INVESTIGATION OF AN EXPLOSIVE ACCIDENT USING SIMULATION AS A TOOL

by

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ABSTRACT

A new energetic polymer (EXP) under development at the pilot plant scale was currently produced in 5-kg batches. Solvent extraction to purify EXP was required and an equipment called Rotary Film Evaporator (RFE) was available and selected for use. The RFE was last operated some 15 years ago with inert polymer. Prior to further use it was cleaned and operated with inert polymer after consultation with the previous users in order for the new users to develop their expertise in operating it. On 12 Oct 89 after 24 hours of preheating of the RFE, the EXP polymer was introduced in the piping. Approximatly 30 to 60 seconds later an explosion occurred in the piping followed by a small fire. One employee was slightly injured and the fire was quickly put out by the other one present. A board of inquiry was immediately formed and interviewed the employees as the first step in the investigation. After examination of the evidence, the temperature recordings and the deposition of the witnesses, a few hypothesis were retained to explain the explosion of EXP. An extensive laboratory study was conducted on samples of EXP left over from the same batch but did not reveal any clear explanation for what happened. Overheating of the equipment or of the piping was still the favored hypothesis despite the fact that temperature recorded at the time of the explosion (between 90 and 135°C) were appreciably lower than the auto-ignition temperature of EXP (215°C). It was only after a detailed and exact simulation of the conditions that prevailed at the moment of the explosion that proof of the existence of a much higher temperature (350°C) in one section of the piping allowed us to explain without any doubt ignition of EXP.

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INTRODUCTION

A new energetic polymer (EXP) had been synthesized at the laboratory scale and its auto-ignition temperature, thermal stability, impact and friction sensitivity determined. EXP was now produced at the pilot plant scale in 5kg batches and the production process was viewed as a breakthrough. Every one in the division was enthusiastic about its potential military applications and confidence was building-up. Solvent extraction to purify EXP was required and an equipment in one of the pilot plant buildings was identified as potentially suitable for this purpose. This equipment called Rotary Film Evaporator (RFE) had not been used for about 15 years. After consultation with the engineers who had operated the RFE previously with inert polymers, a young engineer responsible for the development of EXP decided to use it for the purification of EXP. After cleaning of the equipment and a test run with an inert polymer, the operating conditions were established and a run with EXP was planned. During this first run, an explosion occurred in the feeding pipes of the equipment and the engineer suffered minor injuries.

An investigation team was immediatly formed to find the cause of the ignition of EXP. This report describes how this investigation team conducted their study. It covers the different hypothesis that were examined by the investigation team and establishes that a detailed experimental simulation of the accident conditions allowed them to find the cause of the accident.

THE EQUIPMENT

A schematic of the equipment used is shown in Fig. 1. The polymer is fed by gravity from a reservoir to valve #1 through a flexible plastic tube (section A) and flows in the equipment pipes. From section B to C, the stainless steel pipes are heated with electric heating tape and covered with insulation. The purpose of heating is to lower the viscosity of the polymer and allow easy flow through the system. In that same section a gear pump is used to move the polymer to the evaporator. Valve #2 and a by-pass is used to prime the system. The stainless steel piping from section C to D had just been equiped with new heating tape, the old one being faulty, and the insulation was not replaced since it was judged unnecessary. Two thermocouples (T2 and T4) gave readings of the temperature at the locations indicated in Fig 1. The Rotary Film Evaporator (RFE) is equiped with heating mantles at both ends and temperatures recorded with thermocouples T1 and T3 at these locations. A spring valve in section CD is adjusted to open only at 35 psi to maintain a good vacuum in the RFE.

THE ACCIDENT

On the day prior to the accident, the heating of the equipment for the purification process was started to ensure equilibrium and readiness to proceed on the next day. In the morning of the accident, the temperatures were read on the multi point recorder as follows: T1 and T3 showed 135°C, and T2 and T4 showed between 85 and 95°C. The technician and the engineer responsible for the production of EXP at the pilot plant scale were then ready to proceed and introduced their last batch of EXP (#39) in the reservoir of the purification process equipment. Valve V1 and V2 were opened and the gear pump started to prime it. Valve V3 was then opened and V2 closed. When EXP started to flow at the exit of Valve V3, the gear pump was stopped and the evaporator motor started to adjust the rotation speed of the equipment. At this moment the two operators noted some bubbling in the EXP reservoir. Realising that something was wrong, the motor of the RFE was stopped. An explosion then occurred in the piping at the elbow (point C in the schematic) almost at the same moment. The engineer was hit on the head by a fragment but managed to exit the building. The plastic pipe in Section A was projected away and a flame was emanating from the piping at this point. The technician, who was not injured, extinguished the fire, phoned for help and exited the building.

A picture of the equipment is shown in Fig. 2 after the accident. Polymer residues was seen on the walls, the ceiling, the floor and the equipment. Figure 3 shows the polymer reservoir attached to the ceiling and the gear pump in the back with the different valves and piping. Figure 4 shows the remaining part of the pipe that was burst open and the heating tape that was wound around. Finally, Fig. 5 shows the stainless steel elbow where the explosion occurred and some plastic parts that connected the EXP reservoir to the equipment.

THE INVESTIGATION

An investigation team was formed immediatly to find the cause for the ignition of EXP. After inspection of the site of the accident and taking several photos of the equipment, the operators were interviewed.

Several hypothesis were made to explain the ignition of EXP:

a) the presence of an unstable by-product in EXP
b) a malfunction of the gear pump
c) a high temperature at some point in the system.

The first hypothesis was based on the fact that in batch #39, the chemical reaction that lead to the formation of EXP had been altered to facilitate its production at the pilot plant scale. More specifically, the order of addition of the reactants had been changed. This procedure was used previously for batch #37 and the chemical analysis had not shown any difference compared to the original process, but further verification was warranted here due to the experimental nature of this process. Fortunately, about 1kg of batch #39 was left on the site of the accident. Several tests, namely Carbon 13 NMR, DTA, TGA, DSC and GPC, were conducted at the Chemistry laboratory to detect the suspected presence of an unstable by-product that could have been formed during the production of EXP.

Unfortunately, nothing out of the ordinary was found by the analyses. The auto-ignition temperature of EXP had been established previously as 214°C, way above the temperatures recorded by the thermocouples on the equipment. It was decided to run an auto-ignition temperature tests on a sample from batch #39 to confirm that nothing was wrong with the polymer. These tests gave an average auto-ignition temperature of 216°C.

The second hypothesis was quickly checked by disassembling the gear pump. Examination of the parts showed no sign of abnormal friction.

In the mean time, the investigation team was performing a simulation of the piping being heated with the same heating tape and the very same rheo stat that was used at the accident site. The objective was to see the effect of the number of layers of heating tape on the temperature of the wall of the pipe.

A schematic of the simulation test is shown in Fig. 6 and the results appear in Fig. 7. It can be concluded from the results that the number of layers has a strong effect on the temperature of the pipe but in this case, it does not seem to bring it high enough (170°C) to explain the ignition of EXP.

A closer examination of the conditions that prevailed at the moment of the accident revealed that a short section of the pipe that was heated with heating tape was also insulated.

A second simulation similar to the one just described above but with the addition of insulation over the heating tape (see Fig. 8) was prepared. As shown in Fig. 9, this simulation revealed that the temperature inside the piping could have reached, after equilibrium, a temperature as high as 370°C, a temperature more than sufficient to cause the auto-ignition of EXP (auto-ignition of EXP is 214 ± 2°C).

The result of this simulation concluded the investigation of the accident and was a great relief to the scientists working on the development of EXP. It was now clear that the stability of EXP was not at fault.

The investigation team made a number of recommendations to prevent another similar accident and prevent injuries to personnel. These are:

1) installation of a safety valve in the equipment;

2) not using heating tape as a source of heat in the presence of energetic materials;

3) formation of a team of experts to study the risks associated with new processes or new equipment and make the proper recommandations.

4) writing of SOPs even for a one time operation when the level of risk is high.

5) operation of equipment by remote control whenever possible.

CONCLUSION

The objective of any accident investigation is to find the cause of the accident in order to take the appropriate measures to prevent it from happening again. It has been demonstrated here that a detailed simulation of the conditions of the accident gave the information that allowed the investigation team to understand what caused the ignition of EXP and make proper recommendation to correct the situation. It is not implied that simulation is the only tool that will reveal the cause of an accident, but whenever practical or feasible, it will put the investigators on the right track to find the absolute cause of an accident.

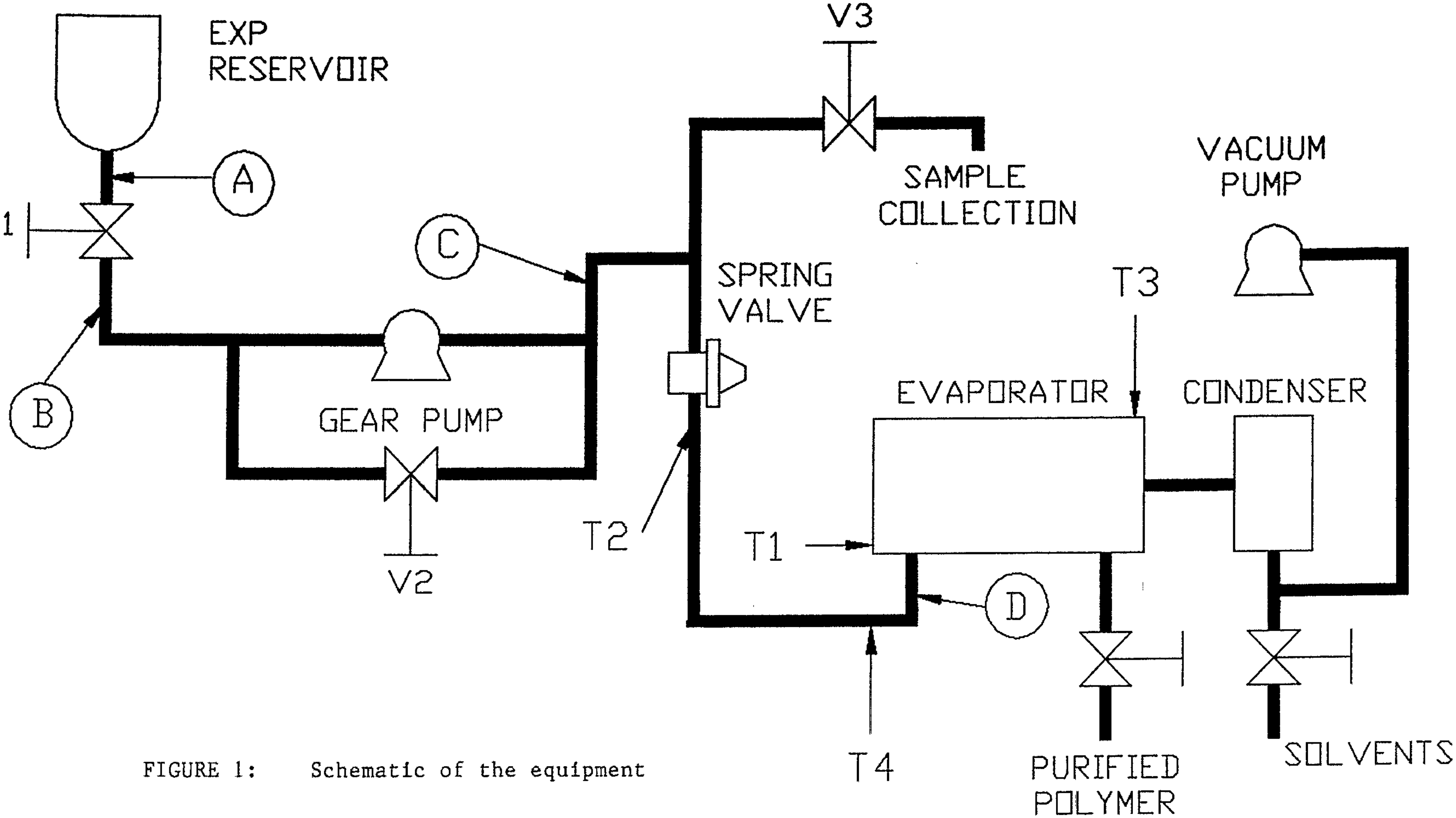


FIGURE 1: Schematic of the equipment

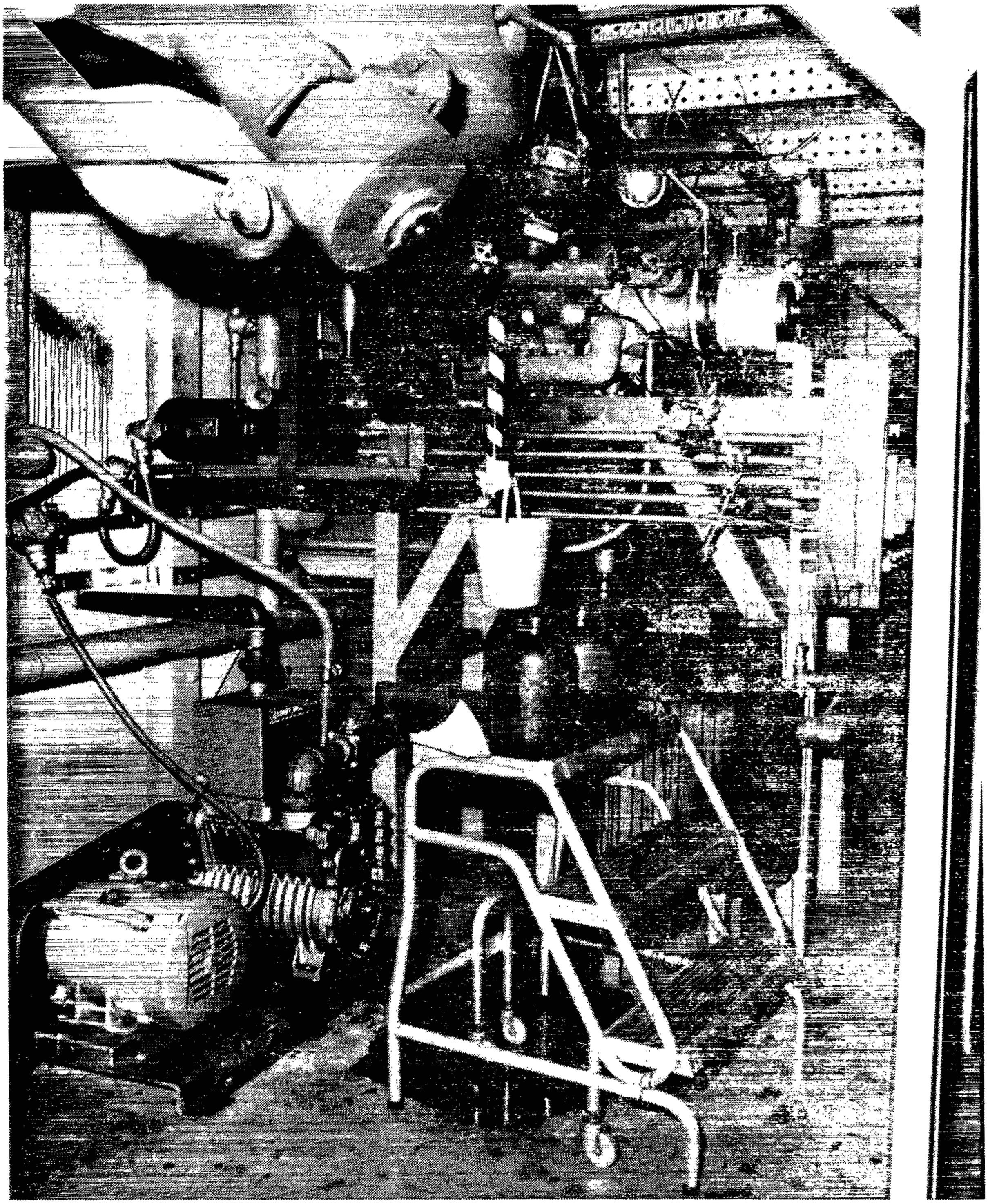


FIGURE 2: Overall view of equipment

FIGURE 3: EXP container after accident

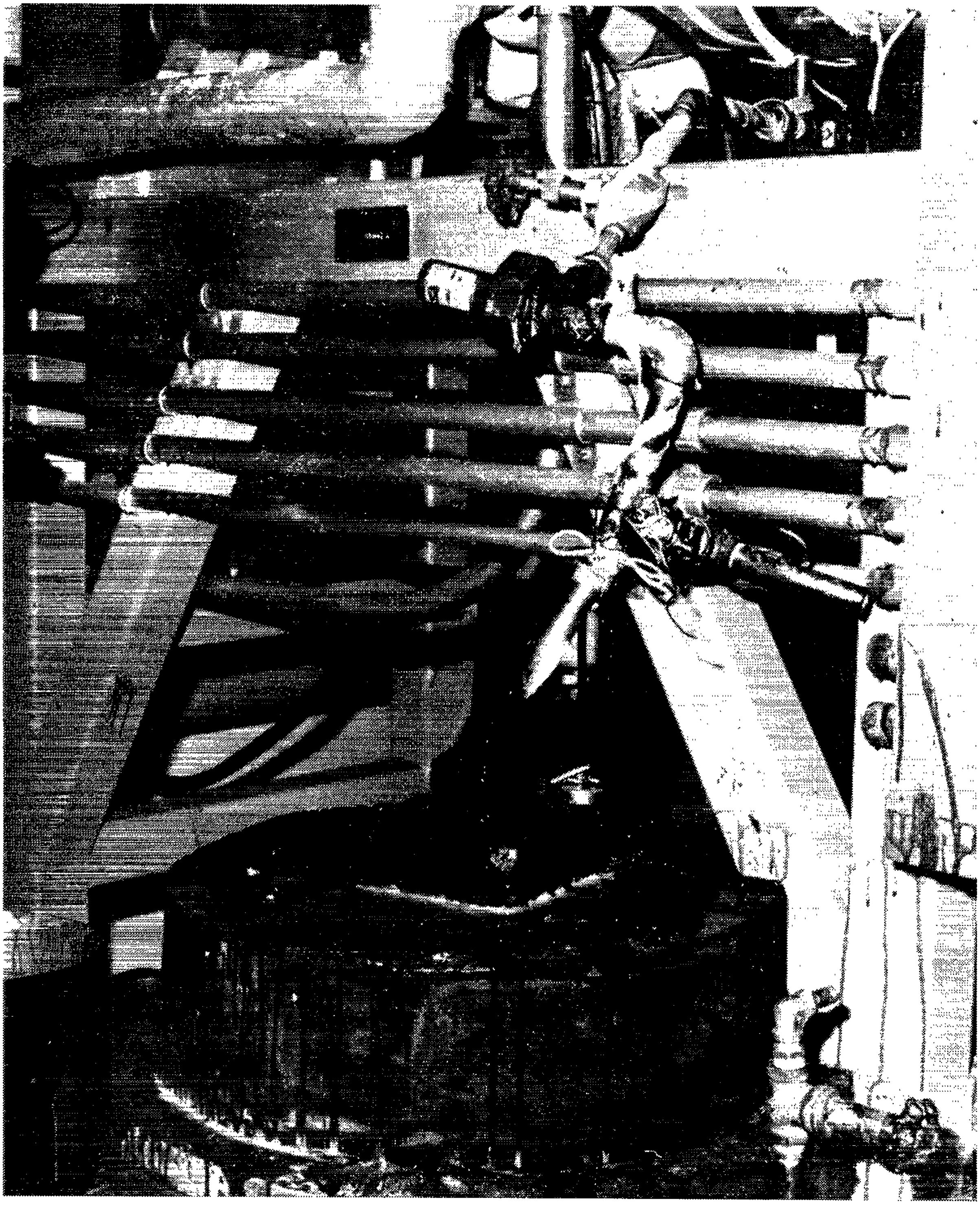


FIGURE 4: Section of Broken piping

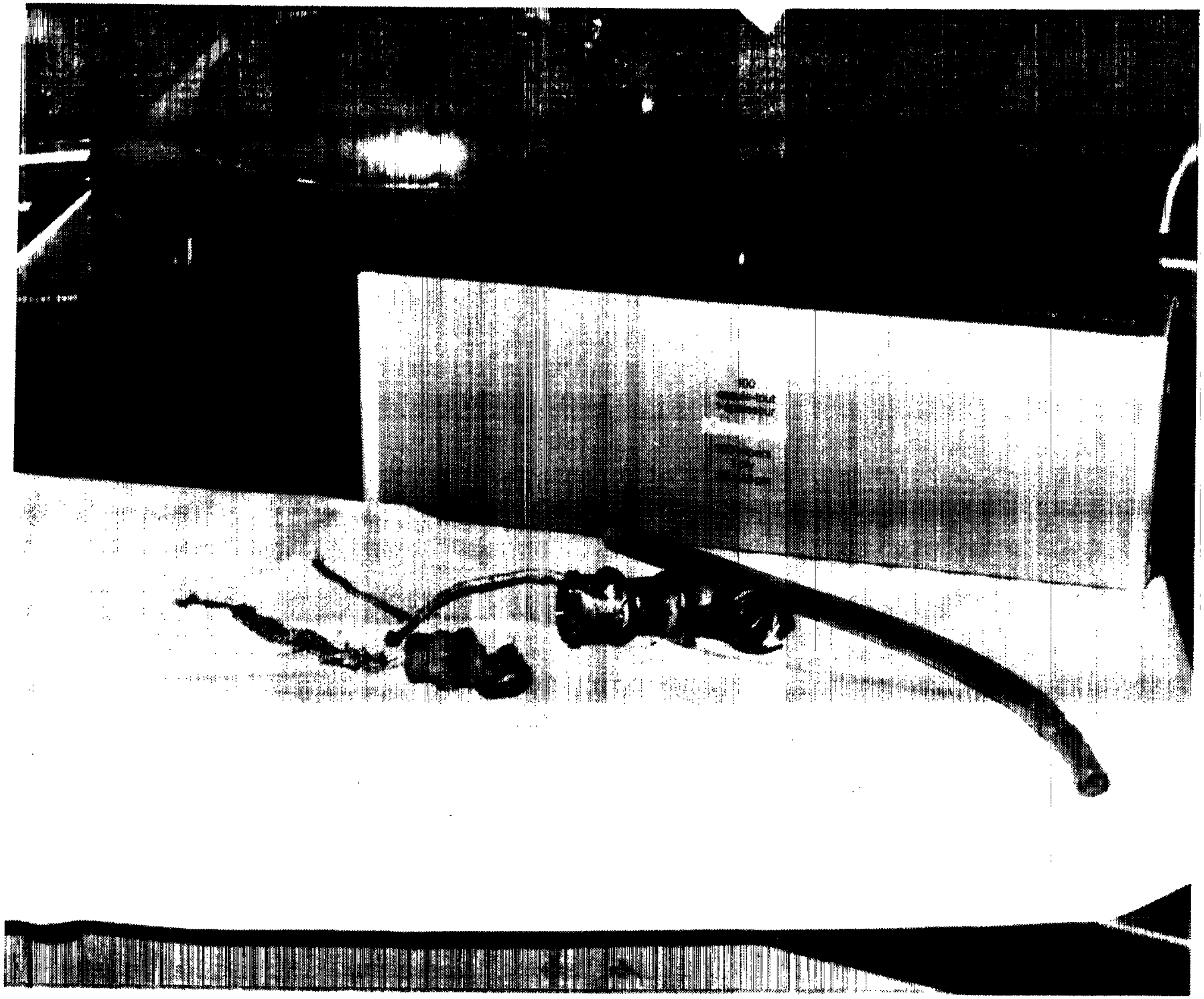
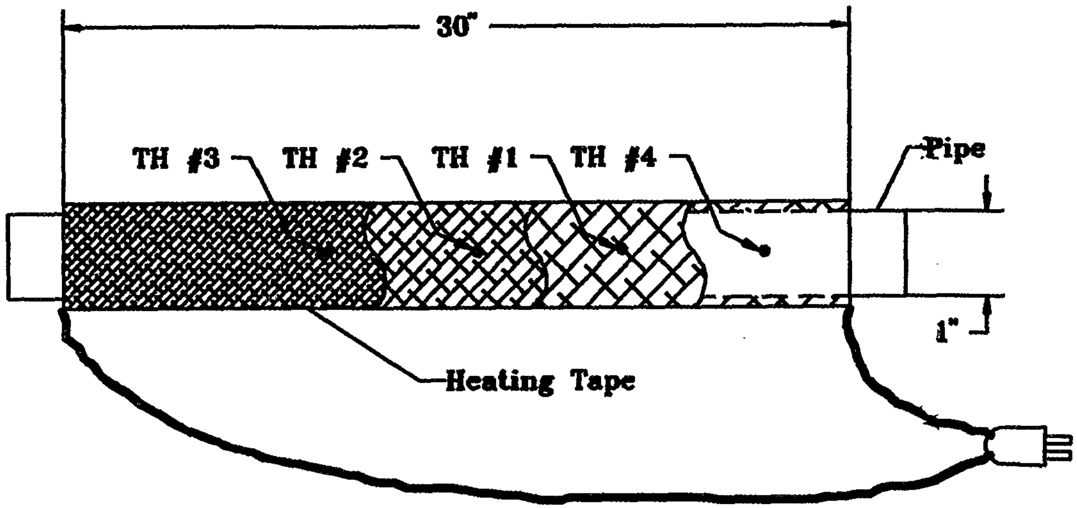


FIGURE 5: Stainless Steel Elbow where explosion occured

FIGURE 6: First simulation test

SIMULATION OF PIPE HEATED WITH ELECTRIC TAPE



Thermocouple #1 – under one layer of heating tape
Thermocouple #2 – under two layers of heating tape
Thermocouple #3 – under four layers of heating tape
Thermocouple #4 – inside closed pipe

Note: Pipe was filled with air and closed at both ends.

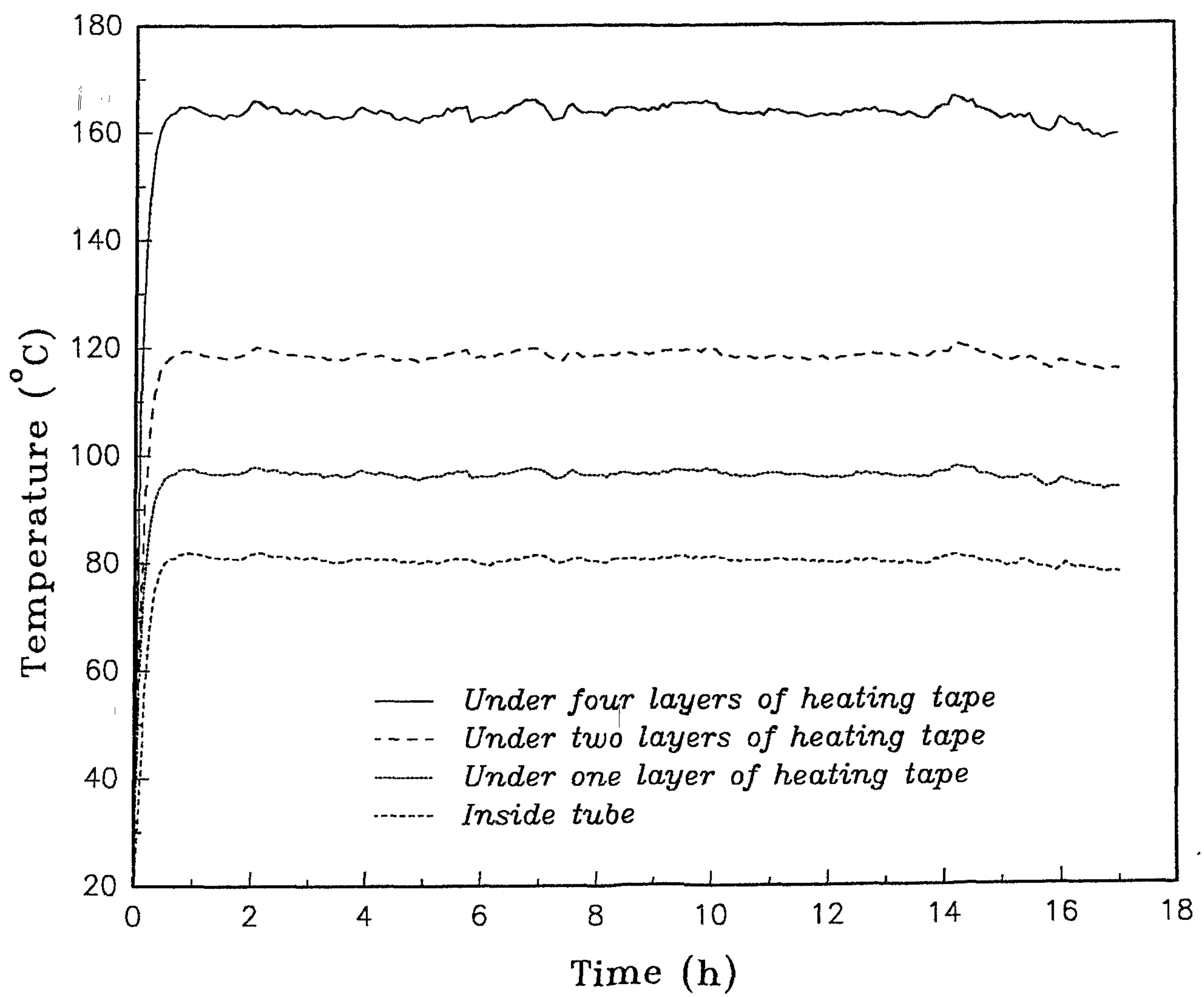


FIGURE 7: Test results from first simulation

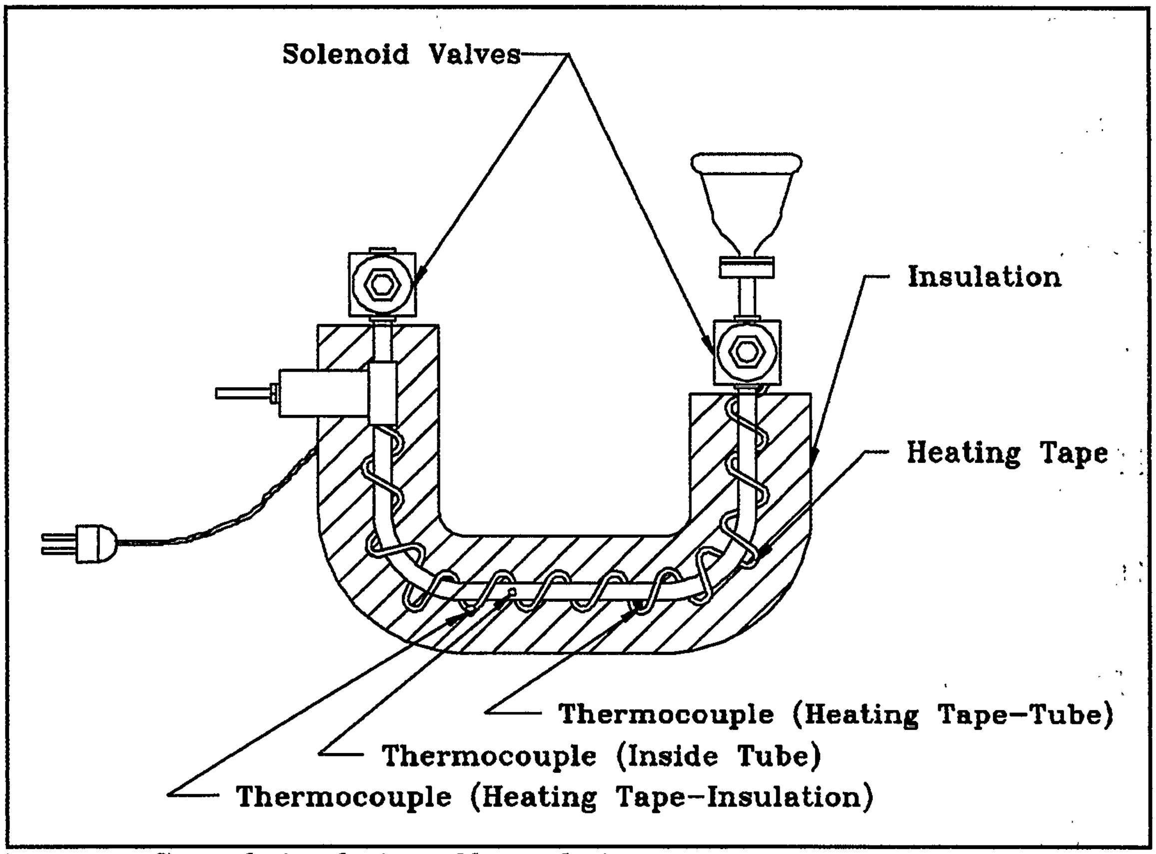


Figure 8: Second simulation of heated pipe.

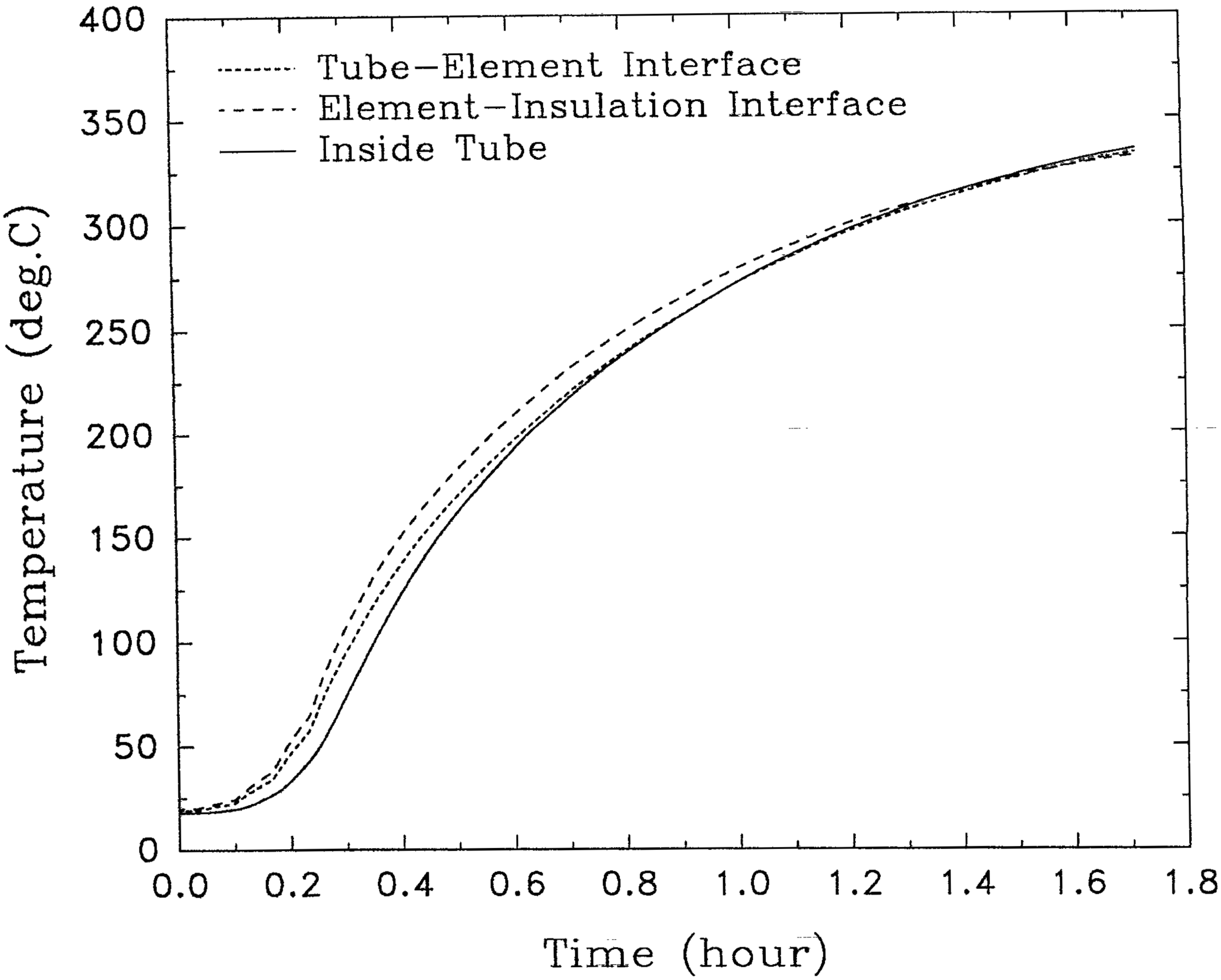


Figure 9: Experimental results of second simulation test.