Oil Shale, Vol. 14, No. 3 Special
pp. 328-334

ISSN 0208-189X

CRACK IN RECOVERY BOILER

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Recovery boiler "Mitsubishi-315" erected at the end 1964 has worked more than 240,000 hours.

Boiler consists of two drums connected with bank tubes, furnace with waterwalls, the first and the second stages of superheater and the vertical economizer with its headers. Some basic elements of boiler have been exchanged during operation – the economizer tubes due to corrosion problems – two times, the second stage of superheater, and the lower part of waterwalls in the furnace have been reconstructed. The fin tubes on the level below the second oil burners have been changed with smooth tubes so that one upper tube has been connected with two tubes by Y-joints. Original basic parts are drums with bank tubes, the first stage of superheater, upper waterwalls in the furnace and most of headers.

Long-term operation has been ascertained two problems – heat transfer surfaces' corrosion and cracking in the drums. The main safety problem of boiler is developing of cracks during the operation. The reason of forming and developing of cracks is the subject for this paper.

OPERATING CONDITIONS

Operating pressure of steam is 3.3-3.5 MPa and temperature 450°C. Usually recovery boiler was shutdown during operation in every month due to different reasons, for example for cleaning, for technological reasons and so on. Duration of such outages was 48-72 hours. One of the longest shutdown in year for the repair the boiler continued for a month. The number of all shutdowns is about 350-380.

CRACKING

In the table 1 the composition of drum metal is given. Material used for the drums of boiler Mitsubishi-315 is SB49B. The other materials shown in table 22K and 16ГНМ as extensively used in boiler industry for drums are given for the comparing.

Table 1. **Materials Used in Boiler Drums**

Material	Tensile stress, MPa	Yield stress, MPa	Composition, % C	Si	Mn	Si	P
SB49B	560-580	380-400	0.24-0.27	0.20-0.26	0.84-1.27	0.009-0.013	0.011-0.013
22K	510	250	0.18-0.26	0.17-0.40	0.7-1.0	<0.04	<0.04
16ГНМ	529	356	0.12-0.18	0.17-0.37	0.7-1.1	<0.04	<0.04

As seen in Table 1, the materials SB49B and 16ГНМ are similar according to mechanical properties. Investigation showed that the intensity of stress in the eyes of tubes in the drum of steel 16ГНМ is equal 400-600 MPa after of few ten thousand hours of operation, i.e. limit of creep-rupture strength in the temperature of 350°C. Cracking of drums manufactured from steel 16ГНМ is observed after operation of 10-30 thousand hours [1]. According to Finnish review [2] cracking was most commonly found in the cylindrical shell region, and about 25% less often in the heads and in the man-hole areas.

By examinations of steam drums of Mitsubishi-317, the cracks were observed in two different places. At first the crack was found in the welding between the head and cylindrical part of drum at the inside surface. It appeared after fifteen years of operation. The depth of this crack was 5-7 mm and the length was three quarters of perimeter the drum. After sharpening on a grindstone the crack has not been developed further to depth.

The second-type cracks were developing around bank tube holes in the steam and water drums.

The bank tubes were rolled in the drums, and besides that the tube ends in ligaments of the border rows at the three sides (Fig. 1, bold line) were welded too.

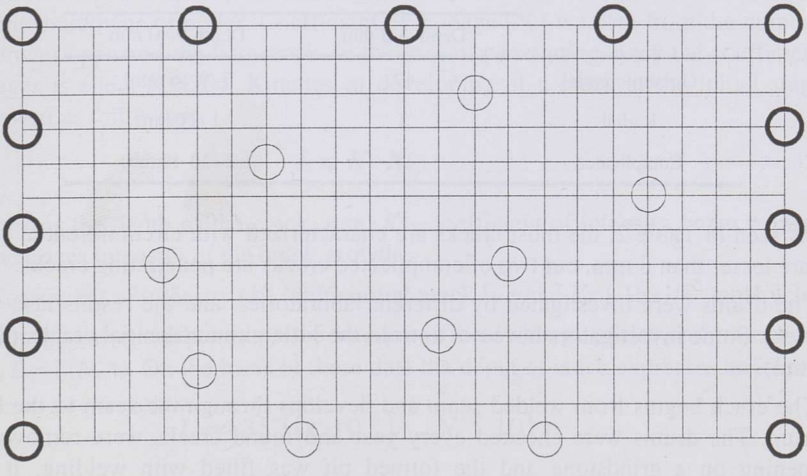

Figure 1. Layout of bank tubes plate in steam and water drums. Front of boiler; bold line shows welded rolled eyes

The first cracks in these welded eyes were observed after 20 years' operation, about 160 000 h and after 220-240 shutdowns. Most of formed cracks had been aligned in two directions: radial and circumferential of tube holes. Some cracks had more complicated shape. Cracks with different shapes are represented in Figure 2.

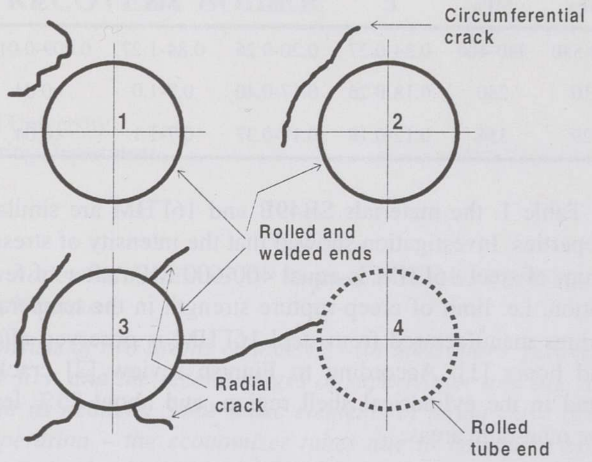

Figure 2. Cracks with different shape

Tube eyes No-s. 2 and 3 have circumferential cracks. Tube eye No. 1 has crack with complicated shape. Tube eye No. 3 has the both type cracks – radial and circumferential. After 232,000 hours' operation, the radial crack began from eye No. 3 and penetrated through ligament between eyes No-s. 3 and 4. In the Table 2 parameters of cracks are given which are observed in 92 tube eyes.

Table 2. **Nature of Cracks**

Nature	Number of tube eyes	
	Depth 3-8 mm	Depth 9-40 mm
Circumferential	40	7 (9-16 mm)
Radial	2	1 (10mm)
Complicated	11	2 (30-40mm)

As seen in Table 2, the most cracks are characterized with circumferential shape and are lesser than 8 mm, but two of complicated cracks are penetrating cracks.

The drums were investigated by different laboratories, and the results also were different. Some investigators have not noticed the little circumferential cracks (depth 1-5 mm).

The crack begins from welded seam and develops through the seam to the body of drum. The drums were checked every year and found cracks were removed by sharpening on a grindstone and the formed pit was filled with welding. It was observed by checking that with aging of metal the number of formed cracks continuously grew. After 176,000 hours' operation was observed a crack in 1 tube eye, after 208,000 h in 3 tube eyes, 216,000 h in 8 tube eyes, 232,000 h in 63 tube eyes.

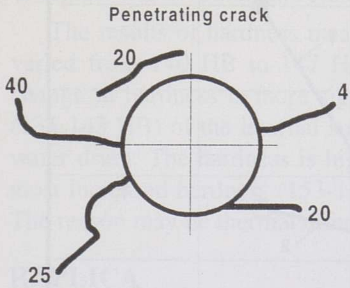

Figure 3. Penetrating cracks in water drum. Numbers show the depth of crack

The first crack in tube eyes presented in Figure 3 was observed after 176,000 hours' operation. The measured depth of crack was 5 mm. Checking after 32,000 hours, the depths of cracks were 7 and 8 mm, and after extra 8000 hours (totally 216,000 hours) the depth of cracks was increased to 12 mm, and for 232,000 h operation some cracks run through the wall (40 mm) of water drum.

Presumably the developing of through crack was the following: the first crack with depth 5 mm, observed after 176,000 h was not sharpened with a grindstone to peak of crack and the crack continued to penetrate deeper. So this process repeated every year, and after 232,000 hours' operation the crack run through the wall of drum.

KINETICS OF CRACK DEVELOPMENT

The developing of thermal-mechanical crack is described to occur in two stages: beginning of the initial crack and growth of formed crack [1]. Conventionally it is taken so at the beginning stage the initial crack from both stresses – the thermal and the mechanical stress started at the same number of cycles of the heat changes at present shutdowns of boiler. Coefficient of damage (N_o) is taken from the number of shutdowns appeared the first crack. In the case of penetrating crack the coefficient of damages is equal N_o=264. Kinetics of developing of a crack at the initial stage is expressed as following:

$$L = K \cdot N_o, \tag{1}$$

where L is the depth of the crack, mm; K – coefficient of intensity, main parameter characterizes intensity of the crack growth.

Coefficient of intensity (K) of the initial crack is equal K=1.16×10^{-3} mm/cycle.

Depth of crack depends on the number of heat change cycles and on operation time, L = f (N, τ). On the basis of these data the depth of crack expresses as follows:

$$L = 4.35^{-1}\left(\tau \cdot 10^{-5}\right)^{2.9} \cdot N^{1.5} \cdot 10^{3}, \tag{2}$$

where τ is operation time, h; N – number of shutdowns.

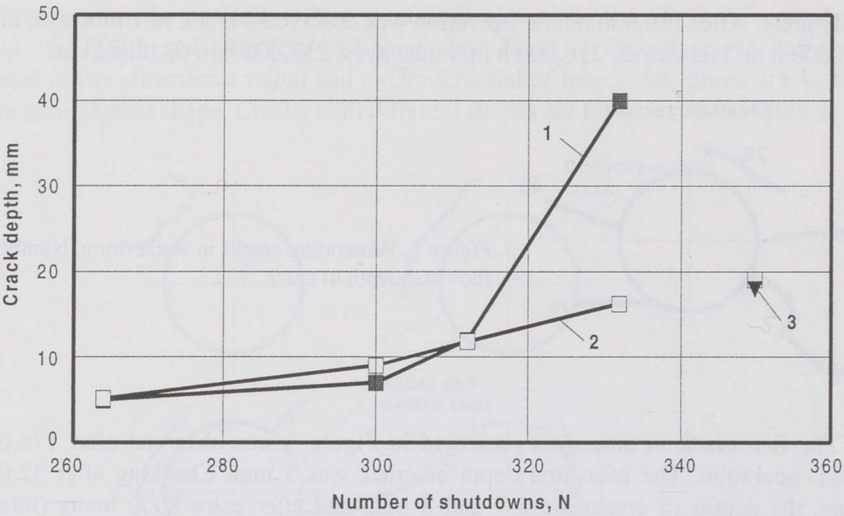

Figure 4. Development of penetrating crack. 1 - current crack, 2 - calculated crack, 3 - single crack formed during one year after 240,000 hours' operation

As seen in Figure 4, the calculated crack depth (line 2) corresponds to the current depth at the first stage of the crack forming. Obviously these cracks are formed and developed due to thermal fatigue. Marked labels on line 1 are showing measured depth of penetrating crack according to the number of shutdowns. Label 3 marks the depth of crack which forms during one year after 240,000 hours' operation.

During some time depending on the cycles of shutdown and operation time, the mechanical stress exceeded the thermal stress, and crack developed due to mechanical fatigue. At this stage the intensity of crack growth induced by mechanical fatigue is much more than the intensity induced by thermal fatigue.

Minimum required thickness of shell plate of drum is 26.56 mm, and it was actually taken equal to 29 mm. At the same time the calculated thickness of tube plate in drum equals to 44.25 mm, actually and it was determined equal to 46 mm. It is seen that if the depth of crack in the ligament equals to more than 46-26.65=19.35 mm then residual thickness of plate is less than required minimum thickness. Obviously it is time of increasing the intensity of crack developing due to mechanical stress. It is shown by the current data (Fig. 4, the upper part of line 1) as well.

Point 3 in Figure 4 shows the depth of a crack formed in boiler drum during one year after 232,000 h operation and 336 shutdowns, i.e. the crack formed after these conditions. After that, boiler worked extra 8000 hours and had 14 shutdowns.

Calculated by the equation (2) under conditions τ=240,000 h and N=350 shutdowns depth is equal to 19.06 mm. As seen in Figure 4, the difference between depth of actual crack (18 mm) and calculated value (19.06 mm) is equal to 1.06 mm.

DETERMINATION OF HARDNESS

Determination of metal hardness was made by mobile hardness meter BПN-2. Rate of impact was 0.75 m/s and etalon hardness was 143 HB.

The results of hardness measuring on the internal surface of the water drum has varied from 140 HB to 147 HB, i.e. in the narrow range. In the steam drum the change in hardness is more significant. In the volume of steam the hardness value (135-143 HB) of the internal surface is the same as the hardness value of surface of water drum. The hardness is higher at the height of water level (143-157 HB). The most increased hardness (153-161 HB) belongs to the area of circumferential crack. The reason may be thermal effect during grinding the crack by grindstone.

REPLICA

The samples are plastic replicas from polished and etched metal surfaces. The samples were taken from the boiler drum.

The replicas were coated with gold and examined with a scanning electron microscope (SEM).

The microstructure in a replica is shown in Figure 5. As seen, it is mainly acicular ferrite or bainite with network of ferrite at the grain boundaries of prior austenite. Acicular ferrite and bainite likely was the base metal of drum. Only bainite structure characterizes transient zone or weld.

Examining the Figure 5, it may be noted that the phenomena of structure changes during the boiler operation are not observed.

Figure 5. Microstructure of sample on the internal side of drum. Magnification 500 times

DISCUSSION

Operating cyclic loads in the drum are classified into low-cyclic load resulting from starting, shutdowns, accident removal boiler from service and hydrotests, for example 15 times a year at the present, and high-cyclic load concerned with long term operation of drum at optimal regime.

Fluctuation of temperature in the wall of drum is about 15-20°C with periodicity 20-50 s and 5-12 K with periodicity 36 s. Thermal stresses under these conditions are equal to respectively 60-80 and 20-50 MPa at cyclic recurrences 5×10^6-5×10^7 and 5×10^7-5×10^8 [1]. Near the eyes of tube in the drum the additional stresses from the heat changes are much more than that value far from holes.

Mechanical loads under transient regime may be considerable. Mechanical loads during transient regime may be extent to 300 MPa [2].

Cyclic thermal stress arising from nominal regime of drum influences with static extending stress from internal pressure and together they exceed the yield limit at the edges of holes.

In the present case the effect of welding on the developing of cracks must be mentioned. Cracks formed in the eyes of tubes welded in the drums. So far the forming of cracks in the eyes of tubes rolled in the drums has not observed.

Long-term operation with low-cyclic and high-cyclic loads is a reason of forming of cracks in the welded rolled eyes in tube plates of drum.

One-year operation of the boiler after long-term working with frequent shutdowns (12-16) is a sufficient time to form dangerous cracks (more than 18 mm in the present case).

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Presented by A. Ots
Received March 17, 1997