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Development of a Water Dew Corrosion Resistant New Steel Element for Air Preheaters at Natural Gas Fired Power Plants

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Abstract

A corrosion resistant new steel element for air preheaters at natural gas fired power plants was developed against water dew corrosion. 25-month-long field tests proved that the new steel element, containing 7% Cr, has the following excellent characteristics: (1) corrosion rate of the 7%Cr steel element was one third of that of conventional CRLS (Corrosion Resistant Low Alloy Steel), (2) corrosion products formed on the 7%Cr steel elements were more adhesive and less voluminous, which suggests that the 7%Cr steel elements can mitigate blockade troubles by rust at intermittent operations, (3) the same manufacturing process, set up, operation and maintenance methods can be applied for the new steel elements as for the conventional CRLS elements. Since 2000, the new steel element has been successfully used for not only the cold layers at natural gas fired power plants, but also the intermediate and hot layers at oil fired power plants. The developed new steel element will contribute to improve reliability of power plants and to reduce maintenance costs.

1. Introduction

The Ljungstrom type air preheater is typical of the equipment that recovers waste heat by exchanging the heat of boiler waste gas with that of air (**Fig. 1**)[1]. For this equipment are used cold rolled sheets, processed into a wave-like form and layered, as heat transfer elements. The elements are required to be corrosion resistant because of their exposure to low-temperature corrosive environments regardless of the kinds of fuel.

Low temperature corrosion in petroleum fuel is called “sulfuric acid dew corrosion” stemming from the sulfur contained in the fuel[2]. As measures against this corrosion, CRLS (Corrosion Resistant Low-alloy Steel), represented by COR-TEN steel to which corrosion-resistant elements like chromium and copper are added, has so far been used. Since the CRLS is fully resistant to sulfuric acid dew corrosion that develops at the cold end layer of an air preheater at an oil-fired plant, the problem of corrosion has almost been solved.

On the other hand, when LNG (Liquefied Natural Gas), which is being used mainly for thermal power plants in recent years, is used as fuel, so-called water dew corrosion takes place because no sulfur is contained in the fuel. However, in the environment where water dew corrosion occurs, CRLS is not as corrosion-resistant as in the sulfuric acid dew corrosion environment.

A new kind of steel resistant to condensed water dew corrosion has therefore been requested. Furthermore, a material that scarcely chokes has been in demand in addition to corrosion resistance be-

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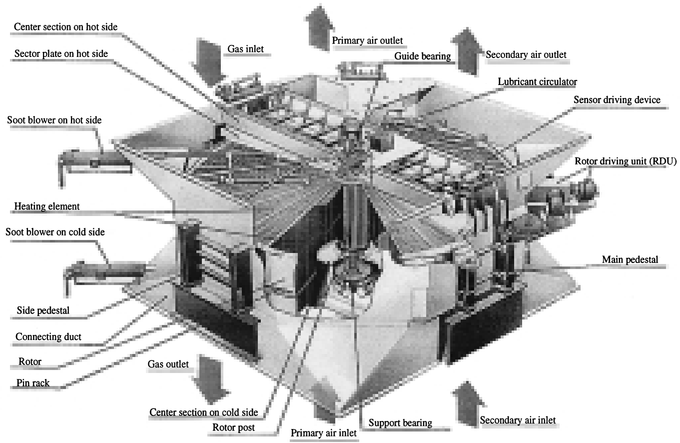

Fig. 1 Rotary regenerative air preheater (Ljungstrom type)

cause an increase in pressure drop is brought about due to passage choking with the high-volume rust peculiar to water dew corrosion. Enamel-coated or stainless steel sheets can be counted among the promising materials now available[2]. The enamel-coated steel sheets are excellent in resistance to the environment of sulfuric acid dew corrosion or water dew corrosion and are exhibiting satisfactory results. Stainless steel sheets are also excellent when used only for water dew corrosion resistance.

The authors et al. developed new corrosion-resistant elements for the air preheater of a gas-fired boiler through the demonstration test using the actual facilities. The new products are economically superior to the existing materials, have a satisfactory corrosion-resistant service life in the water dew corrosion environment of the actual facilities, and can mitigate pressure drop due to loose scales. In addition, the methods of manufacturing, maintenance, and control, that are the same with those of the conventional CRLS, can also be applied to them[3-6]. This paper introduces the outline of the water dew corrosion that takes place in the air preheaters along with the characteristics of the new corrosion-resistant elements.

2. Elements Resistant to Water Dew Corrosion

Table 1 shows an example of the chemical composition of the water dew corrosion resistant element. In consideration of required working properties and corrosion resistance, the element is composed of low C-low Si-7%Cr.

3. An Example of the Corrosion of the Cold Layer of the LNG-fired Air Preheater, and the Environment

Fig. 2 shows the results of investigation of the changes in cold end's mean temperature (CMT) of the air preheater of a gas-fired boiler at full load and half load in summer and winter, respectively. The water content in exhaust gas was about 17 vol.% (dew point: 57 ˚C). The figure suggests that the CMT usually or temporarily drops to below the dew point of the (flue) gas depending on the boiler load or season resulting in producing condensed water and water dew corrosion.

Photo 1 shows the changes in appearance of the CRLS-made elements two years after their use for the air preheater of a gas-fired boiler. Corrosion starts gradually from the edge of the cold end layer with comparatively thick rust formed like the opening of flowers. The results of X-ray diffraction analysis revealed that the rust of the CRLS-made element consists mainly of α-FeOOH (goethite), β-FeOOH (akagenaite), γ-FeOOH and Fe_3O_4 in that order and that the rust also contains significant amounts of chlorides (0.22 mass%). Those features agreed with those of the iron rust formed in the atmospheric condition at coastal areas. The pH of the drain water was 4 to 6. These results lead to postulation that the corrosion of the element in the cold end layer of the air preheater of a gas-fired boiler is caused by the water dew corrosion due to the condensed water of the combustion exhaust gas in which the corrosive substances in the environment, such as chlorides and the exhaust gas are dissolved.

Table 1 Example of chemical composition of developed steel element resistant to water dew corrosion

(mass%)

	C	Si	Mn	P	S	Cr	Al
Developed steel	0.01	0.02	0.28	0.005	0.005	7.1	0.025

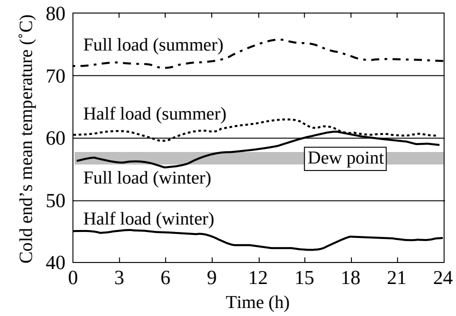

Fig. 2 Example of transition of cold end's mean temperature (CMT) at a LNG fired power station

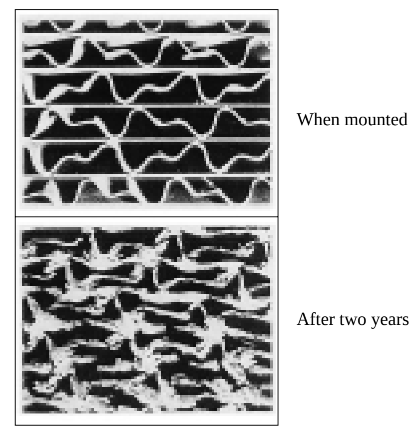

Photo 1 Condition of water dew corrosion at cold end of CRLS-made elements

4. Laboratory Corrosion Tests and Investigation in Field Coupon Tests[4]

The influences of chemical composition on corrosion resistance were investigated at the laboratory by implementing wet and dry corrosion tests using the test solutions in which the ingredients of condensed water are reproduced while supplying the gas of exhaust gas composition. **Fig. 3** shows the influence of the addition of chromium on corrosion rate (laboratory test results). In addition, 20-month field exposure test, the longest one, was carried out with small flat-sheet test pieces attached to the cold ends of two air preheaters at LNG-fired power plants. The materials used were low-C-low-Si-5-10%Cr-steel, low-C-P-Cu-Ni-steel, and the CRLS. **Fig. 4** shows the corrosion curves of CRLS and 7%Cr-steel in the field tests. No sig-

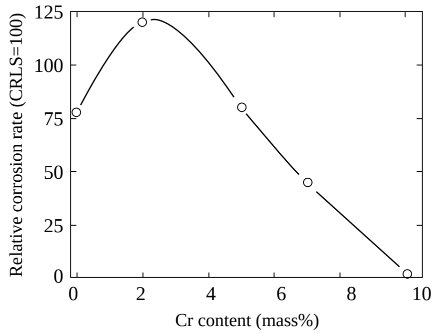

Fig. 3 Influence of Cr addition on corrosion rate (accelerated corrosion test in the laboratory)

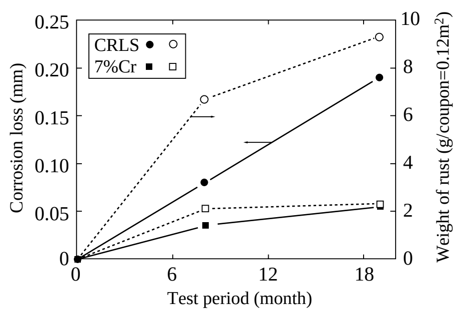

Fig. 4 Results of exposure tests of 7%Cr-steel sheet and CRLS (LNG fired power station)

nificant difference was observed in corrosion resistance between low-C-P-Cu-Ni-steel and the CRLS depending on the kinds of boilers. However, 5-10%Cr-steel agreed well with the laboratory test results in both of corrosion rate and weight of rust formed on elements. It was confirmed further that 7%Cr-steel is three times more corrosion-resistant than the CRLS.

5. Evaluation of Element Productivity of 7%Cr-steel Sheets and Field Application Tests

The 7%Cr-steel sheets (300 mm (height) $\times$ 200 mm (width) $\times$ 1.1 mm (thickness)), which were satisfactory in the field exposure tests, were rolled for wavy shapes to investigate their element productivity. It was confirmed that 7%Cr-steel is good in workability with accuracy of wave-shape for profile included, can stand comparison with CRLS, and is not a burden on productivity. Furthermore, it posed no problem in the manufacture of a variety of element profiles (NF, DU, FNC, etc).

Next, its durability was investigated as the actual member material by inserting it to the cold layer of the air preheater of a gas-fired boiler. **Fig. 5** shows the corrosion curves of various materials. Even in element shapes, not only 5%Cr-steel but also 7%Cr-steel showed little corrosion volume loss similar to the small flat-sheet test pieces. The 7%Cr-steel was found about 3 times more corrosion-resistant than CRLS.

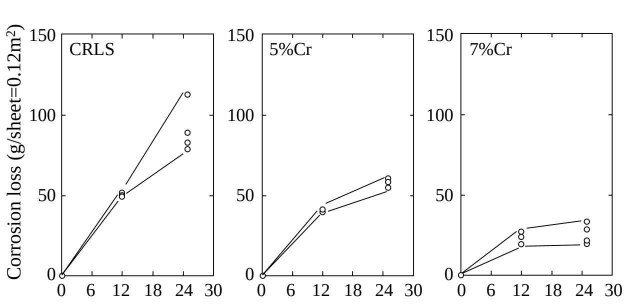

Fig. 5 Corrosion loss -time curve of test elements

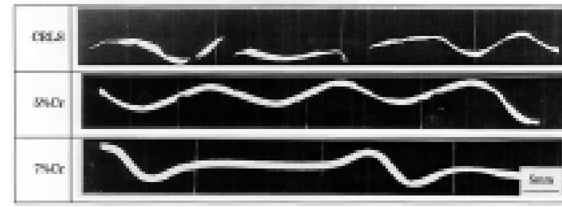

Photo 2 Closs sectional photographes of the test elements (cold edge + 10 mm)

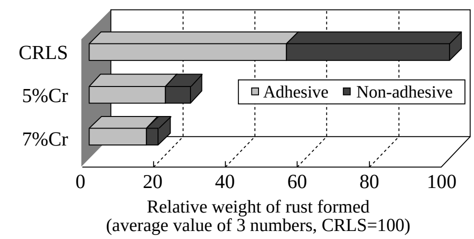

Fig. 6 Weight of rust formed on element resistant to water dew corrosion

Photo 2 shows a cut surface, 10 mm away from the cold edge. A CRLS-made one is remarkably corroded due to general corrosion with pits. However, it is evident that localized corrosion prevails in Cr-steel with only a slight decrease in sheet thickness except for pits.

Again, **Fig. 6** shows the weight of rust formed on test elements used for 25 months as an index of gas passage choking. The 7%Cr-steel-made one was about 1/7 of the CRLS-made one in non-adhesive rust volume.

From these results it was confirmed that the 7%Cr-steel-made element is about three times more corrosion-resistant than the CRLS-made one, and about 1/7 of the latter in the formation of non-adhesive rust responsible for choking.

6. Application to Water-induced Corrosive Environment

Since the hot end layer of a rotary regenerative air preheater is not in the dew corrosion environment regardless of the kinds of fuel, thin cold rolled steel sheets (SPCC) (standard thickness: 0.6 mm) are used.

Although SPCC is not in the corrosive environment when in use, it is water-washed when operation is stopped (for periodic inspection) except for the gas-fired air preheater, resulting in developing corrosion. Again, water in the air leads to corrosion due to dewing when it is not used after water washing during shut down. An example is reported that even in the case of an air preheater not water-washed at a gas-fired power plant, corrosion developed due to moisture adsorption in the intermediate and hot layers during shutdown. In the corrosion as above-described, a rise in differential pressure due to rust choking rather than corrosion when re-starting operation after a prolonged shutdown poses a problem in stable operation. There are many cases in which water washing or soot blowing fails to give satisfactory results in the case of rust formed during shutdown.

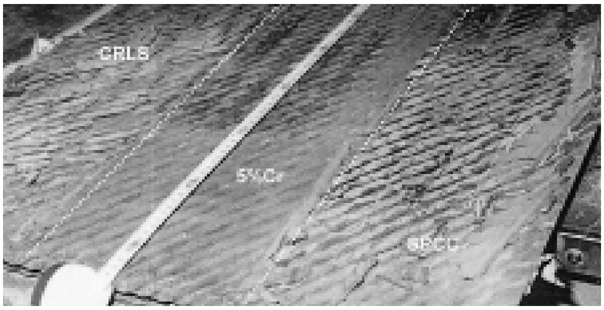

Photo 3 Condition of rust formed on various materials during shutdown

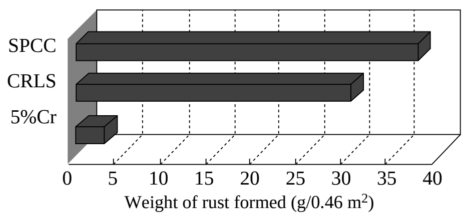

Fig. 7 Weight of rust formed in the medium temperature layer

Therefore, a sheet was inserted into the intermediate layer zone of the air preheater at the gas-fired power plant to investigate how corrosion developed one month after shutdown after 15-month operation. The sheet in question was joined into one by spot welding the elements made of CRLS, lowC-5%Cr-steel, and SPCC (**Photo 3**). Almost no rust was formed in 5%Cr-steel in contrast with CRLS and SPCC in both of which flaky rust was formed. Again, a comparison of the weight of rust formed on elements (**Fig. 7**) shows that the weight of rust formed on the elements of 5%Cr-steel is almost negligible. This indicates that this element has promise when used for measures against rust choking resulting from corrosion due to dewing and adsorption during shutdown.

7. Conclusion

A corrosion-resistant element made of lowC-7%Cr-steel was developed as measures against the water dew corrosion of the air preheater due to the combustion exhaust gas of the gas-fired boiler. The developed steel is excellent in cold workability into elements, and expected to be three times more corrosion-resistant than the conventional material (CRLS). Furthermore, in addition to their use for measures against water dew corrosion of the cold end layer of the air preheater of the gas-fired boiler, the elements made of 5%Cr-steel and 7%Cr-steel were confirmed to be effective as well when used as measures against rust choking due to water-induced corrosion that develops in the intermediate and hot layers during shutdown regardless of the kinds of fuel. The developed elements resistant to water dew corrosion have been working satisfactorily since they were adopted for use in the cold end layer of the air preheater of the gas-fired boiler in 2000. In addition, they were also adopted for use in the intermediate layer of the air preheater of the gas-fired boiler. In the future, they are expected to be used increasingly for the following applications thus to contribute to extending the service life of the elements and reduction in the cost of maintenance and control of the equipment:

(1) Materials for use in the cold end layer of the air preheater of the gas-fired boiler as measures against water dew corrosion
(2) Materials for use as measures against rust choking of the intermediate and hot layers of the air preheater during shutdown

References

1) The Thermal and Newclear Power. 42(8), 1075(1991)
2) Tezuka, H., Noguchi, T.: CAMP-ISIJ. 9, 1449(1996)
3) Usami, A., Inoue, T., Tanabe, K., Mabuchi, H., Tezuka, H., Noguchi, T.: Japan Society of Corrosion Engineering Technical Papers, 1996, p.135
4) Usami, A., Inoue, T., Tanabe, K., Mabuchi, H., Tezuka, H., Noguchi, T.: CAMP-ISIJ. 9, 1450 (1996)
5) Tezuka, H., Noguchi, T., Usami, A.: The Thermal and Newclear Power. 49(7), 991(1998)
6) Noguchi, T.: Haikan-To-Souchi. (6), 30(1998)