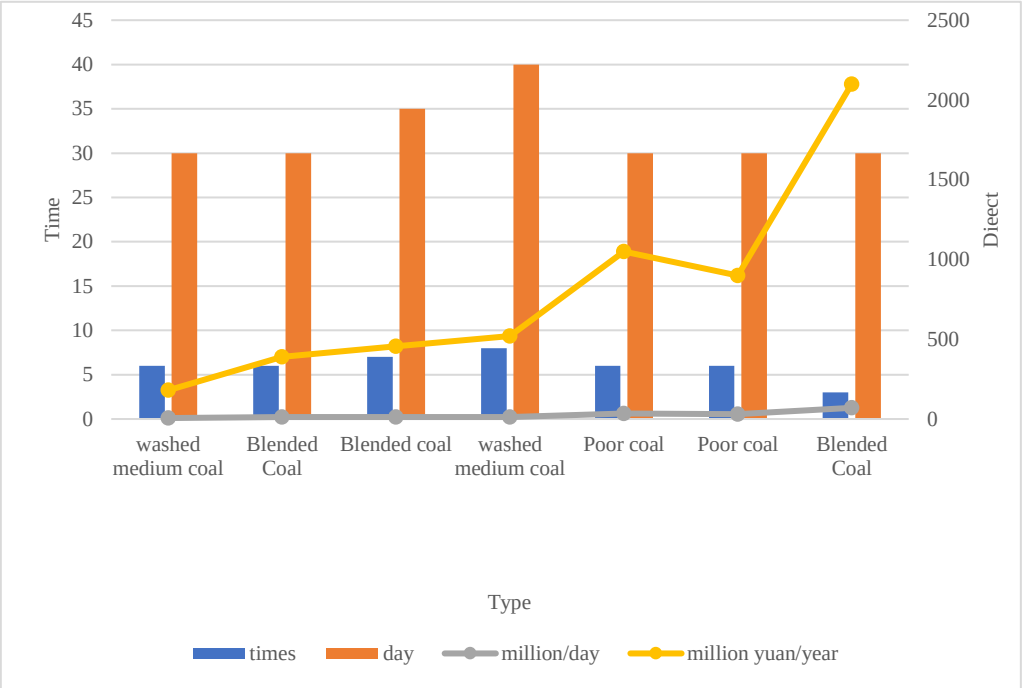


Figure 2. Analysis of circulating fluidized bed boiler shutdown due to WCW wear

As can be seen in Figure 2, plant shutdowns caused by WCWs affect the safe and stable operation of the plant, resulting in economic losses. In addition to the direct economic losses caused by WCW shutdowns, the process from shutdown to maintenance and restart can also generate significant indirect losses. Therefore, solving the circulating fluidised bed WCW wear has become one of the immediate tasks, and the main task of this paper is to start from this perspective.

4.2. Effect of The Width of The Anti-Friction Beam on The Particle Concentration

As the addition of an anti-friction beam affects the continuity of the downward flow against the wall, some of the particles will accumulate above the anti-friction beam after it has been struck, increasing the particle concentration there. The volume of this accumulation is also influenced by the width of the anti-friction beam. The relationship between the height of particle accumulation on the wall above the anti-friction beam and the width of the anti-friction beam is shown in Table 2.

Table 2. Particle accumulation height in relation to the width of the anti-friction beam

	5.15m/s	4.65m/s
3	20	20
6	25	27
9	30	33
12	35	38
15	40	40

As can be seen from Figure 3, the particle accumulation height above the anti-friction beam increases gradually with the width of the anti-friction beam, while the lower the air velocity of the empty section, the higher the particle accumulation height, given the same width of the anti-friction beam.

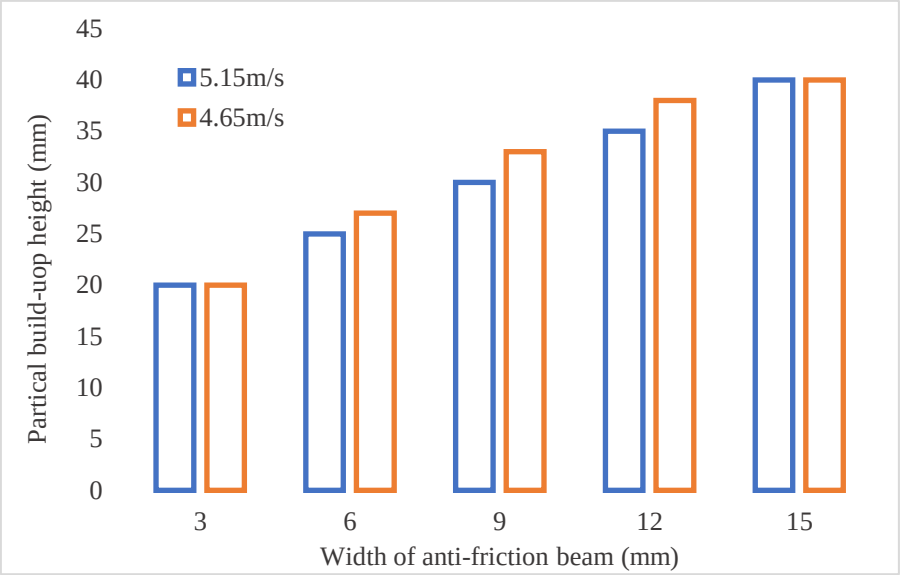


Figure 3. Height of particle accumulation versus width of anti-friction beam

The relationship between the average volume fraction of particle accumulation on the upper surface of the anti-friction beam and the width of the anti-friction beam is shown in Table 3.

Table 3. Average volume fraction within the height of particle accumulation versus the width of the antifriction beam

	5.15m/s	4.65m/s
3	0.105	0.113
6	0.108	0.121
9	0.125	0.132
12	0.125	0.140
15	0.162	0.172

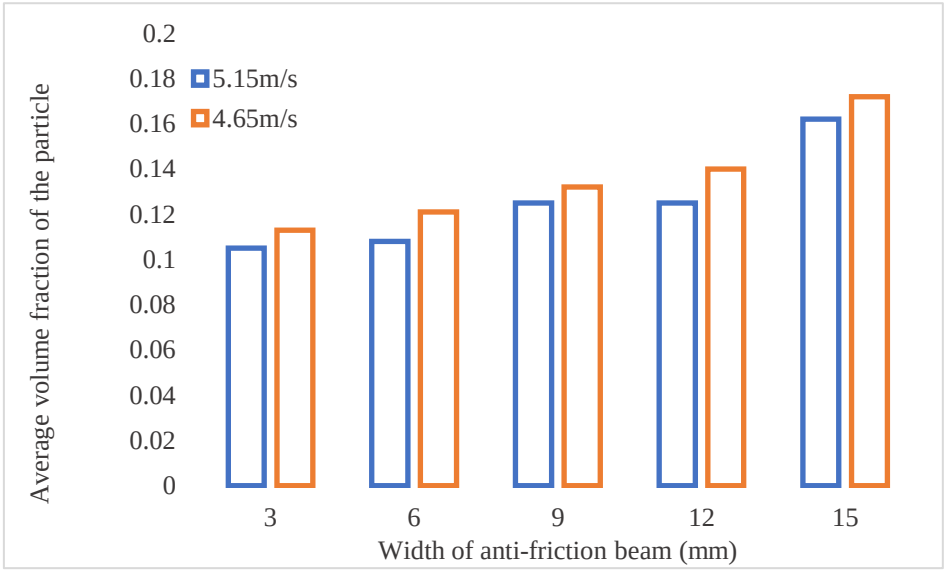


Figure 4. Analysis of the average volume fraction within the height of particle accumulation versus the width of the anti-friction beam

As can be seen in Figure 4, the particle build-up concentration above the anti-friction beam increases with the width of the beam, while the lower the air velocity in the empty section, the higher the particle build-up concentration when the width of the beam is fixed.

5. Conclusion

The water-cooled wall becomes thinner or even leaks due to wear and tear, which will cause unplanned furnace shutdown and affect production. In order to ensure the safe, reliable and long-term stable operation of the boiler, it is necessary to avoid the local rapid thinning of the water-cooled wall caused by wear and eliminate the unplanned shutdown phenomenon caused by the wear and leakage of the water-cooled wall in the furnace. The implementation of the anti-wear technology of the new diaphragm gridded water-cooled wall on the heating surface of the furnace can effectively control the wear of the water-cooled wall tube on the heating surface of the furnace. After the transformation, the long-term safe operation of the boiler can be made, and the unplanned shutdown and maintenance will no longer occur in the whole heating season, which is more guaranteed for residents' heating. Every year, a single boiler can save nearly 1 million of the comprehensive costs of maintenance, main materials, auxiliary materials, consumables, manpower and so on. In addition, a series of livelihood problems can be avoided after the transformation.

References

[1] Georgianna Lin, Malcolm Haynes, Sarthak Srinivas, Pramod Kotipalli, Thad Starner: Towards Finding the Optimum Position in the Visual Field for a Head Worn Display Used for Task Guidance with Non-registered Graphics. Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 5(1): 22:1-22:26 (2021).

[2] Hannes Mareen, Martijn Courteaux, Johan De Praeter, Md. Asikuzzaman, Glenn Van Wallendael, Mark R. Pickering, Peter Lambert: Camcording-Resistant Forensic Watermarking Fallback System Using Secondary Watermark Signal. IEEE Trans. Circuits Syst. Video Technol. 31(9): 3403-3416 (2021).

[3] Benjamin Crysup, Bruce Budowle, August E. Woerner: ProSynAR: a reference aware read merger. Bioinform. 38(7): 2052-2053 (2022).

[4] Isabel Maria Schmid, Janik Wörner, Susanne Leist: Automated identification of different lead users regarding the innovation process. Electron. Mark. 32(2): 945-970 (2022).

[5] Gordon Briest, Lars-Peter Lauven, Stefan Kupfer, Elmar Lukas: Leaving well-worn paths: Reversal of the investment-uncertainty relationship and flexible biogas plant operation. Eur. J. Oper. Res. 300(3): 1162-1176 (2022).

[6] Ulysse Côté Allard, Petter Jakobsen, Andrea Stautland, Tine Nordgreen, Ole Bernt Fasmer, Ketil Joachim Oedegaard, Jim Tørresen: Long-Short Ensemble Network for Bipolar Manic-Euthymic State Recognition Based on Wrist-Worn Sensors. IEEE Pervasive Comput. 21(2): 20-31 (2022).

[7] Andrea Ferlini, Dong Ma, Lorena Qendro, Cecilia Mascolo: Mobile Health with Head-Worn Devices: Challenges and Opportunities. IEEE Pervasive Comput. 21(3): 52-60 (2022).

[8] Atena Fadaei Jouybari, Kenny Jeanmonod, Oliver Alan Kannape, Jevita Potheegadoo, Hannes Bleuler, Masayuki Hara, Olaf Blanke: Cogno-Vest: A Torso-Worn, Force Display to Experimentally Induce Specific Hallucinations and Related Bodily Sensations. IEEE Trans. Cogn. Dev. Syst. 14(2): 497-506 (2022).

[9] Domenico Minici, Guglielmo Cola, Antonella Giordano, Silvana Antoci, Elena Girardi, Mauro Di Bari, Marco Avvenuti: Towards Automated Assessment of Frailty Status Using a Wrist-Worn Device. IEEE J. Biomed. Health Informatics 26(3): 1013-1022 (2022).

[10] Bakhtiar Ostadi, Ramtin Hamedankhah: A two-stage reliability optimization approach for solving series-parallel redundancy allocation problem considering the sale of worn-out parts. Ann. Oper. Res. 304(1): 381-396 (2021).

[11] Benjamin Crysup, Bruce Budowle, August E. Woerner: ProDerAl: reference position dependent alignment. Bioinform. 37(16): 2479-2480 (2021).

[12] Nam Bui, Nhat Pham, Jessica Jacqueline Barnitz, Zhanan Zou, Phuc Nguyen, Hoang Truong, Taeho Kim, Nicholas Farrow, Anh Nguyen, Jianliang Xiao, Robin R. Deterding, Thang N. Dinh, Tam Vu: eBP: an ear-worn device for frequent and comfortable blood pressure monitoring. Commun. ACM 64(8): 118-125 (2021).

[13] Sayma Akther, Nazir Saleheen, Mithun Saha, Vivek Shetty, Santosh Kumar: mTeeth: Identifying Brushing Teeth Surfaces Using Wrist-Worn Inertial Sensors. Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 5(2): 53:1-53:25 (2021).

[14] Vimal Kakaraparthi, Qijia Shao, Charles J. Carver, Tien Pham, Nam Bui, Phuc Nguyen, Xia Zhou, Tam Vu: FaceSense: Sensing Face Touch with an Ear-worn System. Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 5(3): 110:1-110:27 (2021).