Explosion and fire caused by the breakaway of the cover plate from the heat exchanger of the desulfurization equipment

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(Summary)

An explosion and fire occurred at the Sodegaura-refinery of Fuji Sekiyu Corporation. Ten people died, and seven people were injured. The lock ring of the cover plate (channel cover) of a BLC type heat exchanger was broken off, and the channel cover, the lock ring, and other parts were blown off and collided with each other. Finally, an explosion and fire occurred that were caused by the leak of the hydrogen gas from the heat exchanger.

1. Component

The BLC (Breech - Lock - Closure) type heat exchanger of the desulfurization equipment (No.2 VGO isomax equipment) for heavy oil

2. Event

For the purpose of replacing the catalyzer, the heat exchanger was stopped on October 1. It resumed operation on October 16. The hot-bolting process for the heat exchanger (E-2801A) began at about 15:30, and it finished at about 15:42. After that, the hot-bolting process for the other heat exchanger (E-2801B) began. At about 15:47, smoke was observed rising near the detection hole at the upper part of E-2801B, and the process was stopped. At about 15:52, an explosion and fire occurred near E-2801B, the explosion and fire disaster occurred. Excluding the human damages, the cost of the physical damage was about 2.4 billion yen.

In particular, the channel cover, the lock ring, and other parts flew over 130 meters to hit and destroy an oil tank and pipes of Nippon Kougyou Corporation, located next to the Fuji Sekiyu Sodegaura-refinery.

3. Course

The damaged heat exchanger was a BLC type licensed by CHEVRON RESEARCH USA CO LTD and manufactured by Chiyoda Kakoukensetsu Corporation.

Figure 1 shows the structure of the BLC type heat exchanger. Figure 2 shows the details of the airtight design. The pressure exerted on the channel cover of the heat exchanger is supported by the screw thread of the channel barrel via the lock ring. The airtightness between the inside and outside of the heat exchanger is kept by gaskets through the torque of the bolt which fastens the lock-ring. The piping area and the body area are separated by the tube sheet. The separation between the piping area that is at high pressure and the body area that is at low pressure is kept airtight by gaskets through the torque of the channel cover set bolt that is applied through the special partition.

Generally, hot bolting is required at maintenance of heat exchangers which are used under conditions of high pressure and high temperature because the inside fluid tends to leak out with increases of pressure and temperature when the exchangers start to work. In the flange type heat exchanger, the bolts are big, and there are many parts near the flange. Therefore, maintenance is difficult. On the other hand, in the BLC type heat exchanger, the bolts are small and all bolts are located in the front end of the heat exchanger. So, maintenance is easier. E-2801B was manufactured in February 1975. Maintenance was performed at six times between 1975 and 1991. In the latest maintenance operations (Jun 1998 and Jun 1991), the heat exchanger was moved to the factory of Chiyoda-Protech Corporation in Kawasaki, and the maintenance was performed there. The accidents had a great influence on society, so an accident investigation commission was established. In the commission, the causes of the accident, methods to prevent the recurrence of the accidents were discussed, and a report was published.

4. Cause

The causes of the accident are as shown below.

1) Although the diameter of the gasket retainer (disk-shaped, SUS321) that was set at the back of the channel cover to keep it air tight was being reduced by the repeated ratcheting, it was not corrlectly replaced.
2) The thermal deformation of the inner parts of tube area was absorbed by the destruction of the tip of the internal flange bolt set (10). However, the internal flange set bolts were not adequately replaced. Therefore, the load on the channel cover set bolts (17) was increased, and the lock ring was bent. Gradually, the diameter of the lock ring decreased.
3) There were two main causes for the increase of the diameter of the channel barrel (1). One was the thermal deformation caused by the difference of temperature resulting from the removal of the insulation. The other was the variation of the inner pressure caused by the leak of hydrogen gas.
4) Through the combination of the decrease of the lock ring's diameter and the increase of the channel barrel's diameter, the overlap of the screw threads was decreased. Finally, the lock ring was broken by the plastic deformation of the top of the screw threads which were set in front of the channel barrel.
5) The break off of the lock ring caused the lock ring (900kg) and the channel cover (2000kg) to fly through the air. In addition, leaking hydrogen gas caused an explosion and fire to occur.

Figure 3 shows the fault tree that is focused on the fracture mechanics and fracture process. Figures 4 and 5 show the fault trees focused on the maintenance. Figure 6 shows the event tree that describes the separation of the cover plate of the heat exchanger.

5. Countermeasure

The Ministry of International Trade and Industry advised countermeasure to all of the corporations using the same heat exchanger, all petrochemical complex corporations including Fuji-sekiyu Corporation, and the makers of the damaged heat exchanger. Additionally, the High Pressure Gas Safety Institute of Japan held a brief session about this accident.

6. Knowledge

The design of pressure proof parts is based on the concept of elastic design. However, the concept of plastic design is required to design some parts. Either 1) fatigue and ratchet analysis to certify the lifetimes of these parts or 2) regular part replacement are required. In these exchangers, the gasket retainer and the internal flange bolts are particularly relevant.

For regular replacement of parts, a baseline and adequate maintenance management are required. In particular, it is not clear who is responsible for the decision and confirmation of the parts replacement, the owner or the maker of the heat exchanger. The circumstances of owner and the convenience of maintenance engineer often lead to accidents.

7. On the Side

○ Gasket retainer

In general, the cover of a bottle is held to the bottle by the meshing of a screw cutting on the outside of bottle's mouth and on the inside of the bottle's cover. However, in the BLC type heat exchanger, the situation is opposite. There is a screw cutting on the outside of the lock ring, which acts like the bottle's cover, and there is a screw cutting on the inside of the channel barrel's cup, which corresponds to the mouth of the bottle. In medicine bottles, there is a thin disk on the inside of the cover that is outside of the screw cutting. This disk keeps the bottle airtight. The retainer for the BLC heat exchanger is located on the inside of the screw cutting. Although this situation is opposite from that of the medicine bottle, the role of the gasket retainer is also to keep the heat exchanger airtight.

○ Ratchet and ratcheting

The gear that is used to tighten the strings of a tennis racket is called a "ratchet". Deformation that occurs to one way is called "Ratchet deformation". On condition that tensile stress is exerted to a rod, tensile plastic strain in the direction of the tensile stress is accumulated by repetition of thermal stress and tensile plastic deformation. On the other hand, when compression stress is exerted to a rod, compression plastic strain is accumulated in the same direction. This is called "Thermal Ratcheting". Compression stress is performed to gasket retainer of which shape is disk. Then compression plastic strain is accumulated by repetition of thermal stress. In the result, diameter of it decreases.

8. Primary Scenario

01. Misjudgment
02. Misjudgment of Situation
03. Organizational Problems
04. Poor Management
05. Usage
06. Maintenance/Repair
07. Parts Replacement
08. Incomplete Standard of Replacement

09. Gasket Retainer

10. Bad Event

11. Mechanical Event

12. Pinching

13. Leak of Hydrogen Gas

14. Usage

15. Maintenance/Repair

16. Incomplete Standard for Replacement

17. Internal Flange Set Bolt

18. Failure

19. Deformation

20. Plastic Deformation

21. Lock Ring

22. Bad Event

23. Mechanical Event

24. Decrease of height of screw

25. Break Out of Lock Ring

26. Flight of Channel Cover

27. Secondary Damage

28. External Damage

29. Explosion and Fire Disaster

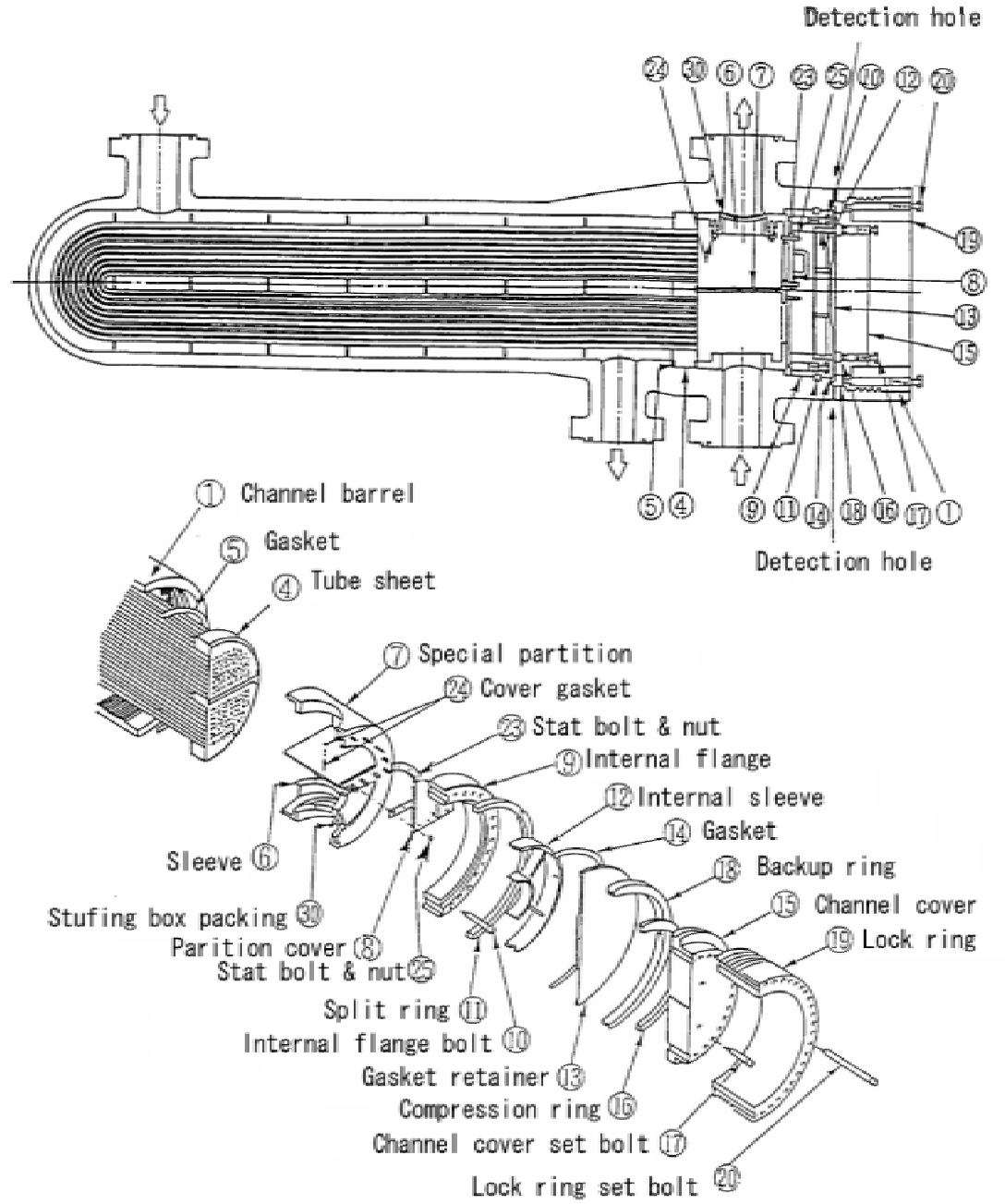

Fig. 1 Structure of BLC type heat exchanger.

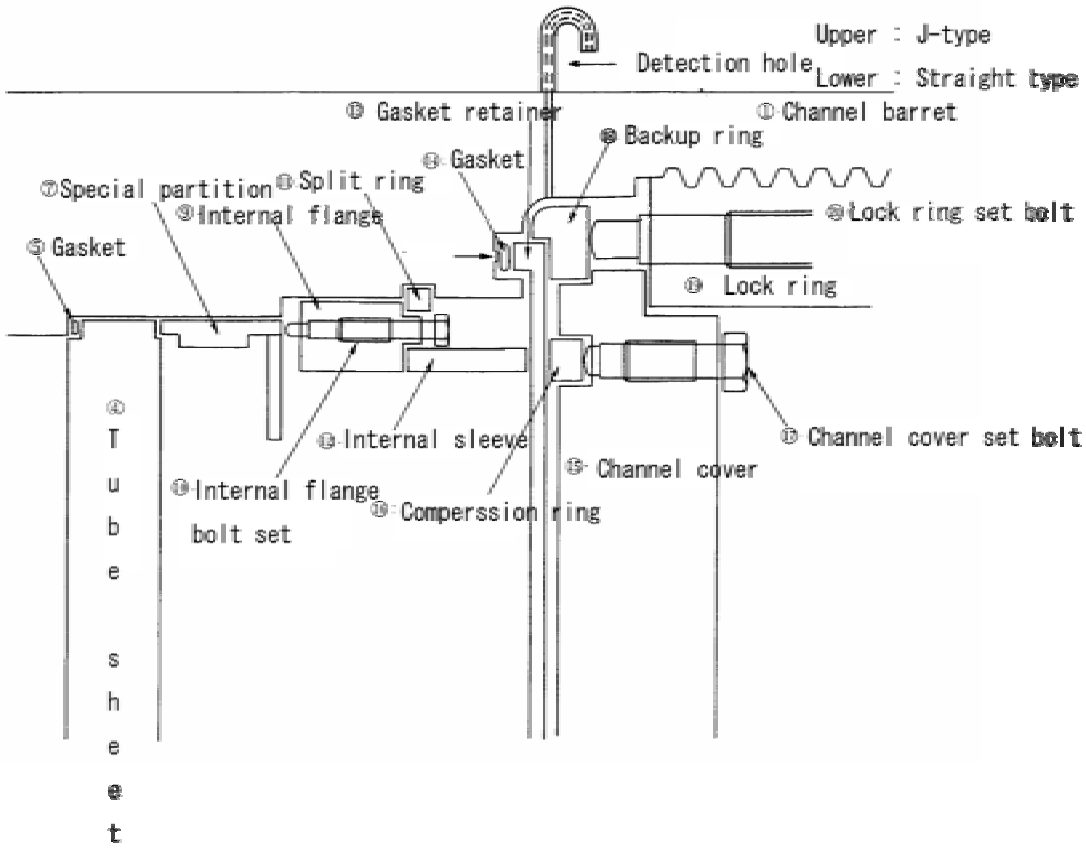

Fig. 2 Detail of airtightness.