Explosion of Resin Factory in Osaka
【August 20th, 1982　Sakai, Osaka, Japan】

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This accident is an interesting example for considering the safety of a chemical plant and the ways of establishing effective countermeasures after the occurrence of an accident.

At midnight on August 20th, 1982, there was a relatively small explosion at a resin manufacturing plant of Daicel Chemical Industries, Co., Ltd. at the Sakai manufacturing complex in Sakai, Osaka, and the order to stop the plant was issued. During the shutdown procedure of the plant, gas leaked from a monomer mixing drum that contained two kinds of monomers as raw materials and a catalyst. The occurrence of the leak was informed to the meeting of the managing staff who were discussing the countermeasures to be taken to the first explosion. When all of the members attending the meeting rushed to the leakage site, the second large explosion suddenly occurred. This second explosion resulted in six fatalities, nine seriously injured, and 198 slightly injured persons. 178 of the 198 persons who were slightly injured were inhabitants of the nearby area. Furthermore, the number of houses damaged in the accident was over 1700.

Before the first explosion, agitation of the polymerization reactor and supply of lukewarm water to the cooling jacket had stopped due to a power failure. In order to keep the reactor cool, cold cooling water was used instead of the lukewarm water immediately. However, the reaction led to a runaway reaction, and monomers evaporated. The evaporated gas by passed the combustion deodorization furnace that had been designed on the assumption of usual exhaust gas processing, and the explosion occurred at the inlet of the stack. However, this first explosion did not cause any human damage or large physical damage.

The shutdown procedure of the plant was executed in the settlement of the accident, and at the same time, the managing staff held a meeting to discuss the countermeasures to be taken. The next day, the shutdown procedure and the countermeasure meeting were continued. In the evening, a gas leakage occurred from a monomer mixing drum, which contained the monomers with which the reactor will be charged. The gas leakage gradually increased, and nobody could get near the leakage place. On hearing the news, all of the members who were attending the meeting came to the leakage site. At that moment, a large explosion occurred. All human damage and large physical damage occurred in this second explosion.

While a liquid mixture of acrylonitrile, styrene and a polymerization catalyst of organic peroxide was left in the monomer mixing drum for 42 hours, a polymerization reaction started and let to a runaway reaction as a result of heat accumulation. Therefore, the pressure increased, and combustible gas leaked out. The gas accumulated in the factory and was ignited by a spark from the electric devices that were installed outside the dangerous facility zone. Staff members of the manufacturing section had thought at that time that a polymerization reaction would not occur at a low temperature of 27℃. However, it appeared that the polymerization reaction started by the delay of the monomer charge to the reactor that resulted from the first accident. When the plant was shutdown, there was still about 3800 kg of liquid in the monomer mixing drum.

1. Event

At this plant, AS resin (a co-polymer resin of acrylonitrile and styrene) and ABS resin (a three-component system co-polymer resin of styrene, butadiene and acrylonitrile) were manufactured, and there were five reactors for AS resin polymerization. On the day of the first explosion, two reactors named C and G were being used for polymerization.

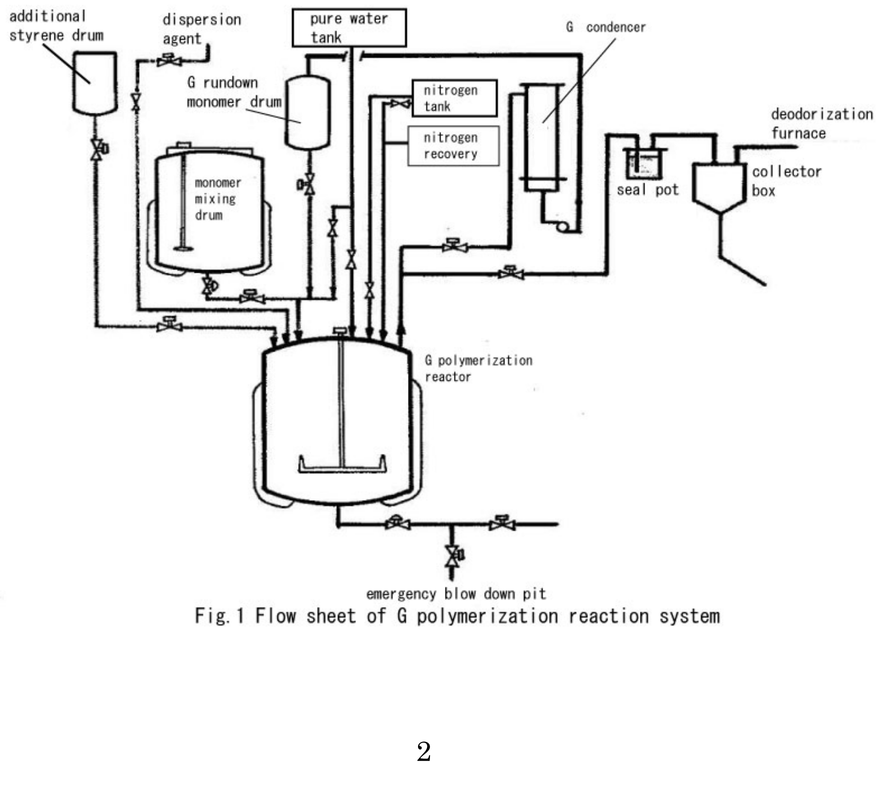

Fig.1 Flow sheet of G polymerization reaction system

The 400V power supply of the polymerization section failed at around midnight. The agitators and pumps for cooling water of the C and G polymerization reactors stopped, so cooling of the reactors stopped. In order to continue cooling, lukewarm supply water was switched to cold water manually. One ton of cold water was added to each reactor to cool them. Some time after, the polymerization reaction in the two reactors became a runaway reaction, and white smoky gas spouted from the manhole of the C reactor. The alarm of the deodorizing furnace rang, and the safety valve of the furnace automatically operated, redirecting the gas directly to the stack for combustion tail gas bypassing the furnace. At that time, the concentration of the combustible gas at the furnace inlet was 35% of the lower explosion limit, and the temperature in the furnace exceeded 830 ℃. The first explosion occurred in the exhaust gas duct, and damage occurred only in the furnace system.

The reason why a large amount of gas flowed into the furnace system is explained below. The liquid in the C and G reactors separated into two layers, a polymer layer and a monomer layer, because agitation in the reactors stopped. Furthermore, since the heat of reaction was not being removed, a rapid polymerization reaction occurred, and the liquid temperature reached the boiling point as a result of heat generated by the exothermic reaction. The remained monomer evaporated, and a combustible gas was formed. The combustible gas flowed from the pressure regulating valve via the vent gas collector to the furnace system. The furnace system diagram is shown in Fig.2.

Outline of first explosion at AS resin plant

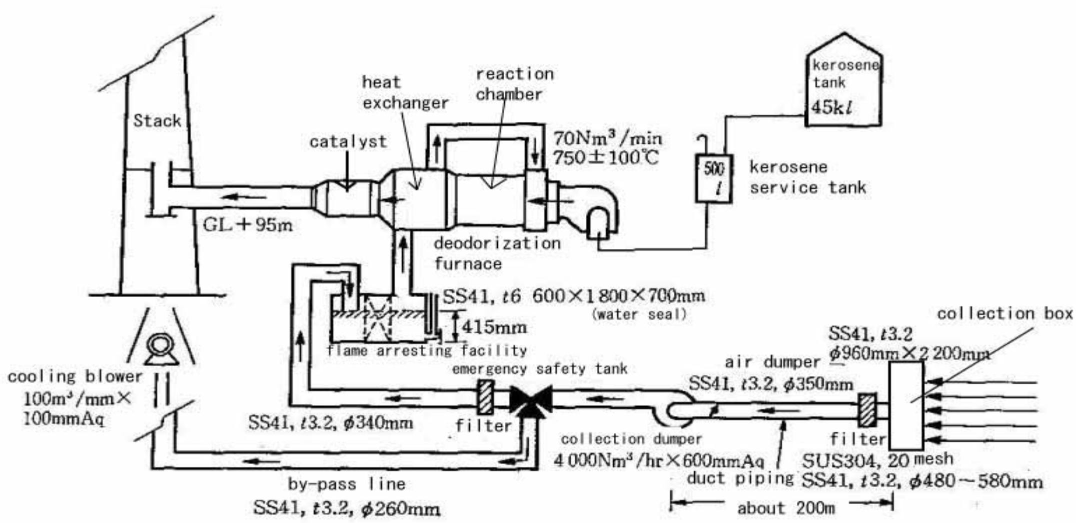

Fig. 2 Flow sheet of the deodorization furnace

The furnace had the following instrumentation system installed for safety: when the combustible gas composition exceeds 50% of the lower explosion limit, or the furnace temperature is over 830 ℃, the gas is redirected through bypass piping and led to the stack which discharges the gas after it is burned. In this accident case, the instrumentation system worked as designed.

After the first explosion, a stop order of the facilities was given by the fire fighting authorities. Therefore, the employees of the factory carried out only the necessary protection work such as drawing off the remaining material in the reactors in order to stop the plant in safe. The next day, thirteen managers of the factory had a preliminary meeting for the accident investigation committee at the same time as the shutdown procedure was being executed. In the evening, gas began leaking from the monomer mixing drum of the C series. An operator who found the leakage tried to enter the building in order to confirm the situation, but he could not enter the building because the leak had increased. Some of the operators left the site to take refuge. One of them informed the managers at the meeting of the leak. All the members attending the meeting rushed to the site. The second huge explosion occurred when they were preparing to cool the mixing drum by spraying water on it with fireplugs.

2. Course

2.1. Course of the first explosion

At around 23:52 on August 19th, abnormal behavior of the agitators of the polymerization reactors was notified, and an operator in the electric device room checked the causes. While he was checking, an electromagnetic switch burned out. He cut the power supply after he informed the incident to the manufacturing section. At that moment, although two reactors were operating, the agitators and the warm water circulation pumps for removing the reaction heat through thermal jackets stopped. The cooling water was switched to cold water manually in order to continue the cooling.

At around 00:10 on August 20th, gas began to leak from the packing part of the manhole of the C reactor. The alarm of the furnace rang at 00:15. The bypass valve of the furnace opened, and the combustible gas before combustion was directly discharged into the stack for burnt tail gas. The temperature inside the furnace exceeded 830℃ at that time.

At around 00:20, the gas detector in the building operated. At around 00:25, one operator heard the sound of the first explosion. The operators tried to extinguish the fire with the outdoor fireplugs and reported the explosion to the related parties.

At 00:28, the public fire brigade turned out, and the fire was extinguished at 00:31.

2.2. Course of the second explosion

As the fire extinguishment was reported, from around 00:30 on August 20th, the factory members started to check the factory. The check and confirmation work continued during a whole day. The check work was executed mainly around the two reactors. The managing staff members were busy grasping the situation, explaining the situation to the fire fighters and to the police, and reporting the situation to the headquarters.

At 13:00 on August 21st, the preliminary meeting was started by the factory staff members for preparing for the accident cause investigation committee at headquarters. This meeting continued until after 17:00.

At 17:12, a whistling sound was heard from the room where the reactors were installed. When an operator looked into the room to check, he found a white gas coming out from the G reactor. Another operator contacted the managers at the meeting. All of the members of the meeting hurried to the site. The white gas flowed from the room towards the north-side center road. At around 17:25, the members of the meeting gathered around two fireplugs, and while preparing to spray the site with water, a huge explosion occurred.

3. Cause

3.1. Cause of the first explosion

Stopping of the agitator by a power failure caused a runaway reaction in the two reactors and the monomers (styrene, acrylonitrile) in the reactors evaporated. The evaporated gas was introduced into the furnace system of the vent system where the capacity was assumed to be designed for the normal operation, and the furnace was bypassed, since the temperature in the furnace became higher than the furnace design temperature. The monomer vapor was ignited by some ignition sauce, and it exploded in the duct of the furnace system. Therefore, a power failure and the subsequent runaway reaction are the direct causes of the explosion.

The occurrence of the power failure may be a cause of the accident, but power failures can occur anywhere. The problem is why a runaway reaction occurred after the power failure and why the explosion occurred after the runaway reaction. The plant was not designed for safety in the event of a power failure and the operation manual did not contain appropriate operation procedures for a power failure. Two items mentioned above must be true causes.

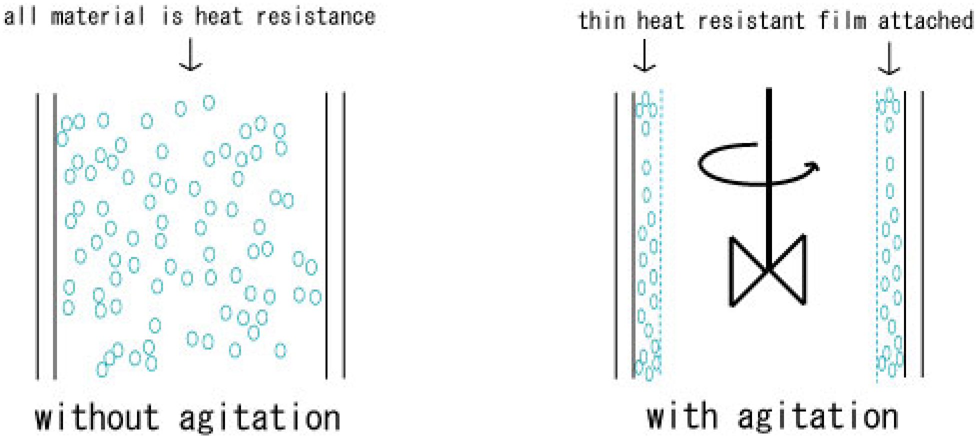

Fig. 3 Effect of an agitation -1 heat transfer

To begin with, the effect of the agitation stop is discussed. The problem can be considered from two aspects. The first is heat transfer. When agitation stops in a big vessel with a diameter of 2 meters, it is not possible to cool the liquid in the vessel. Agitation makes a laminar film on the heat transfer surface thinner, decreasing heat transfer resistance, equalizing the temperature of the content liquid, and thus cooling is carried out. Considering the size of the agitation drum, which is on an industrial scale, it is apparent that effective heat transfer is not possible, if the agitation stops. Furthermore, the polymer in the reactor is prevented from separating from the monomer by agitation, causing the reaction to advance at a moderate rate. The polymer, which is solid and has a high density, separates from the low density monomer, if the agitation stops. The monomer layer with no polymer has high reaction potential. As agitation stopped, heat could not be removed from the monomer layer, and a hot spot was easily formed. The polymerization in the monomer layer advanced, and a runaway reaction occurred. As a result of the temperature rise, it seems to have been unavoidable that the monomer evaporated, its pressure rose, and the vent gas of the monomer increased.

The next aspect is the small capacity of the furnace. As only two out of five resin reactors were in operation at the time of the power failure, a bypass was inevitable. The combustible gas-air mixture that was redirected to the stack did not burn for that reason, and the explosion occurred as a result. The exact reason why the combustible gas-air mixture was formed is unknown, but there seemed to be some problems in the deodorization system of the vent gas. It can be supposed that there were some problems in the vent gas system that might cause an explosion under the conditions resulting from a power failure.

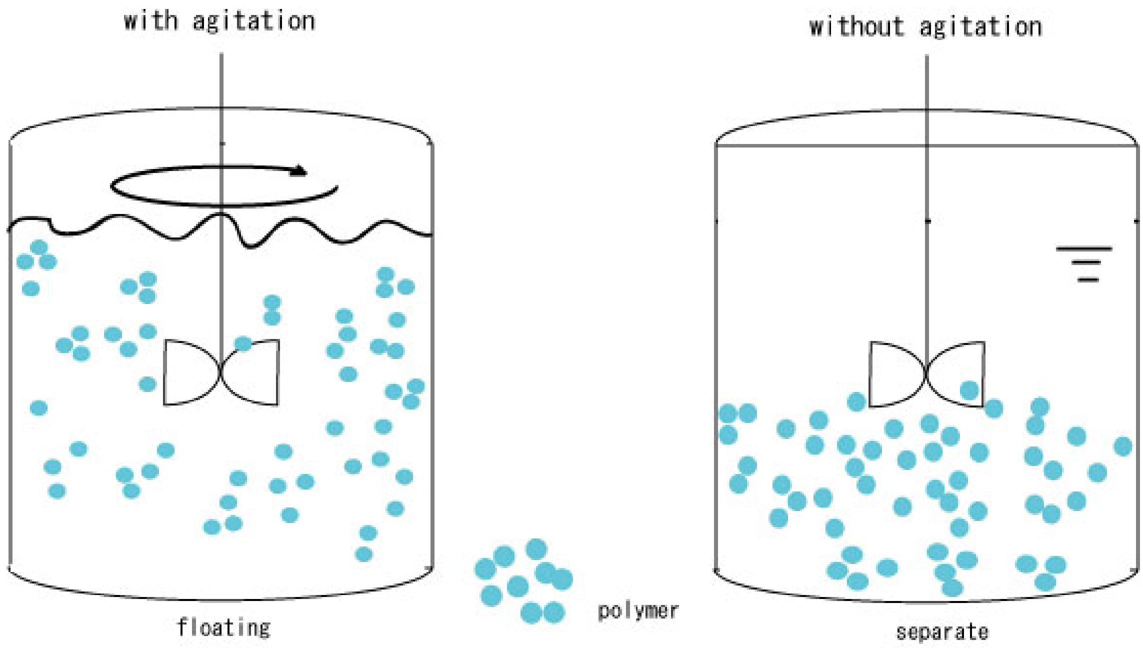

Fig.4 Effect of an agitation -2 mixing

At present, more safety mechanisms for a power failure can be designed, as shown in Fig.5. For instance, a large blowdown drum with diluents or coolants can be installed for receiving the reactor contents or an inhibitor drum can be installed with a high-pressure inert gas cylinder to add the polymerization inhibitor to the reactor. Fig.1 shows that piping to the emergency discharge pit is mounted from the draw-off nozzle at the reactor bottom. Although the contents of the discharge pit are unknown, the piping seems to be emergency piping through which the slurry and the liquid in the reactor could be discharged to a safety vessel when a runaway reaction occurred or predicted to occur. If this case, it is a question why the piping was not used.

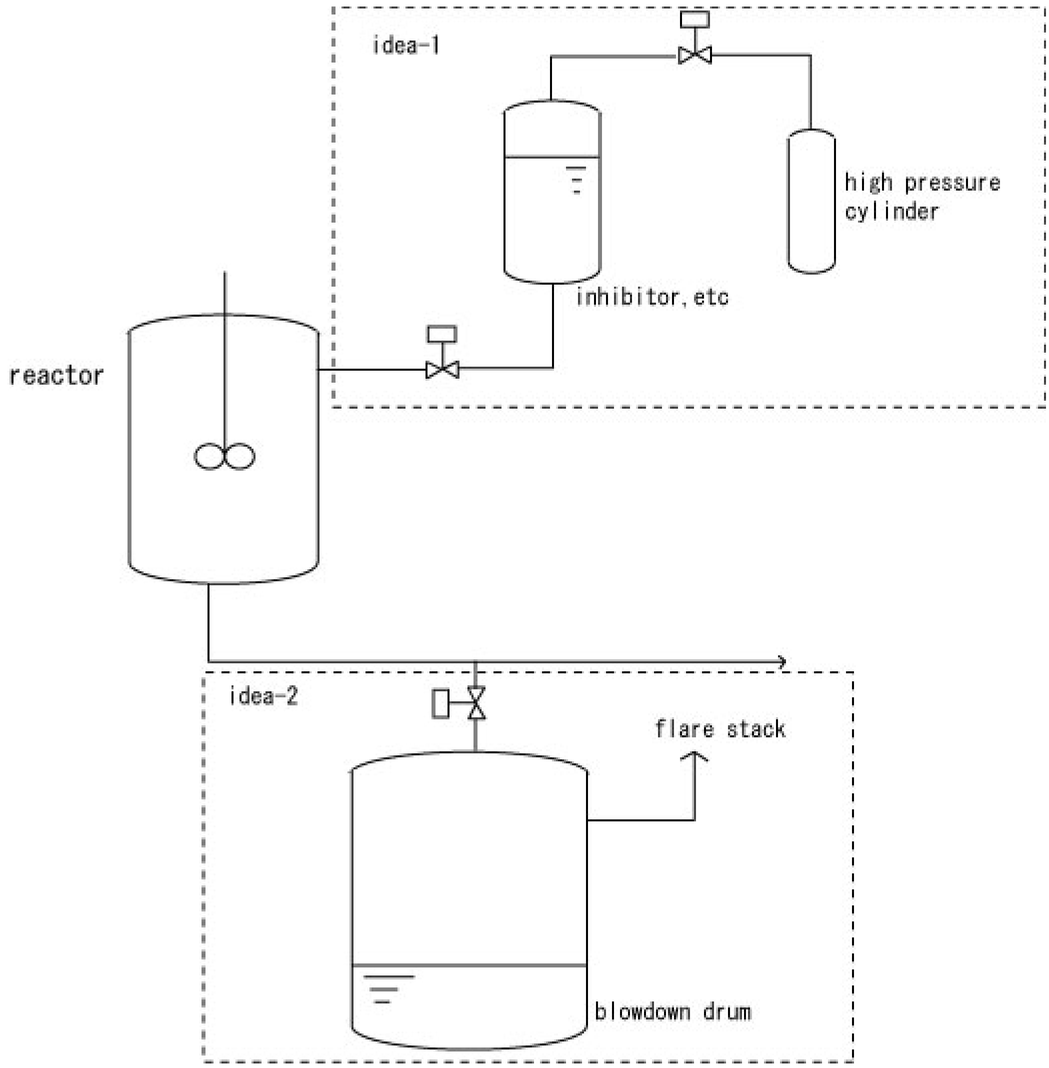

Fig.5 image of emergency measure

3.2. Cause of the second explosion

The cause of the second explosion is thought to be as follows. Since the raw material that had been prepared before the first explosion was left for hours in the monomer mixing drum, a polymerization reaction was caused in the drum. Therefore, the temperature rose, and a gas leakage was caused by the associated pressure rise. The prepared raw material was a mixture of about 3.8 tons of highly reactive acrylonitrile and styrene with initiator added.

Originally, the prepared raw material would have been transferred to the reactor one hour after preparation and it would have reacted by controlling the temperature in the batch. However, since the raw material was left in the monomer mixing drum for 42 hours because of the first explosion, a runaway reaction occurred. The temperature after the preparation was 27 °C, and it may have been thought that no reaction would occur at that low temperature. Furthermore, from the equipment aspect, the prepared raw material in the monomer mixing drum had to be transferred and reacted in the reactor.

Therefore, the true causes of the accident appeared to be one of the following three; insufficient study of safe storage of the prepared raw material on the R&D stage, insufficient process design for the prepared raw material, and the fact that all the factory members did not pay attention to indispensable material for the sake of urgent countermeasures to the explosion.

The human damage resulting from the second explosion was huge. All of the members at the meeting went to the site together without sufficient confirmation of safety. This action appears to be one of the causes that increased the human damage. It is necessary to construct a system that gives sufficient information so that the director can make an accurate judgment in the event of an emergency.

4. **Process of cause elucidation**

The cause of the first explosion can be easily understood from a series of events after a power failure, operation records and the testimonies of the parties concerned. Most of the official accident investigation report was concerned with the second explosion and there was no description of the elucidation of the cause of the first explosion.

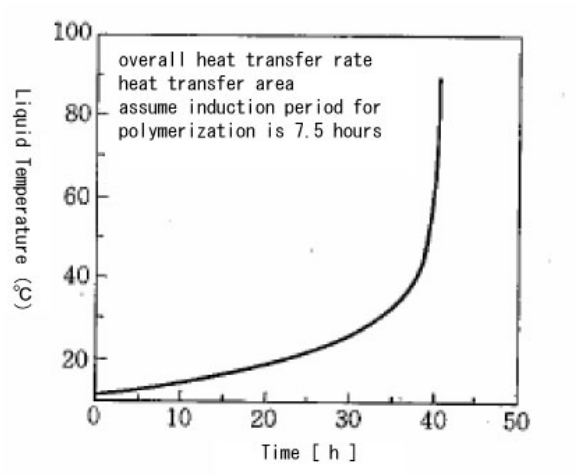

Fig.6 experiment result of the liquid temepratuure increasing in the monomer mixing drum

Regarding the second explosion, the blast center was determined almost perfectly from testimony of witness and on-site study. The source of the leaked vapor was confirmed according to the order below; 1) To specify the vessel where the sufficient quantity of the gas remained, 2) To clarify the reason why the gas leaked from the vessel. The monomer mixing drum and the reactor were assumed the vessel where the gas might leak. The quantity of monomers that remained in the reactor was too small for the size of the second explosion. In the monomer mixing drum, there was about 3.8 tons of raw material monomers which was a sufficient quantity to cause the explosion.

After careful experiments, it was confirmed that the monomers in the mixing drum had begun to react at a relatively low temperature and thus the gas leakage occurred. Since the size and force of the explosion could be explained if leakage from the monomer mixing drum was assumed, it was concluded that the gas leakage was caused by a rise in pressure due to a polymerization reaction that had occurred during the long hours of storage in the drum.

5. Immediate action

In the first explosion, four employees of the resin factory carried out the emergency notification by an alarm and an office phone. In addition, they used outdoor fireplugs to extinguish the fire. One fire engine of the factory turned out, and careful preparations were made in front of the resin factory.

At the time of the second explosion, the company members were spraying water from one fireplug on the site and preparing to use other fireplugs. The following activities were carried out after the explosion: notice to the fire fighting authorities, rescue of the victims, and emergency rescue requests to the fire fighting authorities. After the municipal fire fighting team arrived, the company's fire fighting team executed rescue activities and continued to spray water on the site using outdoor fireplugs under the supervision of the municipal fire fighting team. After extinguishing the fire, they continued to cool the tank yard by spraying water on it for three days.

6. Countermeasure

The future countermeasures, which cover as much as 14 pages, are described in the accident investigation report. In order to assure countermeasures for complete safety, many items are described from many aspects such as management of environmental problems in the neighboring regions, a system for long-distance security and fire prevention, establishment of organizations for disaster prevention, education and so on.

Here, the basic stance of the technical aspect is described.

1. Safety design of the plant: installation of adequate safety systems in the plant

is important to prevent the occurrence of large-scale disasters by minimizing the effect of a small accident, failure or damage in the plant. Based on this viewpoint, redundancy, automatization and mechanization of the control system should be considered. Also, interlocks and depressurizing devices should be prepared for emergent situations. At the plant where the accident occurred, there seemed to be a lack of study of the capacity of the furnace and of consideration of countermeasures when the furnace is by-passed.

2. Improvement of the facilities: it is natural to sufficiently consider the structure and arrangement of the plant. In particular, the plant should be equipped with an early detection method devices and safe shutdown system for emergencies. In addition, if the supply of the utilities fails, prolonged operation of the plant is not possible. The steady supply of the utilities must be assured. Utilities include electric power, steam, and cooling water, which are necessary for plant operation. For example, isolation and duplication of the power supply, and spare diesel driven pumps for cooling water should be considered.
3. Related to chemical reactions: the characteristics of the reactions in the process must be sufficiently understood, and facilities and handling methods should be established according to the characteristics. At the plant where the accident occurred, it would have been effective to have an agitation method of injecting nitrogen gas to maintain the cooling effect when agitation stops and to have blowdown facilities.
4. Thoroughness of operation standards and education: even the best safety design and the best construction of the plant are useless if they are not reflected in operations. It is important to prepare operation standards based on the consideration of the characteristics, dangers of the reactions and the materials, the characteristics of the plant, and to educate the operators based on the operation standards.

7. Knowledge

1) In abnormal situations, unusual phenomena may occur that cannot be imagined under normal operation conditions. It is important to prepare facilities and operation methods considering for utility failures because utilities are the lifeline of the plant.
2) Chemicals may have to be retained for an unexpectedly long period of time or at unpredicted temperatures. It is necessary to carry out prior examinations of these cases.

3) In the case of an emergency, it is dangerous for all of the members to take the same action and/or the same way of thinking. It is necessary to organize a system for allotting the roles of investigation, total management, and so on to each member.
4) Process design and operational control based on sufficient consideration of what can happen when agitation stops are necessary. It is also necessary to consider the way of education in an emergency.

8. Influence of failure

All of the human damage caused by the second explosion was the deaths of six persons and the injured of 207 persons. Among the injured the number of inhabitants of the neighboring area was 178.

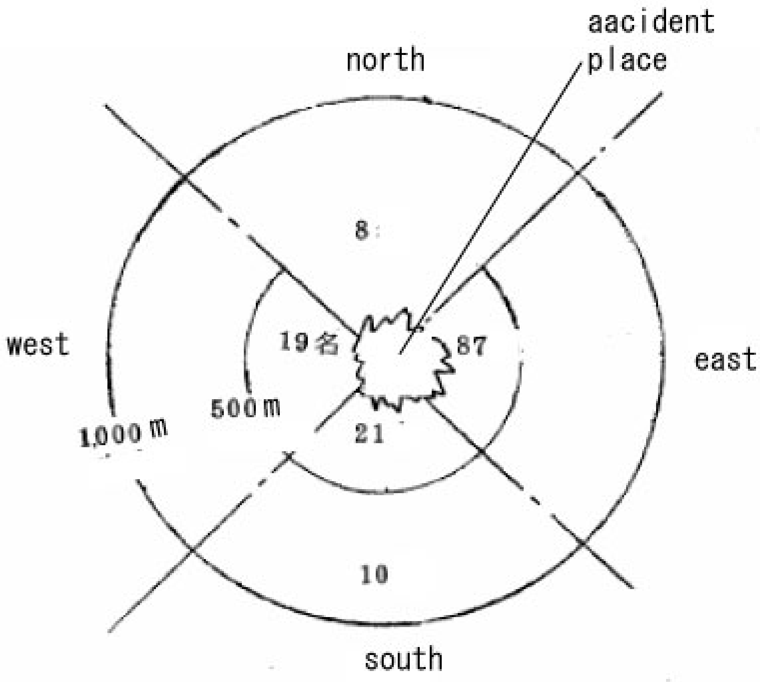

Fig. 7 distribution of human damage

The physical damage was as follows; 1733 buildings of 2812 households in the area within the average radius of 1400m were damaged. As the factory in the densely populated area, considerable damage was caused to the neighboring area.

In the factory, many facilities were burned and were damaged by a blast.

The direct monetary damage has been calculated to be about one billion yen. However, the total damage including compensation, indemnities, restoration expenses and the cost of not operating the plant must be far more.

9. On the side

An explosion of a chemical plant in an overpopulated region is unexpectedly common. A benzoyl peroxide explosion in Itabashi Ward of Tokyo, and a hydroxylamine explosion along the national road route 17 in Gunma Prefecture are the examples. These cases are also included in “Selected 100 accidents”. These accidents resulted in catastrophic damage, and made an excessively strong impact on society. Sometimes, isolation of the factory from the overpopulated region may be only one method for avoiding disastrous damage caused by an accident that occurred at a chemical factory. Furthermore, this accident was caused by a problem related to agitation. Stopping or restarting agitation is one of the most important situation changes at a plant. One example of an accident that was caused by stopping of agitation is "Fire during Ethylidenenorbornene Manufacturing" which occurred at a factory in Kawasaki and is included in “Selected 100 Accidents”. There are also some examples of accidents that occurred during restart of agitation in systems such as a reaction of concentrated sulfuric acid and toluene. What will happen when the basic conditions are changed such as in these examples is a basic problem at chemical plants, and these examples must be learned as a basis of safety engineering.

References

- Yoichi Uehara, “Outline of the AS resin plant explosion. Fire and explosion examples”, J. Japan Soc. for Safety Engineering, 41, 97-111 (2002)
- The fire fighting union in Sakai City & Takaishi City, “Accident investigation report of explosion and fire at the resin plant in Sakai factory ,Daicel Chemical Industries Ltd. ” (1983)
- Ikuo Fukuyama, “Explosion by the runaway reaction” , SE series, “Learn from accidents” pp. 20-23 Safety Engineering (1987)