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Analysis of superheater's pipe wall overtemperature by fault tree diagnose

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Abstract: After research on a 2000t/h subcritical forced-circulation balanced ventilation were applied boiler and the structure and operation of its auxiliary system builds up this heat transfer model of a superheater's pipe wall and analyze the effect of primary factors on the overtemperature of the pipe wall. Fault tree structure was used to uncover the multiplayer logic between the overtemperature of the superheater's pipe wall and the faults.

Key words: Fault tree，Superheater，Overtemperature，Diagnose analyze
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INTRODUCTION

The superheater is the boiler component working at highest temperature and is installed in the higher fume temperature region. The operation security of the superheater mainly focused on the quality of the materials used，the quality of the installation work（Guan，1996；Yan et al.，2002），and the operation conditions inside or outside of pipe wall（Wang et al.，1998；Jin et al.，2002）. Any short or long term pipe wall overheating will lead to pipe cracking（Jin，1999；Li et al.，2001；Cheng et al.，2002）.

THEORY ANALYSIS

Fig. 1 is used to illustrate the mechanism and influencing factors of overheating. It is supposed that the pipe is heated evenly along the circle；that the scale on the pipe's inside flank is even；and that the heat is radially transferred only. Supposition：the outside diameter of the pipe is d_1；the inside diameter of the pipe is d_2；the thermal conductivity of the pipe wall is λ_1；there is even scale layer on the inside wall of the pipe，which results in the diameter reducing to d_3；the thermal conductivity of the scale stratum is λ_2；the fume discharges heat by convection and radiation；the mean coefficient of heat-flow is q_1；the heat is transferred inward by convection；and the temperatures of the outside wall and inside wall are t_1 and t_2 respectively，the temperature of the scale layer is t_3；the temperature of the working substance in the pipe is t_{gz}.

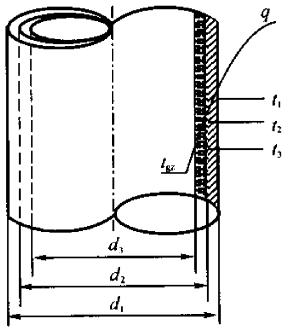

Fig.1 Metal pipe wall model for computation

From the figure，we can deduce the temperature of outside wall of the pipe as：

$$\begin{aligned} t_1 &= t_{gz} + \Delta t_{3gz} + \Delta t_{23} + \Delta t_{12} \\ &= t_{gz} + \frac{q_1\beta_1\beta_2}{\alpha_2} + \frac{q_1\beta_1}{\lambda_1} \times \frac{2\delta_1}{\beta_1+1} + \frac{q_1\beta_1\beta_2}{\lambda_2} \times \frac{2\delta_2}{\beta_2+1} \\ &= t_{gz} + q_1\beta_1\left[\frac{\beta_2}{\alpha_2} + \frac{2\delta_1}{\lambda_1(\beta_2+1)} + \frac{2\beta_2\delta_2}{\lambda_2(\beta_2+1)}\right] \end{aligned} \tag{1}$$

Where:

$\beta_1 = (d_1/d_2)$;

$\beta_2 = (d_2/d_3)$;

$\delta_1 = (d_1 - d_2)/2$;

$\delta_2 = (d_2 - d_3)/2$

Superheater operation research must also consider the following actual situation:

1. There is certain directivity in the high temperature fume's outburst and in the radiation heat transfer to the pipe. The heat-flow differences along the pipe circumference will lead to some variance of temperature distribution along the circumference, and result in circumferential and radial heat conduction. The temperature apex generally faces the flow direction of the fume.

2. Superheaters in various pipe rows are often heated non-uniformly and the working substance's speeds are often not uniform, which cause heat flow difference between outside various pipes rows and temperature difference between working substance in various places. Pipe wall overtemperature analysis should consider the worst working conditions. We use the temperature deviation of working substance in different pipes Δt_{gz} as the direct revision.

3. Non-uniformly thickness of the scale layer will lead to partial overheating of the pipe wall. This can be remedied by revising the scale layer non-uniformity coefficient μ_2; after which, the metal temperature formula of the superheater's outer wall may be expressed as:

$$t_1 = t_{gz} + \Delta t_{gz} + \mu\beta_1 q_{\max}\left[\frac{\beta_2}{\alpha_2} + \frac{2\delta_1}{\lambda_{11}(\beta_1+1)} + \frac{2\beta_2\delta_2\mu_2}{\lambda_2(\beta_2+1)}\right] \quad (2)$$

RELEVANT FACTORS OF PIPE WALL METAL'S TEMPERATURE

Eq.(2) basically contains the essential factors influencing the superheater pipe wall metal's temperature. But when boiler units are operating, the causes leading changes in these essential factors are manes and complex. Once the pipe wall metal is overheated, searching for the cause often requires analysis of the indications based on the above theory analysis in design, installment, overhaul, operation and so on. The notably high vapor temperature t_{gz} and large thermal deviation Δt_{gz} will result in heating up of the pipe wall. There are also some other causes for pipe wall heating up. For instance, because of the low load, and various choke and relief valves movements, the vapor flux will decrease and the heat discharging coefficient α_2 will become smaller, so that heat discharged from the fume would not be significantly taken away by the vapor and the pipe wall warms up considerably.

A problem deserving special attention is scale accumulation inside the pipes, which is not allowed in a high-parametered power plant boiler. If a scale layer has accumulated because of deteriorating water quality and other reasons, even if it is very thin, the resulting warming up of the pipe wall will be very harmful to operation. Concerning the pipe wall's outside flank, if the fume temperature at the hearth outlet is excessively high, or deviates considerably, or secondary combustion has occurs in the flues, the fume temperature inside the superheater would be excessively high and cause $q_{\max}$ in all the pipe rows or in some regions to become excessively large, or soot and plaques to accumulate partially and the μ to increase. The combined effect of all of these would inevitably enhance the partial temperature and mean temperature of the metal pipe wall.

CONSTITUTION FAULT TREE FOR OVERHEATING

The cause analysis above is shown as a fault tree (Fig. 2). Fortunately Structure Function (Huang et al., 1996) is useful and we can write out the mathematic aspects of the fault tree and carry out qualitative analysis and quantitative computation(Zhu, 1989).

The structure function can be expressed as below:

$$\Phi = x_{88} \cup \cdots \cup x_{99} \cup x_{102} \cup \cdots \cup x_{137} \cup x_{150} \cup \cdots \cup x_{160} \cup x_{346} \cup \cdots \cup x_{382} \cup (x_{100} \cap x_{101}) \cup (x_{384} \cap x_{385}) \cup (x_{39} \cap x_{58} \cap x_{41}) \cup \cdots \cup (x_{39} \cap x_{58} \cap x_{56}) \cup (x_{39} \cap x_{57} \cap x_{41}) \cup \cdots$$

$$\cup(x_{39}\cap x_{57}\cap x_{56})\cup(x_{40}\cap x_{58}\cap x_{41})\cup\cdots\cup(x_{40}\cap x_{58}\cap x_{56})\cup(x_{40}\cap x_{57}\cap x_{41})\cup\cdots\cup(x_{40}\cap x_{57}\cap x_{56}) \tag{3}$$

With Eq. (3), we can obtain the minimal cut sets for overheating of the superheater's pipe wall. The bottom events 88. . . , 99, 102. . . , 137, 150. . . , 160, 346. . . , 382, will each compose a minimal cut set. There are 96 minimal cut sets altogether. In addition, one of the bottom events 41, . . . , 56, one of the bottom events 39, 40 and one of the bottom events 57, 58 comprise a cut set. There are 64 minimal cut sets altogether. The bottom events 100 and 101, 384 and 385 comprise two minimal cut sets. So we will have 162 minimal cut sets altogether and each will be a minimal set which engenders a top event. From this we can obtain the fault model for overheating of superheat's pipe wall.

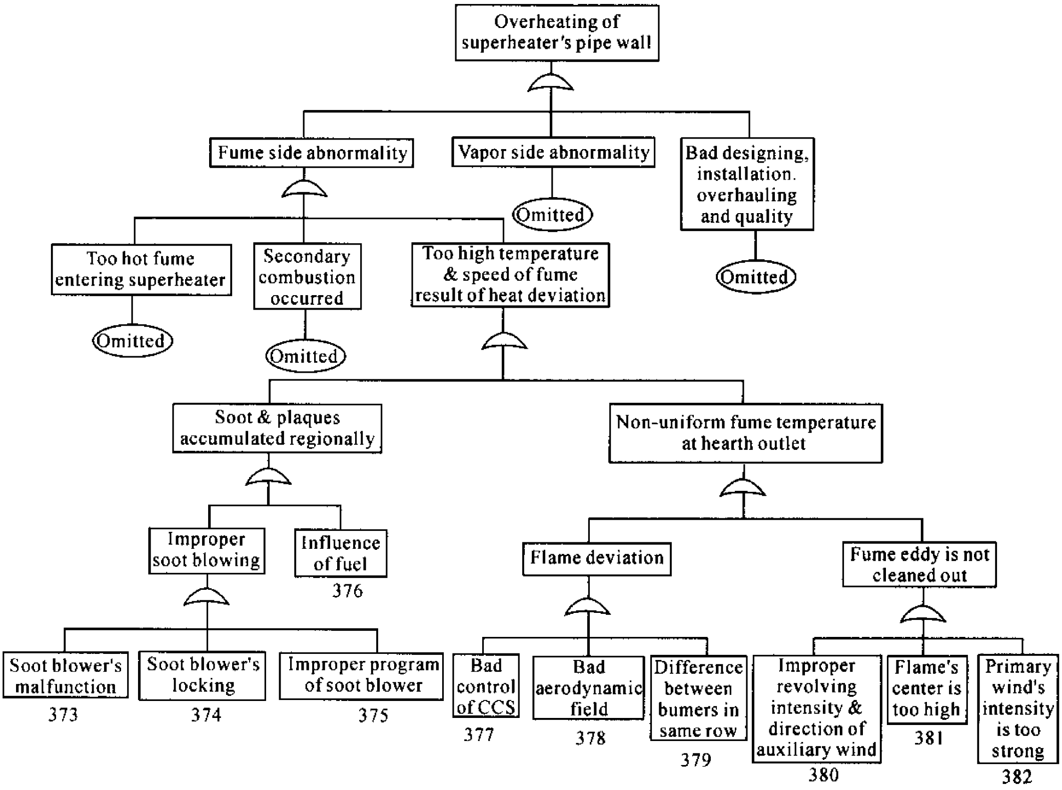

Fig. 2 The fault tree of overtemperature of superheater's pipe wall

Then we can compute the structure importance of every bottom event in the fault tree according to the structure function and the structure importance of bottom events (88. . . , 99, 102. . . , 137, 150. . . , 160, 346. . . , 382) could be expressed as shown below:

$$I_{\phi}(i)=\frac{2^{24}-64-2}{2^{120-1}}=2.4345\times10^{-29}$$

$$i=88,\cdots,99,102,\cdots,137,150,\cdots,160,346,\cdots,382 \tag{4}$$

The structure importance of bottom events 39, 40, 57, 58 can be expressed as shown below:

$$I_{\phi}(i)=\frac{2^{24}-32-2}{2^{120-1}}=2.524350\times10^{-29}$$

$$i=39,40,57,58 \tag{5}$$

The structure importance of bottom events 41, . . . , 56 can be expressed as shown below:

$$I_{\phi}(i)=\frac{2^{24}-(64-4)-2}{2^{120-1}}=2.524346\times10^{-29}$$

$$i = 41, \cdots, 56 \tag{6}$$

The structure importance of bottom events 100, 101, 384, 385 can be expressed as shown below:

$$I_{\phi}(i) = \frac{2^{24} - 64 - 1}{2^{120-1}} = 2.524345 \times 10^{-29}$$

$$i = 100, 101, 384, 385 \tag{7}$$

In short, the results indicated that all the structures have similar importance. This is because there are too many bottom events (120) and minimal cutsets (96) comprised of single bottom events that make the structure importance of each bottom event become more minor (the denominator in the Eq. (7) is greater than the numerator).

CONCLUSIONS

1. This article presents analysis of the overheating mechanism of the superheater's pipe wall under condition of non-uniform heat transference and scaling in pipes and provides some computing formulations in advance.

2. The large-scale boiler's structure and operation characteristics are used to establish a fault tree for analysis of the overheating of a superheater's pipe wall.

3. The analysis can be advantageously applied to ensure safe operation of boiler.

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