Explosion of air bottle by mixing oil

July 31st, 1995, Okegawa-city, Saitama Prefecture

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(Summary)

The accumulator in the Okegawa factory of Mitsubishi Materials Corporation exploded at 8:27 am on July 31st, 1995. Okegawa is in Saitama Prefecture, Japan. Eighteen people were injured. Two of the injured people were neighborhoods of the factory, and one of neighbors died after thirteen days. Two air bottles, which were parts of the accumulator, burst. In addition to those of the plants of factory, the windows, roofs, and walls of houses that were outside of the factory but were less than 1500m from the accumulator, were broken. Parts of the broken accumulator flew 1200m.

Old oil that had been mixed to the air bottles ignited, causing the explosion. It was recognized again belatedly that the mixture of oil and high-pressure air is dangerous. The management of oil quality and cleaning need to the air bottle which is recognized to have no risk about the explosion.

1. Component

The accumulator (high-pressure gas equipment) is a part of a 1650t extrusion press that makes jointless copper tubes. It consists of an air compressor, two air bottles, the accumulator and so on. The accumulator is a vertical hydraulic type, and the piston compresses and expands air. The two air bottles are identical. One is called A-type air bottle and the other is B-type. The air bottle is multilayer cylinder vessel. The design pressure and the volume of the vessel are 210kg/cm^2 and 1.8m3, respectively.

2. Event

At 8:27 am on July 31st, 1995, in the Okegawa factory of Mitsubishi Materials Corporation in Saitama Prefecture, a worker opened a valve that was in the upper part of the accumulator in order to run the extrusion press equipment. Suddenly, the two air bottles exploded. The outline of the accumulator is shown in Fig.1.

Fig.2 shows the layout of the factory and the situation of this accident. The two air bottles broke into small parts that flew into the neighboring areas and broke the buildings, roofs and walls of the buildings there. The A-type air bottle broke into thirteen parts, and the maximum flight length of the parts was 630m. The B-type broke into eleven parts, and the maximum flight length of the parts was 1200m.

The damage to the accumulator and other nearby parts of the extrusion press was not so bad. However, the wall, the roof and the center pillar of the building in which the press equipment was housed received greater damage. Furthermore, the windows, roofs and walls of neighboring houses that were not inside the factory but were less than 1500m from the air bottles, were seriously damaged. Eighteen people were injured, two of whom were the neighborhood of the factory. Thirteen days later, one of them died.

Because there are so many plants that are similar the one in the accident, the Ministry of International Trade and Industry established a committee for investigating the course of the accident and developing measures to prevent its recurrence.

3. Course

The air bottles were installed as parts of the accumulator that was added to the extrusion press in 1966. It was thirty years before the accident. The latest regular self-inspection was performed on Dec 11th, 1994, and the latest safety inspection was performed on July 6th, 1995. However, the insides of the air bottles were not appropriately cleaned since the time that they were built.

The air part and the oil part were not completely isolated from each other because the accumulator uses a piston as a compartment. The oil leaks along the side of the piston into the air part. Through the investigation of the accident, it was determined that oil had collected in the hand valve, the inside of the connection tube and the lower part of the air bottle. Also, the operating oil of accumulator was leaking out because of the accident, so the piston was at its lowest position. Oil had accumulated on top of piston to a height of 42mm (about 14L). Although it is not clear whether the oil had accumulated before or after the accident, it is certain that there was oil in the air bottles and in the upper part of the piston before the accident.

Although the amount of oil that had accumulated in the air bottles was verified using liquid level indicator, the quality and amount were not verified. It discharges to the drain gutter.

From the results of gas chromatography of the oil left in the accident plants, lubricating oil for the air compressor was found only near the compressor and the connecting tubes. The rest of the oil was the press oil for the accumulator. Therefore, the oil causing the explosion is concluded to be the oil for the accumulator. Through repeated compression and expansion of air over the thirty years of operation, the quality of oil deteriorated, and hydrocarbons with low boiling temperature accumulated. Consequently, the ignition temperature of the old oil was 60 degrees C lower than that of new oil, and it could easily explode.

Until July 29th, the plant was operated. The start and stop process in which the open and close process of hand valve was accompanied often occurred. At 15 p.m. on July 29th, when the plant was stopped, the pressure of air bottle was 195kg/cm^2.

The leak of press oil was verified by the accident's investigation. It was verified by the results of the leak test of the solenoid valve that is set in the pipes. Therefore, the press oil leaks from the solenoid valve when the plant is stopped for long time or when the pressure inside the accumulators drops to atmosphere pressure. From the analysis of the accident, the length time that had passed from the time that the plant was stopped on July 29th to the time when it was re-started on July 31st was estimated to be about 41 hours and the pressure inside the accumulator was estimated to be 22.5kg/cm^2. When the hand valve was opened, the high pressure air in the air bottles combined with the oil in the bottles to form an air-oil mixture that splashed into the accumulator where the pressure was low, and the inside of accumulator was misty with the air-oil mixture.

In the hand valve and the connecting pipes of the air bottles, the phenomenon of plastic deformation,

which caused the expansion of the pipes, was confirmed. It was hypothesized that the flame had propagated along the air-oil mixture in pipes before causing the explosion of the air bottles.

Considering the fact that the two air bottles had exploded at the same time, and from knowledge of fracture mechanics, the ignition was hypothesized to have occurred in the inside of the accumulator and the connection pipes. The possible causes of the ignition are shown below, but which actually occurred could not be determined.

(1) Rise of temperature by adiabatic compression

(2) Elec trostatic discharge

(3) Friction heat by solid

In summary, first ignition occurred in the accumulator. Next, the flame propagated through the inside of the pipes and reached the two air bottles at the same time. Suddenly, an explosion occurred in both bottles by the air-oil mixture and the old oil.

Moreover, a new impact mark made by the explosion was confirmed on the sheet of safety valve.

Fig. 3 shows the fault tree describing the fracture mechanics and process. The event tree of air bottles' explosion is shown in Fig. 4.

4. Cause

(1) Deterioration of press oil

Operation was continued without confirming the pressure difference between the accumulator and the air bottles when the plant began to operate.

When the hand valve is opened under the condition of low pressure in the accumulator, the temperature in the accumulator increases by adiabatic compression. Through the repetition of this process, the oil that was mixed with air in the accumulator and the air bottles was deteriorated (carbonized). This carbonization of the oil resulted in the formation of hydrocarbons with a low boiling point, causing the risk of ignition and burning to increase. Checking of the quality of the oil and the drain and cleaning of the equipment were inadequate. It is thought that regular cleaning would have prevented the accident.

(2) Difference of pressure

The main cause of this accident was the formation of the burnable mixture of air and fuel that occurred when the hand valve was opened under the condition of a large difference of pressure between the accumulator and the air bottles.

5. Countermeasure

The countermeasures proposed to prevent future accidents are shown below.

(1) Use of nitrogen instead of air. This measure is costly.

(2) Keep the air and oil isolated. It is difficult to keep them perfectly isolated.

(3) Change system to check condition of inside of equipment

(4) Check the quality of the drain and oil, and clean the equipment regularly

(5) Change the mechanism to prevent impact of airflow when the hand valve is opened, or fix the process to open the valve

The countermeasures that were finally adopted are (3) and (4). They are daily maintenance. Prior to the accident, this factory had not paid attention to the leak of pressure oil in the accumulator and had not cleaned the inside of the air bottles for thirty years.

6. Knowledge

○ The quality of oil changes over time

The quality of even non-burnable oil used for long time will change and become burnable. Removal of the old oil and regular cleaning of the equipment is required.

○ Risk of mixtures of high-pressure air and oil

The risk of fire when old oil is mixed with high-pressure air must be recognized.

7. Primary Scenario

01. Organizational Problems
02. Poor Management
03. Poor Process Management
04. Disregard of Procedure
05. Ignorance of Documentation
06. Ignorance of Process Documentation
07. Usage
08. Maintenance/Repair
09. Management of Oil's Quality
10. Cleaning
11. Accumulator
12. Bad Event
13. Thermo-Fluid Event
14. Fluid Reaction
15. Difference of Pressure
16. Burnable mixture air
17. Bad Event
18. Chemical Phenomenon
19. Ignition
20. Burn
21. Failure
22. Large-Scale Damage
23. Burst
24. Air Bottle
25. Secondary Damage
26. External Damage

27. Equipments of Factory
28. Buildings Outside of Factory
29. Bodily Harm
30. Death
31. Bodily Harm
32. Injury

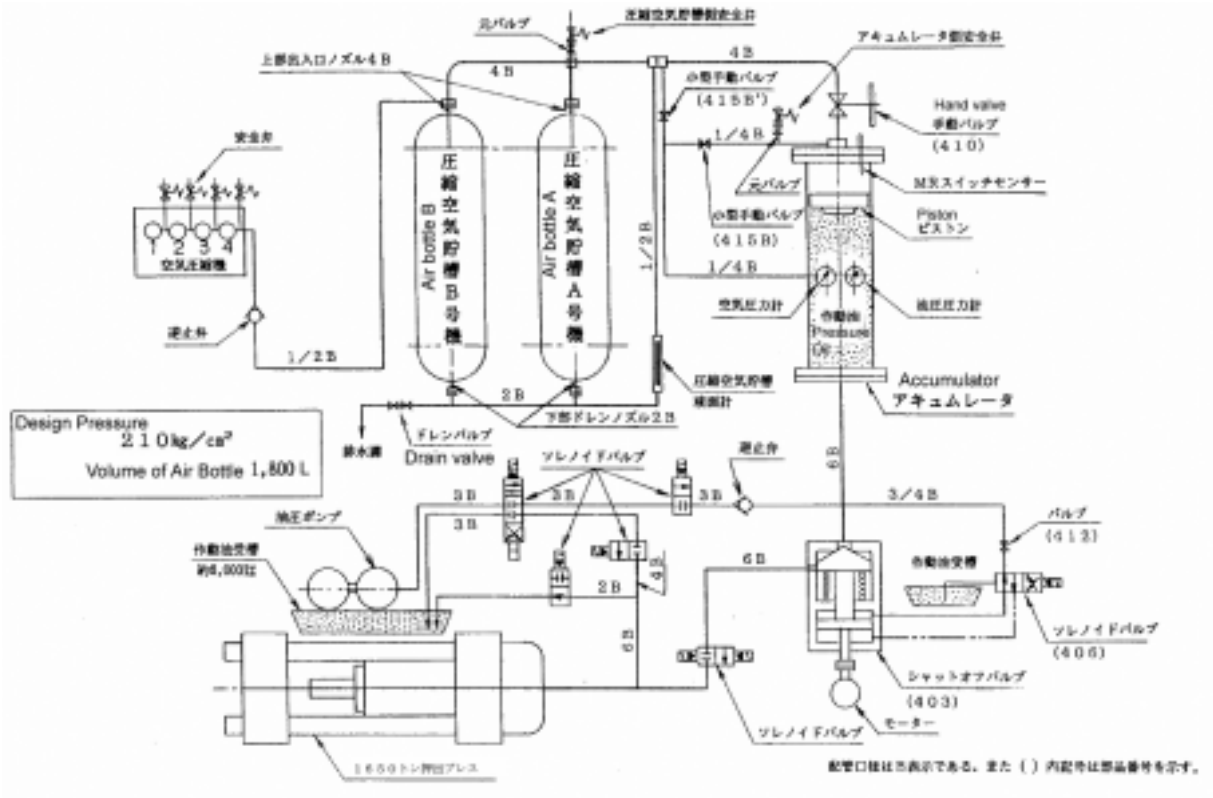

Fig. 1 Outline of Accumulator.

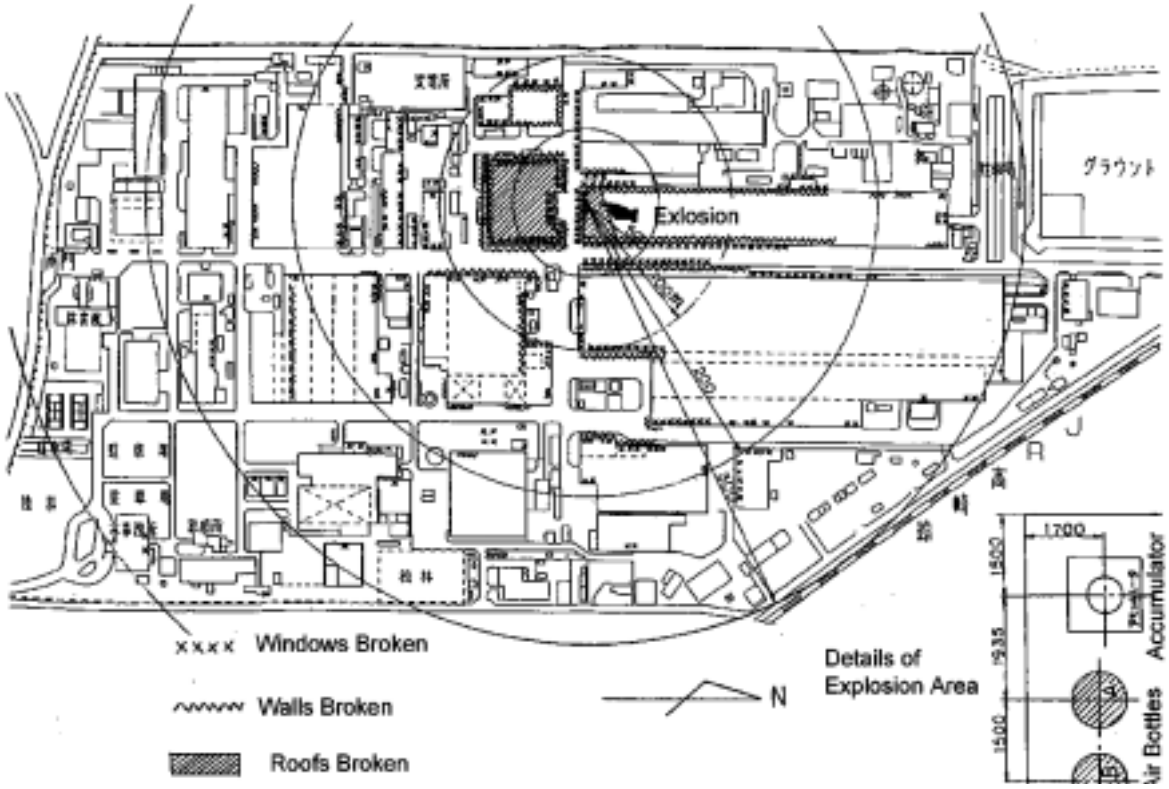

Fig. 2 Layout of Factory and Details of Damage.

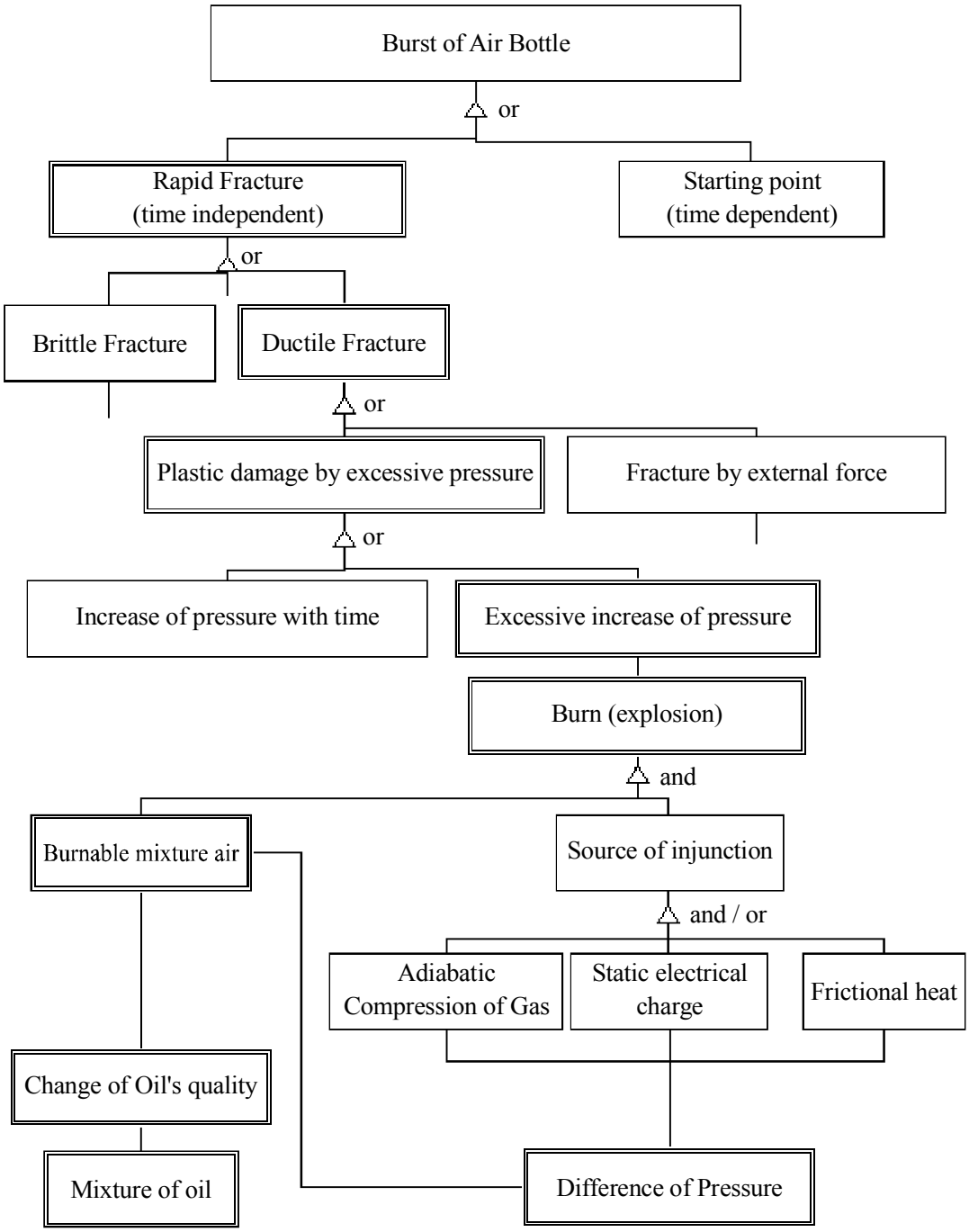

Fig. 3 Fault tree focused on fracture mechanics and process.

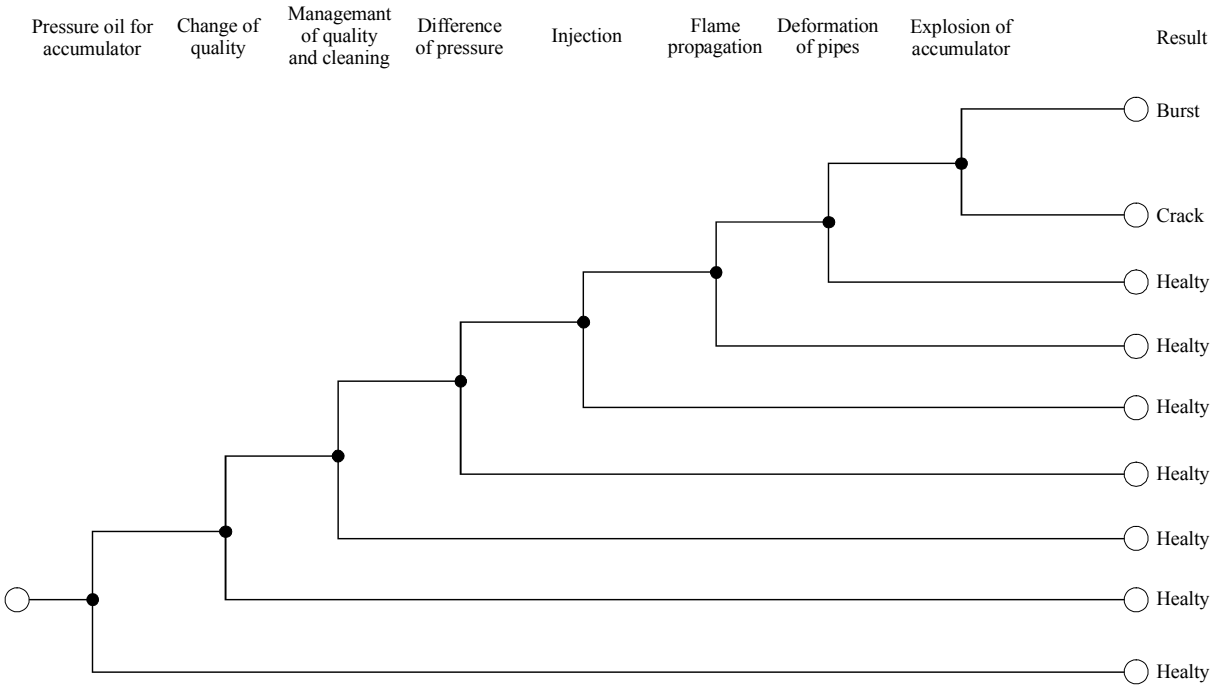

Fig. 4 Event tree of breakaway of heat exchanger's cover plate.