EXPLOSION IN EXPANDER DISCHARGE PIPING

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While the literature contains information concerning the failure of air systems under pressure at normal or above normal temperatures, I can find no reports of failures of low temperature air systems. Consequently, I thought that this report would be of interest to this group.

This incident occurred in a 75 ton/day liquid oxygen plant which is one of a family of 15 plants. Like a number of the other plants, it is modified to recycle the waste nitrogen stream from the top of the low pressure column back to the air compressor suction, to increase liquid nitrogen production.

Prior to the explosion, the plant had been operating on nitrogen recycle. The operator reported difficulty transferring liquid from the high pressure column, thus reducing the crude oxygen stream flow to the low pressure column. As had been the practice in the past, the operator kept the plant on recycle while he attempted to clear the possible obstruction in the transfer piping or carbon dioxide filters by blowing down the receiver and filters.

Automatic shutoff

The shift changed at 2300 hours. Difficulty with the liquid transfer continued. At about 2310 hours the automatic shutoff valve in the recycle nitrogen line closed on signal from the analyzer which was set to trip the valve on detecting 15% oxygen in the nitrogen stream. Waste nitrogen purity is usually 7 to 8% oxygen. The operator later reported he had neither heard nor noticed anything unusual in the operation of the expander. At about 2315 hours the expander discharge piping exploded.

The operator, who was standing at the control board not more than 10 ft. from the end of the expander, was untouched by flying debris. The blast caused some temporary injury to his ears, but did not rupture the ear drums.

Most of the windows in the east end of the building were broken. Damage by flying debris was not extensive. The major damage was confined to the discharge piping system of the expander, and to a lesser degree the piping in the oil filter. The multiplicity of failures in the discharge pipe is graphically shown in Figures 1 and 2. The encircled numbers on the figures correspond to the numbers on the photographs showing the failures in the pipe.

Failure at ten locations

The piping system had failed or exploded at ten separate locations between the expander and the penetration into the oil filter jacket. With the exception of about 5 ft. of the pipe, just prior to the penetration into the oil filter jacket, all of the pipe had been stressed beyond its elastic limit by internal pressure which had increased the outside diameter by as much as 1/2 in. (The pipe was 3 in., Schedule 40, 304 stainless steel. Stressing to the elastic limit would have required an internal pressure of 8,500 lb./sq. in.) Five of these failures occurred at 90° or 45° ells; eight other ells, although deformed to varying degrees, remained intact.

Inside the oil filter box the inlet valves to both filter bottles had blown loose from the inlet piping. This was a mechanical failure of the silver soldered joints caused by a high pressure surge in the piping. The momentum of the valves acting on the pipe as a lever arm twisted and deformed the pipe downstream of the valves; the inlet pipe on the No. 1 filter bottle had twisted completely off. The drain pipe on the No. 1 bottle was bulged from internal pressure.

The filter bottles themselves showed no evidence of damage. Outside diameters of both bottles showed no increase in measurements or bulging. Visual inspection of the inside surface of the No. 1 bottle which was on stream at the time of the explosion was clean except for a patch of hard, black carbonaceous residue about 3-in. × 8-in. on one side.

The jacket of the oil filter box was bulged from the release of high pressure air when the inlet valves pulled loose from the pipe. There was also damage to the heater controls, pressure gauges and temperature gauges on the box.

Broken valve spring

The most significant detail found when the expander cylinders were dismantled was the broken spring on the inlet valve of the No. 1 cylinder, Figure 3. As can also be seen in the picture, the end of the spring guide is heavily marked and deformed. This would indicate that the spring had broken prior to the explosion, as the expander shut itself down at the time of the explosion.

Two details stood out as being of particular importance.

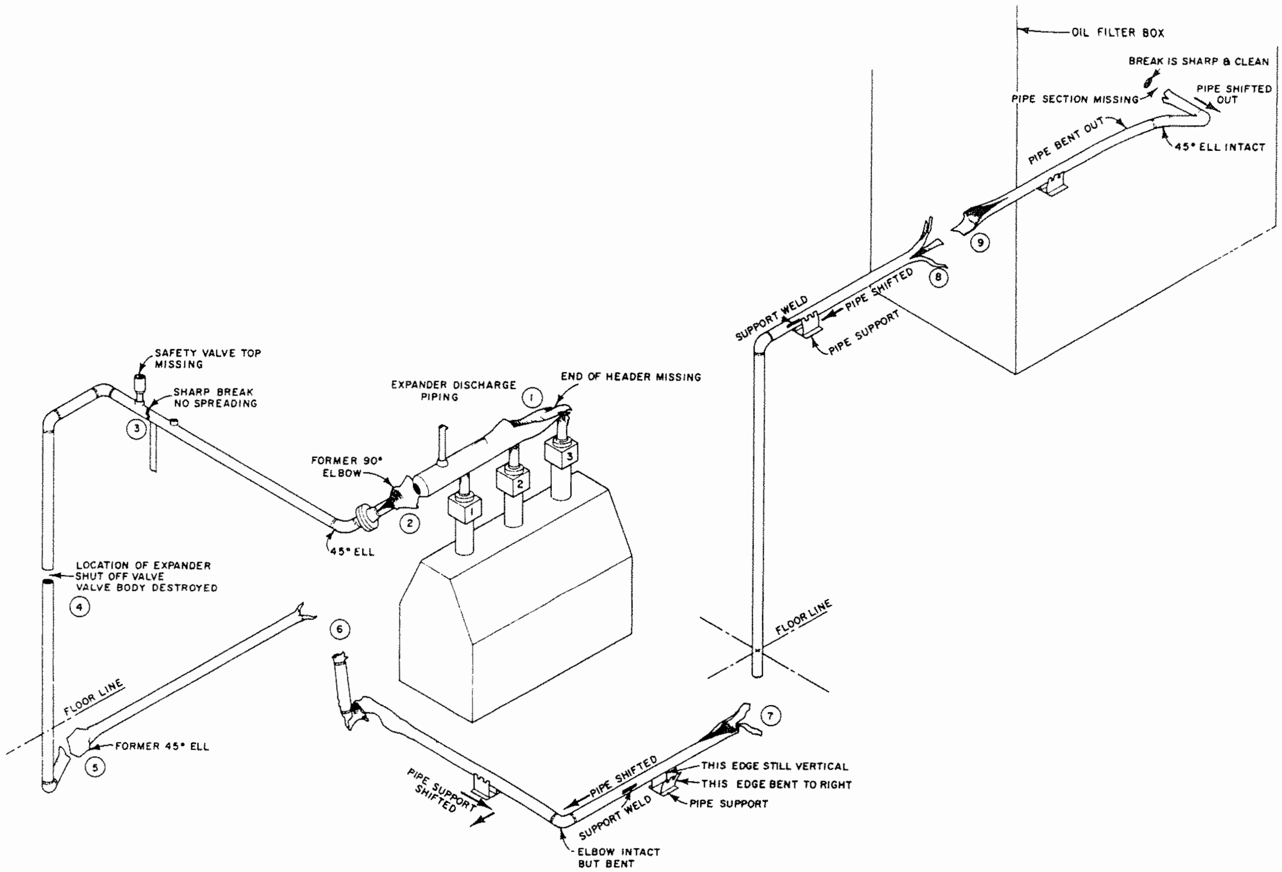

Figure 1. View of expander discharge piping damage.

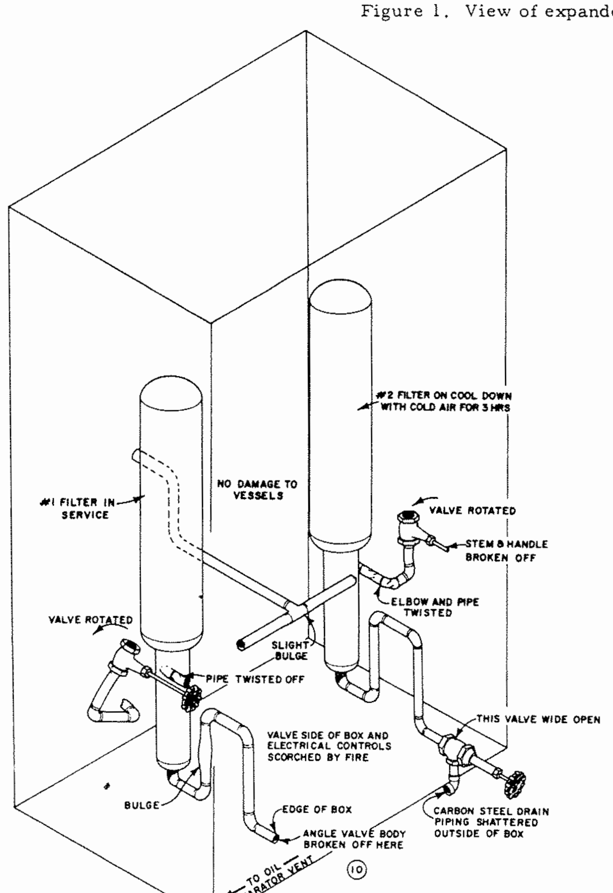

Figure 2. View of oil filter box damage.

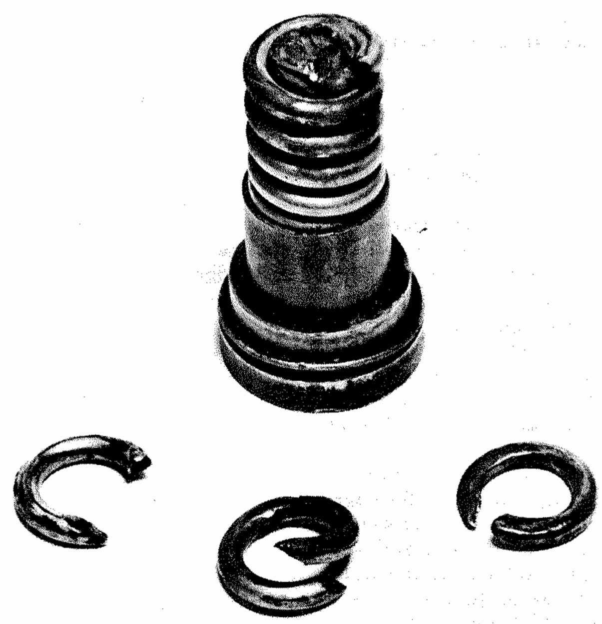

Figure 3. View of broken spring on the inlet valve of the No. 1 cylinder.

(a) The fact that the operators had been having difficulty with the liquid transfer system, and that the analyzer had closed the recycle valve because of at least 15% oxygen in the recycle nitrogen which suggested the possibility of a higher than normal oxygen concentration in the process stream to the expander.

(b) The failure of the inlet valve spring in the No. 1 cylinder suggested a possible source of heat for ignition.

Purity change of nitrogen stream

To determine the rate and magnitude of change of purity of the waste nitrogen stream from the low pressure column with a plugging in the carbon dioxide system, the O-1 valve of one of the other plants was closed. The purity of the waste nitrogen stream was read from the waste nitrogen analyzer and also by a Beckman D-2 portable oxygen analyzer taking its sample from the sample line to the main analyzer.

Closing the O-1 valve completely shut off the crude oxygen reflux to the low pressure column. This admittedly caused a much more drastic reaction than a carbon dioxide plug in the transfer system which would restrict, but not completely shut off, the crude oxygen flow.

	Percent oxygen in waste nitrogen stream	
	Regular analyzer	Portable analyzer
Before closing O-1 valve	7	7
1 min. after closing O-1 valve	10	20
2 min. after closing O-1 valve	25	55

The loss of purity in the waste nitrogen line was much faster than expected as experience with plants other than these 75 ton/day units indicated it would take about five minutes for the purity to degrade to about 40% oxygen. This rapid reaction in the 75 ton/day units is caused by the fewer number of trays in the column. The test also very graphically illustrated the slow response of the regular analyzer. With a sudden upset of the column, the stream passing the sample point could be as high as 30% oxygen before the analyzer could detect 15% oxygen and close the recycle valve.

Analysis of performance

Subsequent analysis of the performance of the waste nitrogen analyzers and sampling system on all 75 ton/day plants indicates:

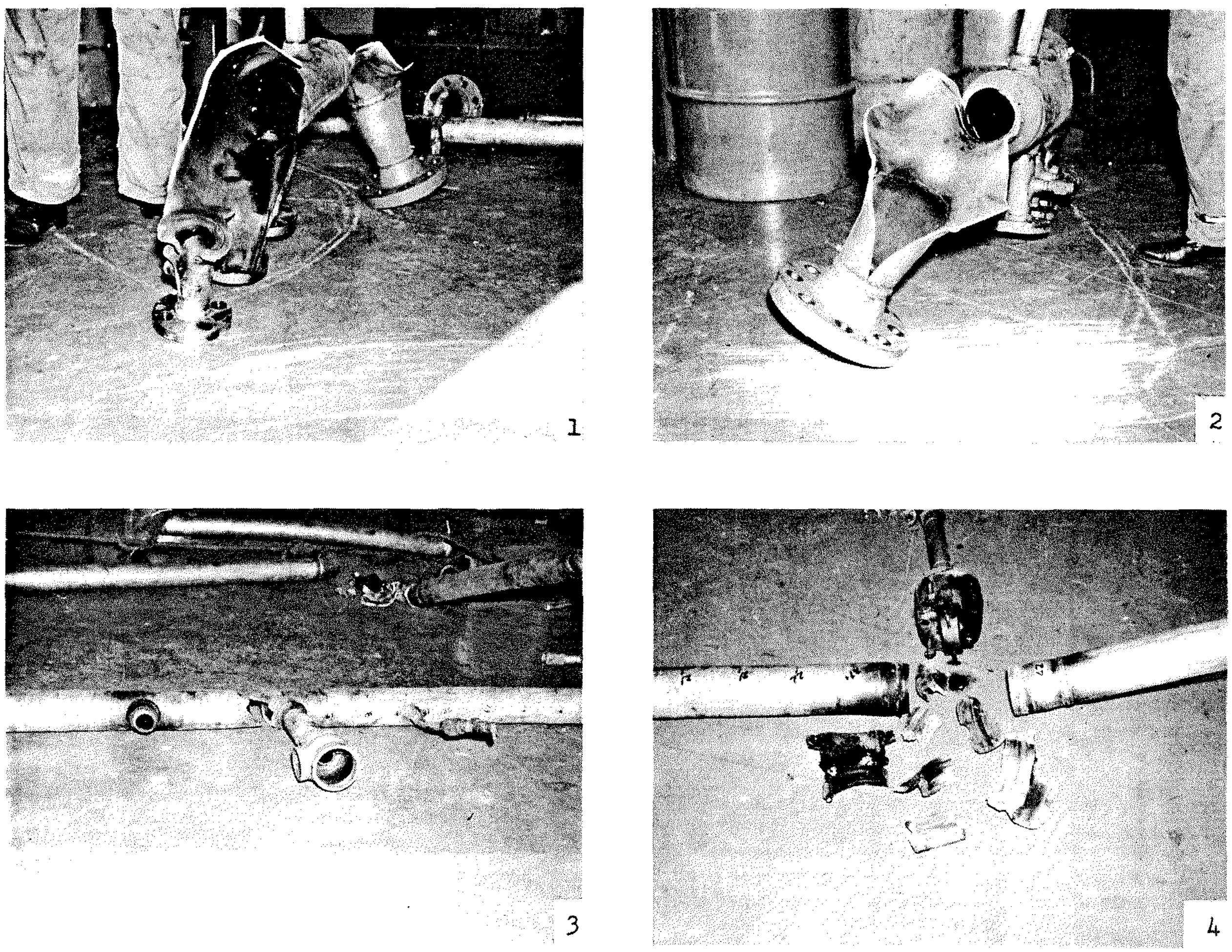

Figure 4. Ten photographs showing specific piping damage.

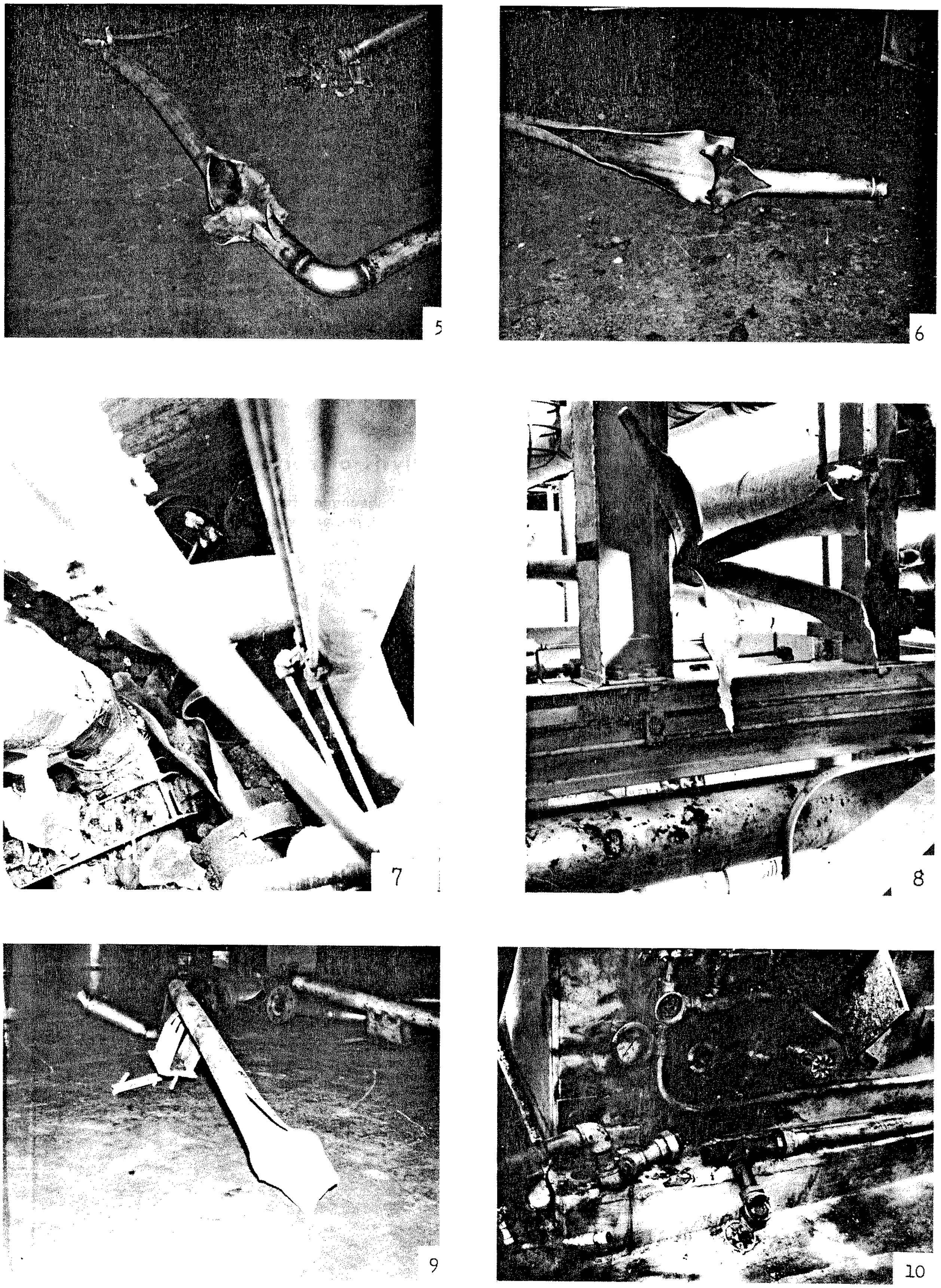

Figure 4 (continued).

(a) Sample lag of 30 to 45 sec. to the analyzer.
(b) Response time of the analyzer to go from 0% to 14% oxygen varied from 15 sec. to 35 sec.

The flow velocity of waste nitrogen gas in the plant has been calculated and indicates that a particle passing the sampling point at the low pressure column waste nitrogen outlet will reach the recycle shut-off valve in 6 sec.

From a safe operating viewpoint, except for the fact that it operates at a low discharge temperature of -150°F, this expander and the associated piping are very similar to an oil-lubricated, reciprocating compressor system. Both the expander system and the compressor system normally contain air with sufficient oxygen to support combustion. The cylinder lubricating oil carried over by the process air is an ever present fuel in both systems. The low operating temperature of the expander system would tend to inhibit combustion and would also necessitate a much stronger source of ignition energy to initiate a sustained reaction. The low temperature would tend to narrow the flammable limits and raise the lower flammable limit (i.e., require a richer fuel mixture for a sustained reaction).

Decreased ignition energy

When operating on recycle, the recycle nitrogen stream containing about 7% oxygen is mixed with about an equal volume of air in the compressor suction. The process air to the expander would contain about 14% oxygen. If the column were upset and the waste nitrogen purity increased to 30% oxygen, the air to the expander would contain about 25% oxygen. Any increase in the oxygen content of the process air above normal would tend to decrease the ignition energy required and assist a sustained reaction, thus counteracting the inhibiting effect of the low temperature.

The quantity of oil that existed in the header is indicated in Picture No. 1. The expander discharge pipe in an identical system at a sister plant was opened to observe the extent and condition of any oil deposit. It was found that a small rivulet of frozen oil about 1- to 1 1/2-in. wide existed along the bottom of the pipe. The presence of such a deposit in this plant was indicated by dark combustion stains in the bottom of unruptured pipe sections while the sides and tops of the pipe were bright and clean.

It may be noted that most of the failures, Figure 4, occurred where oil would tend to collect, in the header (failures 1 and 2) and at low points (failures 5, 6 and 7). Failures at 8 and at the box penetration may be explained by oil accumulations at weld joints. The drain valve at point 10 would also be a natural point for oil to collect.

Conclusions

It has, therefore, been concluded that:

1. Failure of the inlet spring of the number one cylinder provided ignition energy to ignite a fuel-enriched air mixture in the cylinder. Upon expansion and opening of the exhaust valve this ignited the oil accumulations in the header with a resultant explosion. This explosion produced a shock and combustion wave that traveled through the discharge piping toward the oil filter causing the damage as discussed above.
2. The explosive reaction was assisted by the higher than normal oxygen concentration present in the plant air feed. Combustion did not occur in the main air compressor because of the inhibiting qualities of the synthetic lubrication and because no localized hot spots or other sources of ignition energy existed at the time.
3. This reaction, except that it occurred at a normal operating temperature of -160°F., was essentially the same as occasionally occur in compressor piping systems. The low temperature will tend to inhibit a reaction, but given the proper fuel-oxygen combination and an ignition energy of sufficient magnitude a self-sustaining reaction will occur.

DISCUSSION

WIEGAND—Ingersoll-Rand: You said that the compressor lubricant was synthetic. What was the lubricant at the expander?

BALL: We were using a straight hydrocarbon lubricant, something in the neighborhood of a DT105.

FAATZ—Foster Wheeler: Was there any evidence that this broken valve had existed for any length of time prior to this other combination of unfortunate events? And if so, would it have been possible by a more careful scrutiny of the instrumentation to have discovered that this valve had been broken?

BALL: The operating history of those plants would indicate that a valve failure of that type would have been audible to the operators. There was no such indication to the operators of any abnormal operating conditions. In other words, they did not suspect that this failure had occurred.

GLASS—Monsanto: As a result of this experience have you made any effort to remove the entrainment? Do you have any entrainment steps, or the like, that will reduce the oil carryover from your compressors or from your expanders?

BALL: There has not been any change in that particular design. It is now operating exactly as it was before. I think that in future designs we would change the piping system to reduce the number of points where oil can accumulate. The most extensive changes that were made were in the analytical systems and the operating procedures so that we can detect and shut down the system in a matter of a few seconds rather than almost a minute and a half.

BOSSLER—U. S. Steel: Did you say that the oil filters themselves were not harmed? If so, then why didn't they get it too?

BALL: There was no change in the dimensions of the oil filters. They did see a pressure surge but it was not sufficient to change dimensions. There was very little if any indication of any combustion reaction within the filters or in the desiccant within the filters.

SVOBODA—Dow Chemical: Can you tell us what type analyzer you use on this?

BALL: I'm sorry, I do not have the details of the exact change in the analyzer.

SVOBODA: You might find that the Hays oxygen analyzers have a response of about 5 sec.

HOWARD —Monsanto: You mention that there has been no basic change in the mechanical parts of the system. Could the lubricant in the compressor be changed to some other material than a hydrocarbon oil? The same thing on your expander? There are out now some so-called fire retardant or fireproof lubricants.

BALL: This idea has been entertained. We found some operating difficulty in changing to a synthetic-type lubricant. These particular plants, as I mentioned, there are 15 of them, have a combined operating history of between 75 and 100 plant operating years, which indicates a fairly good operating history for the total operation.