LARGE PLANT OPERATION

The larger plants have had their share of problems, but experience has been gained and is being engineered into the new plants to make them operate better and safer

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During late 1963 and early 1964, the two largest ammonia units that engineering contractors were willing to build were placed in operation. One of these two plants, each rated at 600 short tons per stream day, was built by the M. W. Kellogg Co. Based on steam methane reforming at 275 lb./sq.in.gauge, the plant used steam turbine-driven centrifugal compressors for air and refrigeration, and was the first to use a single gas turbine-driven centrifugal compressor for synthesis gas compression to 2,200 lb./sq.in. Two electric motor driven reciprocating compressors boosted synthesis gas to the full synthesis loop pressure of 4,500 lb./sq.in.

Subsequently, Kellogg developed and offered the first large, single-train plants using centrifugal compressors throughout, powered in large part by energy recovered from the process, and featuring high-pressure reforming and low-pressure synthesis.

Since early 1964, Kellogg has been actively engaged in the design and construction of 33 such plants ranging in capacity from 600 to 1,000 tons per day. Similar designs were brought out by many competitors, and since 1964, approximately 75 single-train units 600 ton/stream day and larger have been contracted for throughout the world. Figure No. 1 is a photograph of a typical 1,000 ton unit employing natural gas feed.

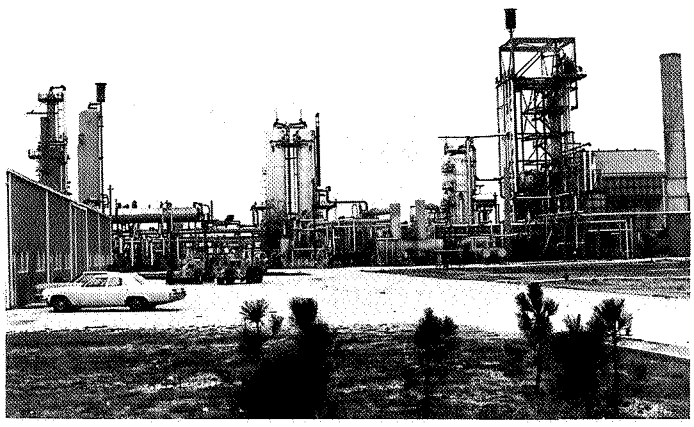

Figure 1. Typical 1,000 ton Kellogg ammonia plant using natural gas as feed.

Operating and Safety Experience

To date, a total of 21 plants representing an investment of \$250 to \$300 million and involving some 5 million construction manhours, have been built by Kellogg in 10 different countries throughout the world. The first of these plants attained full capacity in June, 1965, and has now accumulated approximately 16,000 hours of operation. By September 1967, 19 of the 33 units contracted to Kellogg had been placed in operation and had produced ammonia. These plants, along with two others in imminent startup, have accumulated a total of more than 100,000 operating hours.

As must be reasonably expected, some malfunctions and failures affecting plant operation and production have occurred, but no serious accidents have resulted.

It is the prime objective here to review the experiences of such safety-related service failures, describing the circumstances and corrective measures taken.

It is not the intent to cover all failures and malfunctioning of equipment which have forced unscheduled shutdowns. Indeed, the majority of such incidents do not constitute a safety hazard, and therefore do not merit coverage in a safety symposium. It is estimated that at most one-third of the lost time and production can be ascribed to the failures detailed below.

Primary Reformer

There are over 6,000 catalyst filled tubes in Kellogg-designed steam methane reforming furnaces currently in operation at outlet pressures in excess of 400 lb./sq.in.gauge. Each tube is composed of three or more centrifugally cast HK-40 (25 Cr-20 Ni) sections. There have been no reported failures of these high-carbon 25 Cr-20 Ni tubes.

Cracks have occurred at weld joints in the riser tubes which carry reformed gas from the bottom collecting manifold to the transfer line at the top of the furnace. The cracks are predominantly in the uppermost section of risers, or in attachment welds to the bottom manifold.

No cracks have been detected in the Incoloy 800 base metal of the bottom manifold. Some cracking was experienced in Inconel 182 weld metal joining Incoloy to Incoloy in the bottom manifold, but this is not considered a serious safety hazard because a complete fracture has not occurred and is considered unlikely. Furthermore, this manifold is completely contained within the fire box.

Cracks and complete breaks have occurred in riser tubes at welded joints; these have been in weld metal, base metal, and through both weld and base metal. Failures near the top of the riser have resulted in fire and damage to equipment; fortunately, there was no injury to personnel. Figure No. 2 shows the diagramatic arrangement and location of these weld joint failures.

In order to minimize the likelihood of further failures in the critical upper portion of risers, a design has been developed which will double the effective strength of welds by reducing metal temperatures. In addition, this design will direct the escaping gas into the fire box in the event of a complete tube severance. This design modification is adaptable to existing furnaces and is being made available to individual plants.

*Since January, 1968 with Hill Chemicals, Inc., Dallas, Tex.

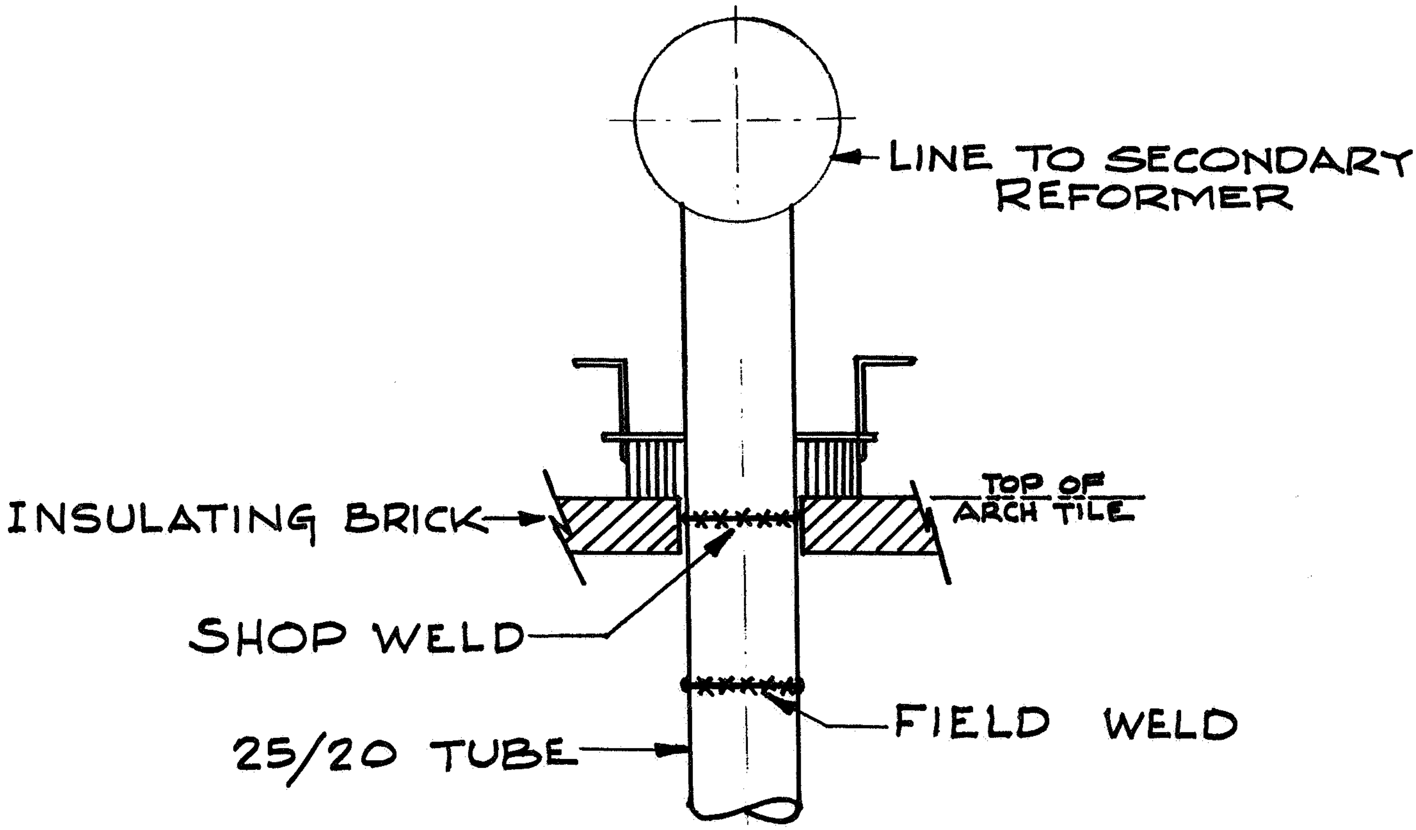

Figure 2. Diagrammatic arrangement and location of weld joint failures.

Shop welds and Field welds

Complete severance of the riser at the shop weld has occurred, resulting in damage to the top of the reformer. Investigation revealed that the welding electrodes used were not as specified. Instead of the required high-carbon 25 Cr-20 Ni composition, the electrodes were Type E310 with carbon content of 0.15 max. Not only does this produce a weld deposit of lower creep/rupture strength, but the composition is more crack-sensitive because of an unfavorable carbon/silicon ratio.

Two reformer furnaces containing a total of 16 welds were made with the wrong weld rod. One weld failed in service; an additional weld showed cracks. All 16 welds were repaired in the field by grinding out the low-carbon material and rewelding with Inconel 182 electrodes.

One other unit suffered failure in the Incoloy forging adjacent to the shop weld. This cracking has been associated with a local area of unusually coarse-grained structure in the forging.

Cracks have developed at the field welds or in tube metal adjacent to the field welds. These have been variously analyzed as creep/rupture failures possibly associated with weld root contour, or as casting defects and inadequate ductility of both cast and weld metals.

Reviews of the design by Kellogg and client companies has led to the conclusion that design stress due to thermal and pressure loading can be held below the level calculated for 100,000 hour life. The fact that failures have occurred suggests poor welding, excessive loading, over-temperatures, and lack of knowledge of weld metal strength. High localized stresses above design values can and have occurred due to a variety of circumstances such as incorrect tube support spring settings, binding of tubes, warping of manifold, etc.

Transfer line

An internally insulated and water-jacketed line is used to carry the reformed gases from the primary reformer to the secondary reformer. Figure No. 3 shows a diagrammatic arrangement of the line connecting the primary and secondary reformer. Loss of the insulation was indicated on two units by excessive boiling of water in the jacket. An examination of the line showed that insulation had eroded away.

In one instance there was an over-heating failure of the pressure shell resulting in fire and severe damage. It is not definitely established whether the failure was caused by lack of water in the jacket, loss of insulation, or other causes. However, it is difficult to explain gross overheating where an adequate supply of jacket water is maintained. The design has been changed to use a low-silica insulating material with better mechanical properties. In addition, more rigid inspection procedures for lining installation have been instituted.

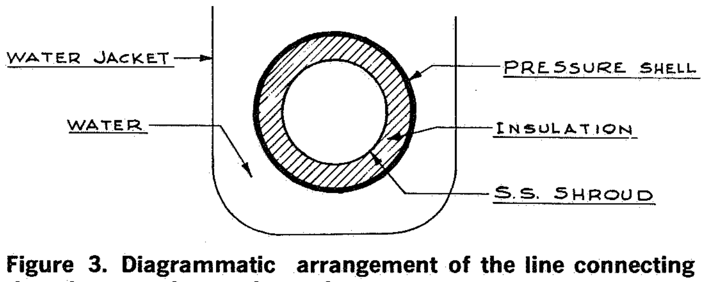

Figure 3. Diagrammatic arrangement of the line connecting the primary and secondary reformer.

Ammonia Synthesis Startup Heater

There have been two instances of explosions in synthesis converter startup heaters. The first blew the stack off, but the heater remained operable. This incident is attributed to improper purging prior to lighting.

The second instance of a startup heater explosion resulted in the heater falling over and severing of the line from the heater to the converter. The converter was depressurized but there was no fire. The heater was in normal operation and operating stably as confirmed by an operator who had been at the heater a few

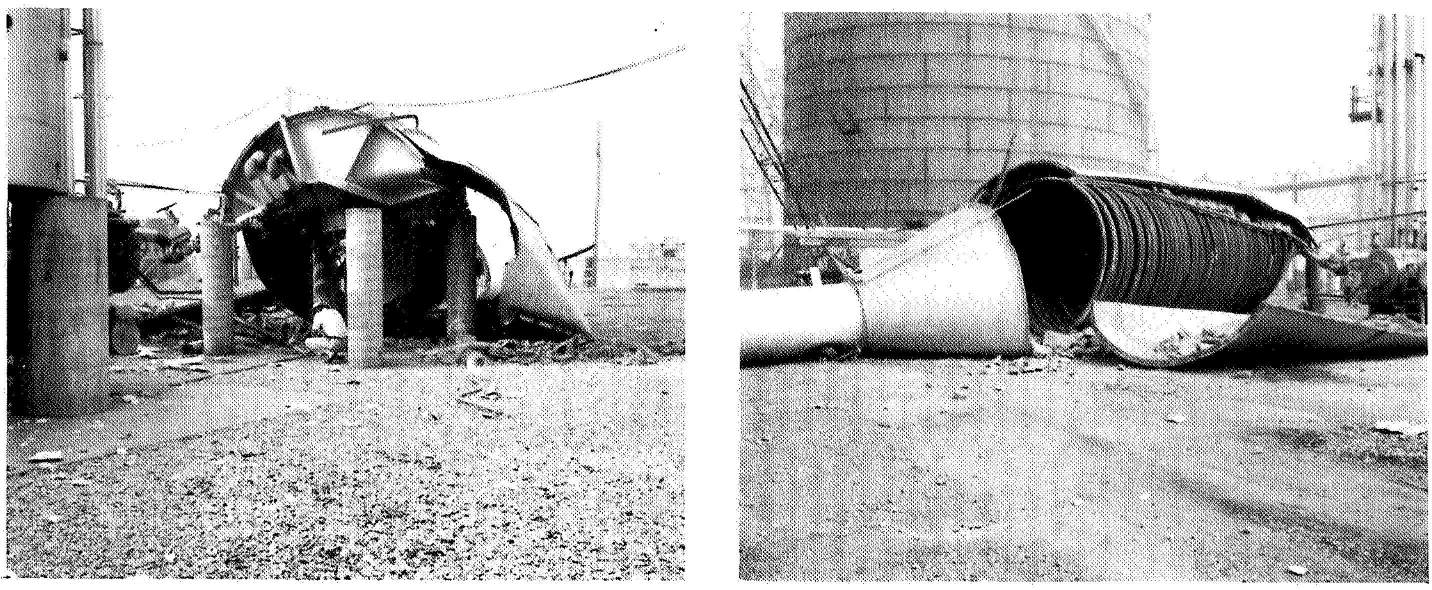

Figure 4. Photo of heater after the explosion.

minutes before the explosion.

The explosion occurred on the combustion side. Examination disclosed separation of the threaded connection of the gas line to the cast iron burner block; there seemed to be insufficient thread engagement and the line had pulled loose. Whether the gas line came loose as the result of the explosion, or before and caused the explosion, is not known. Figure No. 4 shows a picture of the heater after the explosion.

Figure No. 5 shows the standard start-up heater instrumentation. It should be noted that a flow indicator and low-flow alarm are provided in the control room to warn of low flow.

Process Vents

Location of process vents is shown in Figure No. 6. These vents are normally used during startup and in the event of trip-out of a compressor or other interruption of normal gas flow during operation. A synthesis gas compressor trip-out at full rate on a 1,000 ton unit results in venting of approximately 100,000 lb./hr. of synthesis gas.

Vents freguently catch fire and once burning are difficult to extinguish. Normally, it is necessary to stop gas flow to the line in order to put out the fire. Vents should be designed so that they can burn continuously and safely.

The large pressure drop available in high-pressure reforming units together with the large flows has resulted in structural failure of vent lines. Silencers represented to be structurally suitable for pipe mounting without additional supports have failed mechanically. One lesson learned from plant operation is that vent systems should have the same mechanical integrity as continuously operated process systems.

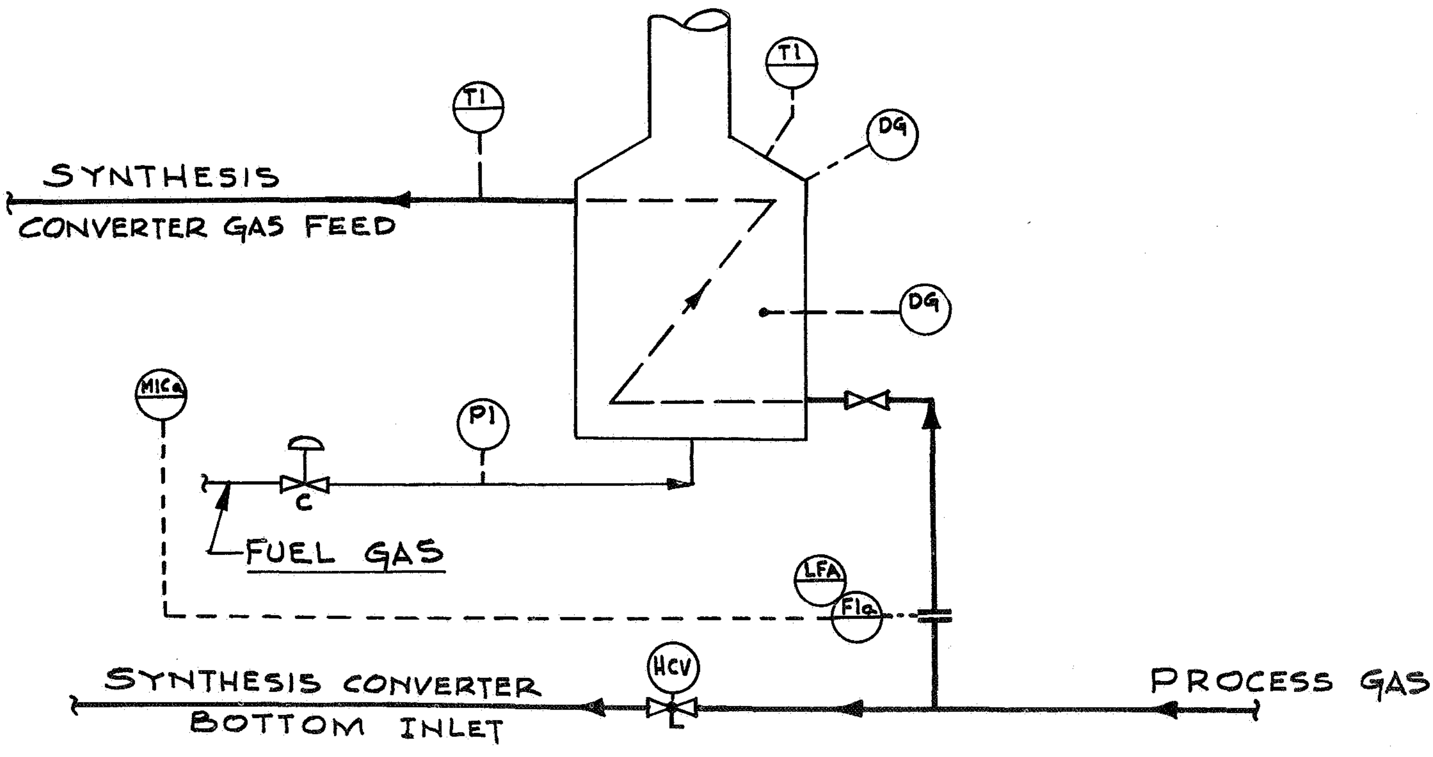

Figure 5. Standard startup heater instrumentation.

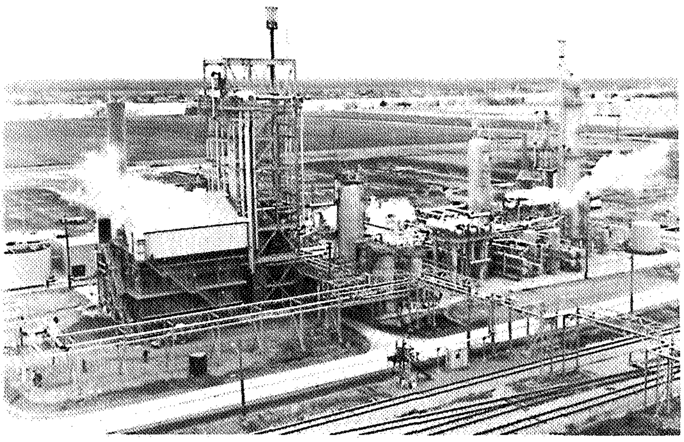

Figure 6. Location of process vents normally used during startup.

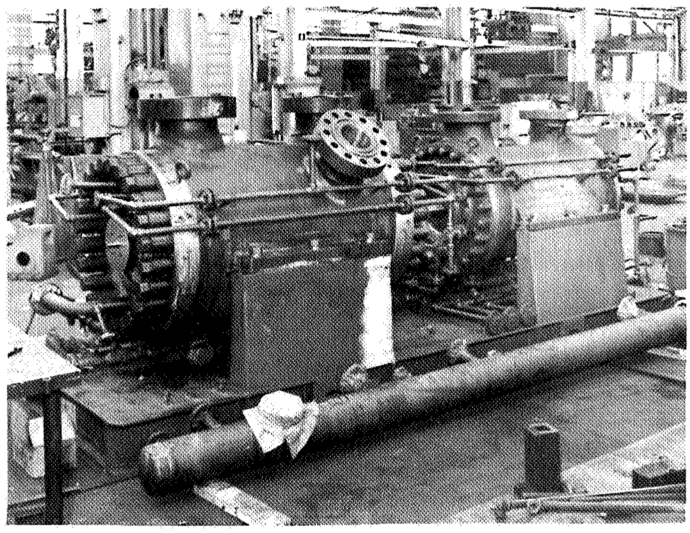

Figure 8. Photo of the synthesis gas compressor.

Steam Let-Down Line

Normal steam flow in the unit is shown in Figure No. 7. In normal operation high-pressure steam is reduced to the medium-pressure level by the topping turbine. During startup and in the event that the topping turbine trips out, steam pressure is reduced through a pressure control valve. On 1,000 ton units, the line downstream of the control valve developed cracks. This was surprising inasmuch as the problem was not encountered on 600 ton units. Field measurements showed low amplitude, high-frequency vibration to be the probable cause of failure.

Corrective measures such as thicker pipe wall and better support of the installation did not solve this problem. Consequently, a digital computer program developed by Kellogg to analyze vibration in reciprocating compressor piping was used to develop a design for an accoustical filter that would absorb the energy. This filter has been successful in all cases and the problem has disappeared.

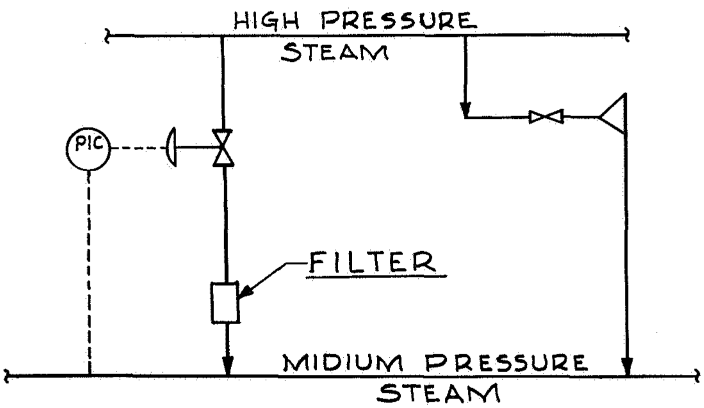

Figure 7. Normal steam flow in the unit.

Synthesis Gas Compressor.

During August and September of 1967, failures were encountered in the high-pressure stage of the synthesis gas compressors in two different plants. Figure No. 8 is a photograph of the synthesis gas compressor.

Plant No. 1 As a result of the compressor failure, gas was pressured into the lube oil reservoir causing buckling of the cover and throwing of oil over the area. The oil and gas caught fire, resulting in extensive damage, and the compressor shut down due to loss of oil pressure. The synthesis loop was isolated from the compressor but the block valve on the compressor suction was involved in the fire and could not be operated. Although feed gas was taken out of the unit, the feed preparation section depressured through the broken seals and fed the fire.

Dismantling of the compressor showed that the thrust bearing had failed and the rotor had moved in the direction of the impeller suction. All wheels suffered damage on the impeller side with 1/8 to 3/8 in. worn off. Prior to the accident, the thrust load indicator showed 4,000 to 6,000 lb. which is well below the 14,000 lb. maximum allowable. The compressor had operated for more than 2,000 hours.

The cause of the failure has not been determined.

Plant No. 2 The failure in the second plant was similar. There was a failure in the high-pressure stage of the synthesis gas compressor. Again gas was pressured into the lube oil reservoir causing buckling of the cover and throwing of oil over the area. The synthesis loop was isolated and the block valve to the compressor suction was closed. The first evidence of failure was reported to be a flame at the coupling between the high and low-pressure cases, followed by a flame at the coupling guard between the low-pressure case and the steam turbine. The lube oil consoles then burst into flame and ruptured. Fire damage was moderate.

Dismantling of the damaged compressor showed thrust bearing failure and extensive internal rubbing. Prior to the accident, the high thrust load alarm had gone off on more than two occasions. However, a check of the thrust load indicator showed a reading of 600 pounds versus a maximum allowable of 14,000 pounds. It was therefore felt that the thrust load was normal and that the switch was not working properly.

There are now more than 20 compressors of this type in operation; many for long periods. These two incidents are the only serious failures that have been experienced. There have been previous cases of lesser damage to synthesis gas compressors attributed to foreign material from the piping system entering the compressor.

Figure No. 9 shows a schematic diagram of the seal oil system. Steps are being taken to add venting capacity to the lube oil reservoir and strainers are being added to the suction lines of all machines.

Pumps and Drivers

There have been a number of failures in one plant where operation was delayed for six weeks due to shaft failures of a pump circulating CO_2 removal solution. Figure No. 10 shows this pump after one such failure in which the coupling was thrown 20 feet through the air. Cause of the failure has been attributed to the use of close-clearance ball bearings instead of the normal clearance ball bearings. Pumps using the proper bearing clearances have now been in successful operation for several months.

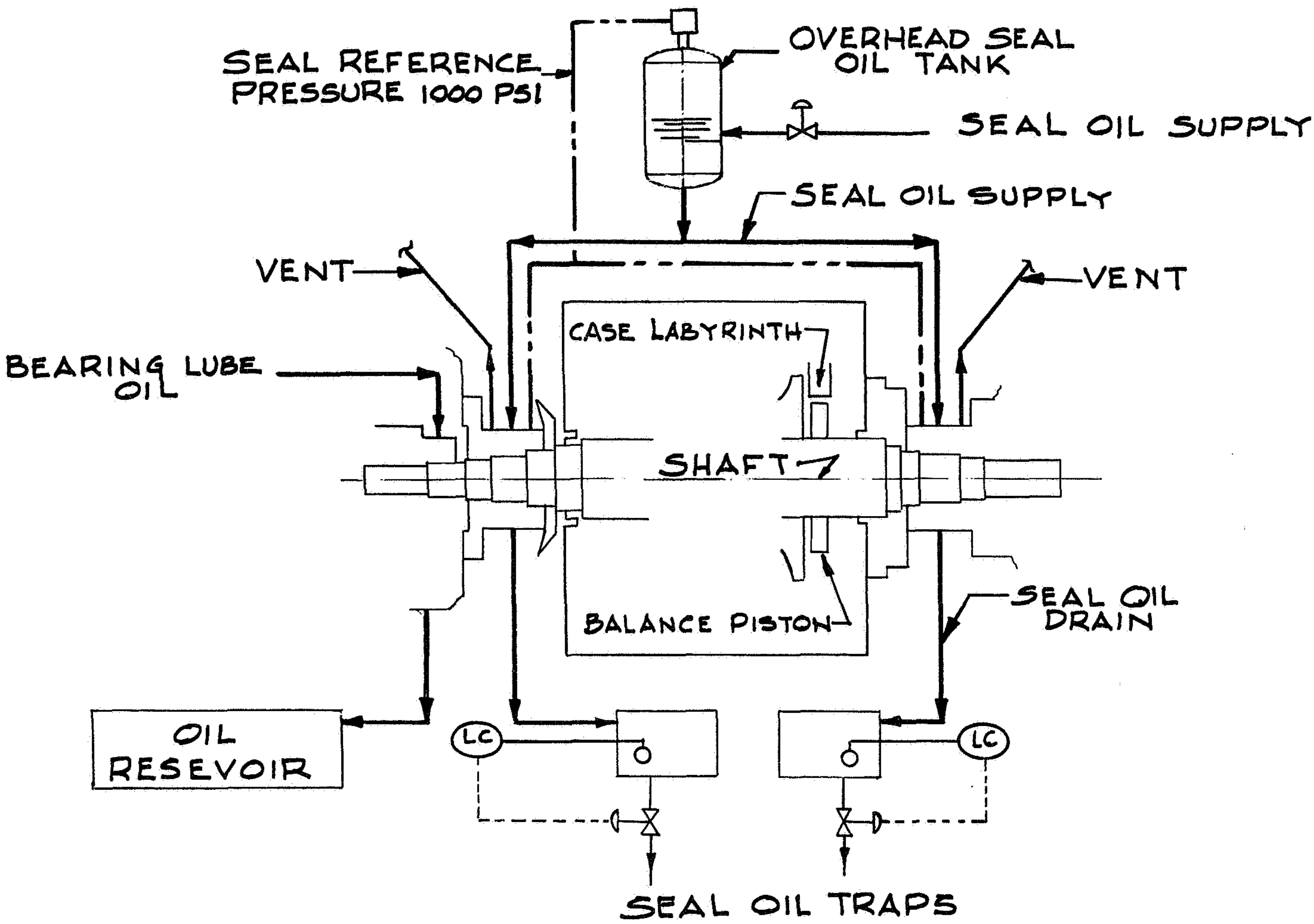

Figure 9. Schematic diagram of the seal oil system.

Safety Record and Productivity

The productivity of a unit and its safety record are necessarily related. Plant operation, like many other human endeavors, involves certain hazards and risks with respect to personnel and property. The acceptable levels of safeguards against hazards and injuries are spelled out in codes. Additional safeguards are to a large extent effected through instrumentation whereby development of hazardous situations actuates instruments which shut the plant down. There is an economic balance between the extent of such instrumentation, the degree of sensitivity to situations causing shutdown, and the operability of the plant.

The safety record with regard to personnel has been excellent. With regard to plant protection, this may have been carried to the point where one might question whether or not the production losses due to shutdowns have not outweighed the value of the hazards protected against.

While more is still to be learned, the record shows that both good safety and operating records have been attained. For 19 of the large Kellogg-designed plants placed in operation, elapsed time between the introduction of gas feed and ammonia production has ranged from 16 days to 50 days. Ten of these units attained ammonia production in 30 days or less. The first five units placed in operation in the United States operated at an average productivity of 85% once sustained operation was attained. Productivity of the five units ranged from 71% to more than 90%.

Reduction of Potential Hazards

On new reformer units now being engineered, the number of field-welded connections is being reduced, and welded joints are being relocated to avoid welds in hot highly stressed regions. Clearances and thermal expansion are being carefully reviewed to reduce the possibility of excessive loading from unexpected restraints. Metal temperatures at some points where failures have occurred are being reduced in order to increase strength. Erection procedures are being worked out in detail in order to assure that spring hanger supports function as designed. Increased inspection is applied to material, including check determination of chemical analysis of castings and welds.

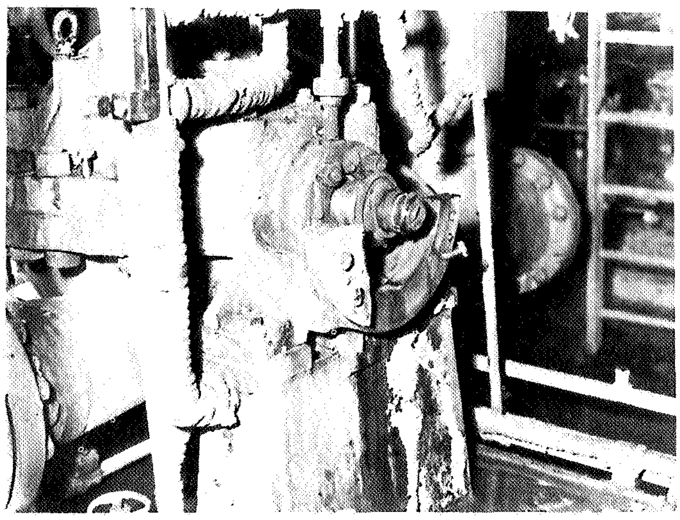

Figure 10. Pump after failure in which coupling was thrown 20 ft.

Use of strainers on inlet lines seems the only answer to avoid damage due to the large amount of foreign material being found in piping. Vibration monitoring equipment on bearings of high-speed centrifugal compressors and drivers, though expensive, seems highly desirable. It should be pointed out that this requires good maintenance on the part of the user or it is worthless.

Automatic shutdown of high speed centrifugal compressors in the event of rotor axial shift is highly desirable, provided a reliable measuring device can be installed.

More rigid quality control on the part of machinery manufacturers is required. There have been many instances of bearings not properly supported in the case and lacking oil holes.

Operator Training

Failures undoubtedly follow a probability curve determined by reliability of individual components. It is not possible to say that good operation will prevent all the problems that have occurred.

Conversely, it can be asserted that trained and alert operators can forestall many types of potentially serious failures by early detection of warning symptoms. Competence and experience is of particular importance in the operation of sensitive heat-balanced units where events feed upon themselves. A unit operating smoothly can be down in 2 minutes due to an error on heat balance, with probable damage to equipment or catalyst. On the other hand, good operation will often carry a unit through air compressor or feed gas compressor tripouts and restart without any major upsets.

It is indeed a paradoxical situation that these new and highly automated plants are in a sense more dependent on the human factor for safe and profitable operation than the older, smaller units. The risks and costs of failures are magnified with increasing plant size, and the level of operator proficiency should be commensurate.