Ammonia Converter Repair That Succeeded

Here's a case history of an installation in a Saudi Arabian fertilizer plant that worked and will provide useful suggestions in the handling of similar problems.

R.M. Gundzik and G.R. Short
Garrett Research and Development Co.
La Verne, Calif.

More than a year of satisfactory operation has been achieved in an ammonia converter in a Saudi Arabian fertilizer installation following major repairs performed on the unit after extensive decarburization and dangerous crack propagation were discovered.

The plant is that of Saudi Arabian Fertilizer Co. (SAFCO) in Dammam, with a design capacity of 600 metric ton/day ammonia and 1,100 metric ton/day urea. Occidental Corp. of Saudi Arabia is SAFCO's technical and management consultant. Garrett Research and Development Co., which supplements Occidental's engineering staff, played a significant role in the evaluation and corrective action.

Late in 1970, SAFCO and Occidental were made aware of the possibility of decarburization occurring in the ammonia converter and subsequently conducted an inspection of the upper and lower forgings. The findings of this inspection indicated no decarburization in the top forging but did show defects in the bottom forging.

A reinforcing pad was added in April, 1971, because of extensive cracking around the nozzle. A fan with a system to inject water into the air stream was also installed to provide cooling to the lower forging to reduce further attack.

In December, 1971, an inspection of the lower forging and outlet nozzle indicated that the crack around the nozzle had grown to a dangerous degree and had propagated an offshoot crack up on the inside of the forging.

Extending the useful life

This article will describe the repairs made to the converter and the steps taken to extend its useful life. Replacement of the lower forging, done in some other cases, was not undertaken because of the inordinate downtime and costs associated with such a repair.

The following specific items were accomplished in the repair and rework operation:

1. A successful repair and replacement of the outlet nozzle was made on the SAFCO ammonia converter after discovery of the extensive decarburization and dangerous propagation cracks.
2. Replacement of the canister with castable bubbled alumina refractory, and removal of a reinforcing pad, reduced the bottom forging temperatures below the range in which decarburization occurs.
3. Over a year of successful operation has been achieved, holding bottom forging temperatures below 400°F.
4. Accurate measurement of the bottom forging surface temperatures has been attained. This was done to confirm that the temperatures where decarburization would occur had been successfully avoided.

The following recommendations are based on the experiences accumulated in correcting the SAFCO converter.

1. Before starting repairs or modifications one should first ascertain the exact extent of the hydrogen attack. Based on this information, calculations can be made to arrive at a prudent decision on whether to replace the lower forging or remove metal and upgrade insulation, as was done at SAFCO.
2. Special efforts should be made to measure surface temperatures at various locations as well as process temperatures. These temperatures should be monitored and a running comparison made. This provides the data to ascertain changes in the condition of the insulation or any bypassing around the insulation canister. It also provides the data to calculate the heat flux and determine the interior surface temperatures as well.
3. In a new converter, it is advisable to measure temperature of the outside surface of the forging. This information can be utilized to estimate the interior metal temperature, which is usually within 20° to 50°F of the outside surface temperature.
4. In the past few years, superior insulations for the temperature range of 400°F to 900°F have been developed. It almost goes without saying that these products should be utilized. One thing to bear in mind always is that a high-pressure hydrogen atmosphere will tend to reduce some of the constituents of an insulation, causing it to lose its insulating value. Therefore, close coordination with potential suppliers is a must.

Excessive metal temperatures

The methane reaction resulting from hydrogen molecules combining with carbon at grain boundaries is a well-known mechanism of hydrogen attack. In the case of the

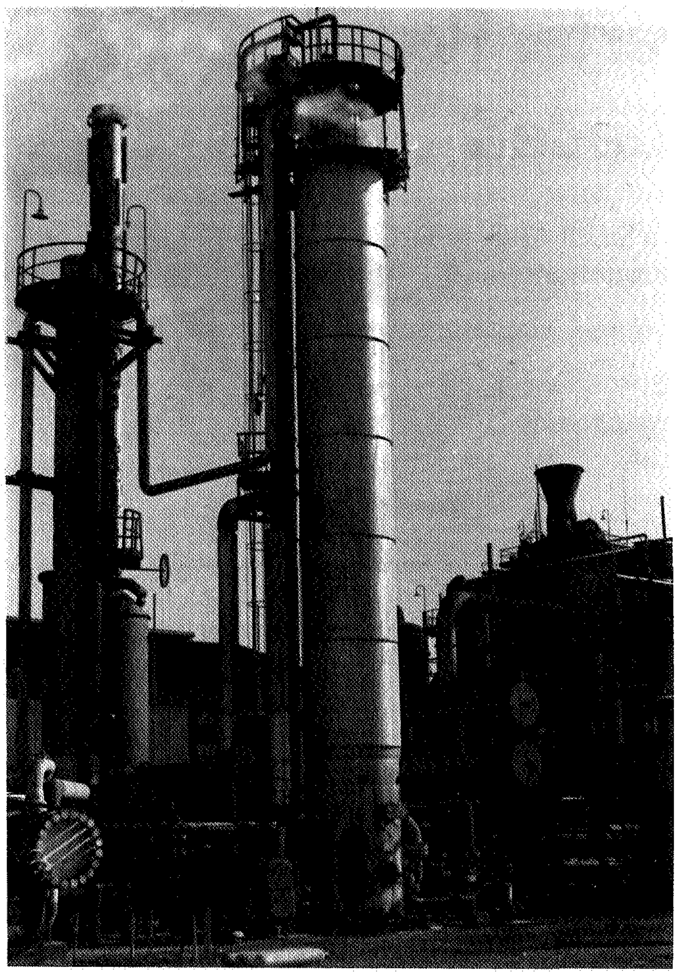


Figure 1. Ammonia converter at SAFCO plant in Dammam.

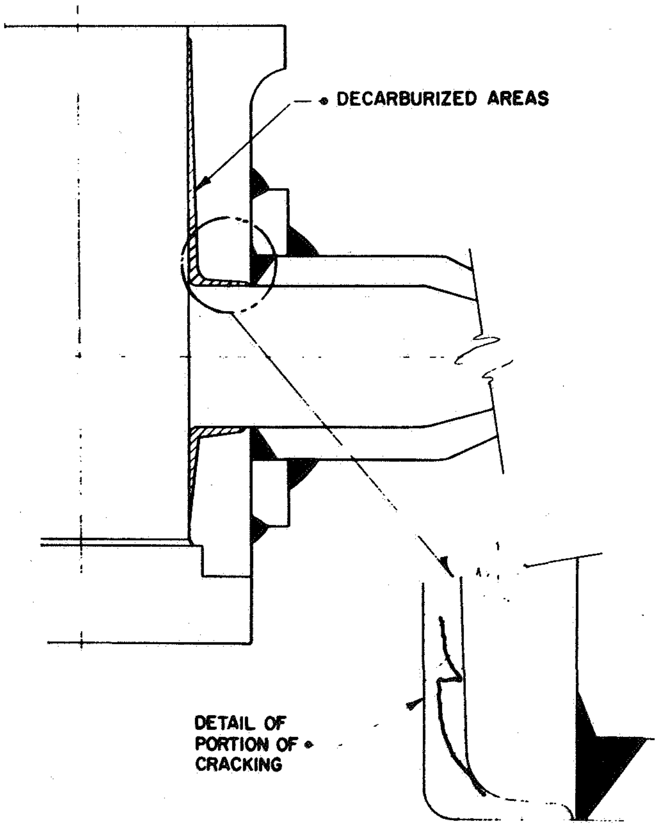


Figure 2. Lower forging with original nozzle.

SAFCO ammonia converter, a number of factors combined to produce excessive metal temperatures at high hydrogen partial pressure. In late 1971, the bottom of the converter, Figure 1, was opened and the canisters removed to investigate the propagation of cracks which had appeared on the inside surface of the forging above the outlet nozzle in the lower forging.

Figure 2 shows the general location of the decarburization and cracking. It was so extensive and widespread that further operation of the converter was inadvisable without bottom forging replacement or extensive repairs including nozzle replacement.

The inspection was thorough in order to define completely the problem. It included not only ultrasonic testing but dye penetrant. Original inspection in early 1971 included microscopic examination as well as ultrasonic testing. A hole then was drilled to a depth of 45 mm. and drill chips taken at depths of 5, 15, and 45 mm. for microscopic examination to verify the ultrasonic tests. Thus, confidence in later testing with ultrasonic inspection was justified and confirmed later during the repair work.

The inspection of the weld between the forging and the nozzle revealed that the cracks in the weld had propagated to a depth of 67 mm. in the 71 mm. thick nozzle. This propagation occurred despite the addition of reinforcement. The outlet nozzle was removed and the 13 in. opening in the forging was bored out to 16-1/8 in. Decarburized and cracked material was removed by on-site machining. The tool used to accomplish this job was a field-type boring machine which removed material in the vicinity of the outlet nozzle by eccentric boring.

A new nozzle installed

Calculation showed that the resulting metal stress of approximately 5,000 lb./sq. in. in the thinnest area was well

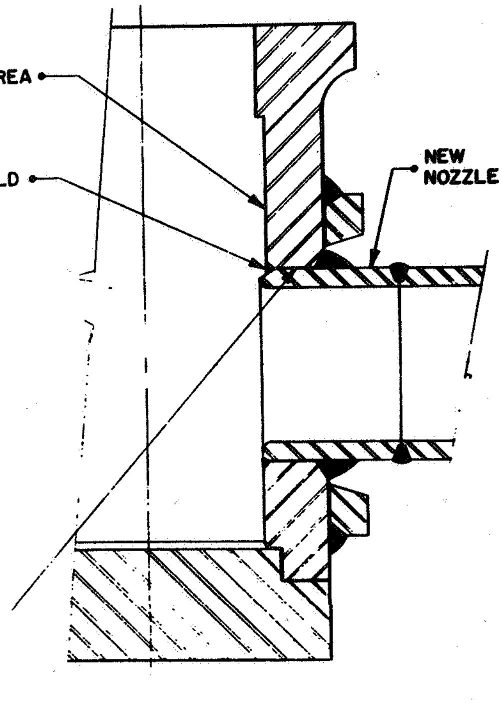


Figure 3. Lower forging with replacement nozzle.

within acceptable limits. At the same time a new nozzle as shown in Figure 3 was installed and the outside weld fillet size was increased over and above the original dimensions to 3 in. on the horizontal leg.

The new nozzle is 2-1/4% chrome, 1/2% molybdenum steel, which is not subject to hydrogen attack at normal operating conditions. The chrome and molybdenum stabilize the carbon; hence no methane is produced. The Nelson diagram *(1)* is a series of curves defining operating limits for steels in hydrogen service and is used as a guide for material selection. The experience at SAFCO generally confirms the validity of these curves. The Nelson diagram has been updated recently by the American Petroleum Institute *(2)*.

The weld rod for the major nozzle weld on the outside of the forging (see Figure 2) was also 2-1/4% chromium, 1/2% molybdenum steel. The interior minor weld was merely a seal weld which served no structural purpose and was carbon steel.

Two blisters were found in the forging interior after annealing which were caused by the hydrogen attack but formed by the post weld heat treatment. The largest was physically 3 mm. deep by 37 mm. in diameter. They were carefully wet-ground out to a depth of 22.5 mm. in the 41-mm. deep decarburized zone, leaving depressions in the forging which were ground smooth with a gentle radius.

A new insulation canister was installed which contained crushed refractory brick and castable refractory. The resulting thermal conductivity was higher than the fibrous insulation which it replaced; however, gains were made in the sense that the new canister was considerably more durable mechanically and the attack on the insulation itself would no longer take place.

Deterioration of the fibrous insulation

The fibrous insulation had deteriorated badly after its long exposure to high partial pressures of hydrogen at elevated temperature. On installation of the new canister, the fan with its water injection system was retained and a system of baffles was installed around the lower forging of the converter for the best utilization of the air-water mixture. This was not a desirable situation, but it sufficed as an interim measure.

A few thermocouples were placed on the forging; however, the measured temperatures were always in doubt due to the manner in which the thermocouples were installed. They appeared to be affected by water from the cooling fan. No thermocouples were placed between the reinforcing pad and the forging at elevations where the highest metal temperatures would be expected. The measurements consequently held little significance.

The plant was started up with the converter repaired as described above on February 15, 1972. The unit was structurally sound but it was not known if the temperature of thyforging had been reduced sufficiently to stop or significantly reduce the decarburization process. Calculations indicated that the metal temperatures were in the region of 450° to 470°F and according to the Nelson curves, decarburization was continuing but at a very slow rate. It was desired to stop this process, and also to improve the temperature measurement scheme and make provisions for periodic, thorough ultrasonic testing of the forging.

A final solution to the converter problem

Once the ammonia plant was back in operation, a number of plans were evaluated in order to select a final solution to the converter problem. Among these was the replacement of both the upper and the lower forgings made from 2-1/4% chrome, 1/2% molybdenum steel. Ordered on an emergency basis sometime earlier these forgings had arrived at the site during the shutdown.

Another approach that had been considered was the lining of the lower forging with the interface between the forging and the liner vented to atmosphere. This plan was abandoned because a number of difficulties were anticipated, the major one being that this type of rework was not considered feasible as a field operation.

On May 21, 1972, the plant was shut down for inspection of the lower forging and the new nozzle as well as to install an improved insulation to replace the normal canisters which had been installed earlier. This improved insulation had been successfully used earlier by both Collier Carbon and Chemical Co. and by American Oil Co., who were kind enough to provide us with information on their experience.

The canister was removed and the lower forging was insulated with bubbled alumina insulation in the form of a castable refractory, as shown in Figure 4. Harbison-Walker "Lightweight Castable 33" was used. Its thermal conductivity is 5.4 Btu./hr./sq. ft./°F/in. at 1000°F, and this value in fact was borne out in actual service. The value is 50%

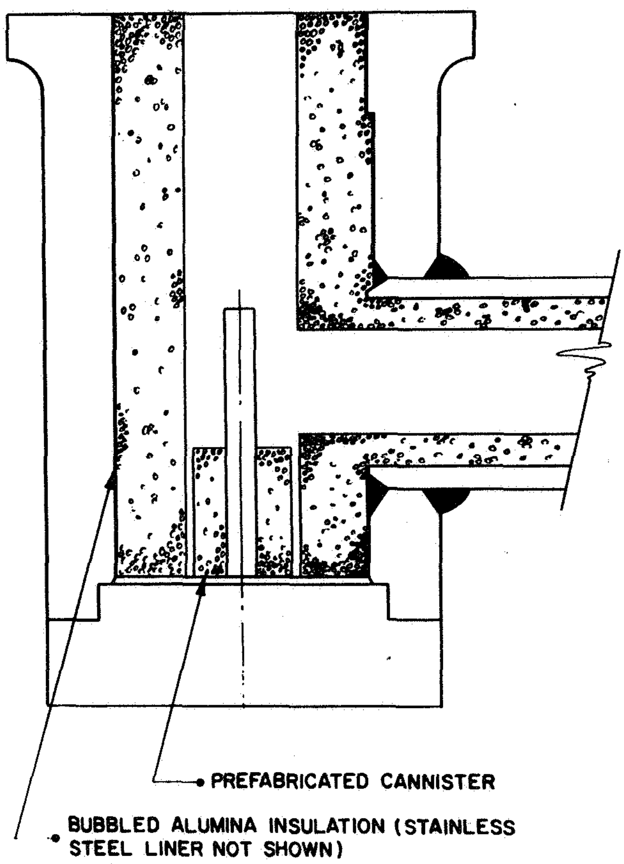


Figure 4. Lower forging with bubbled alumina insulation.

lower than that of the previous insulation, castable refractory and firebrick.

Hangers and finishing tools for the insulation were designed and fabricated in advance. The center lining was to have been inserted and welded into place in a specific sequence coordinated with the amount of refractory installed. Castable refractory subcontractors were brought into the plant at the time to install the Castable 33. They were able to place the refractory by hand in specific quantities, hold it with temporary wooden forms, and move on inserting sections of liner as they went. The sections of liner were welded as soon as they were installed.

This method of refractory placement was superior in two ways. First, time was saved. Secondly, eliminating the requirement to finish-trowel meant that the mix could be drier than originally planned, eliminating voids and increasing strength.

Removal of reinforcing pad

In addition to the insulation change, the reinforcing pad was completely removed because the newly installed nozzle eliminated the need for it. The removal of this reinforcement further reduced the metal temperatures because of the elimination of the air gap between the metal surfaces. It also allowed ultrasonic testing on the forging from the outside, thus eliminating the need to open the converter for inspection.

Upon removal of the reinforcing pad, the lower forging was thoroughly inspected by ultrasonic equipment. It was found that the decarburization had not progressed significantly since the prior measurements. In fact, no further decarburization was found in some of the cooler areas.

During the time the converter was shut down for this improvement, the upper forging was inspected thoroughly by ultrasonic tests. No damage of any kind was found; therefore no further attention has been given to this.

The result of the replacement of the canister by bubbled alumina insulation and the removal of the reinforcement was to nearly eliminate the necessity for forced-convection cooling. Limited forced-convection air-cooling directed at the nozzle junction to the forging has been continued however, to eliminate the possibility of any further attack.

The highest surface temperatures on the forging near the nozzle dropped to below 400°F, whereas other surface temperatures are normally below 350°F. The cooling required to produce this temperature came from a directed application of air from the plant system which supplies an injector and is considered quite minimal. The need for the earlier large fan, the baffles, and the water injection system was eliminated completely.

The thermocouple installation method was improved. Twenty-two points are now monitored. Figure 5 shows the two thermocouple installation configurations used for measuring surface temperatures. Insulation was added over the top to insure that the junction would be at the metal temperature. The forging is sufficiently thick so that the

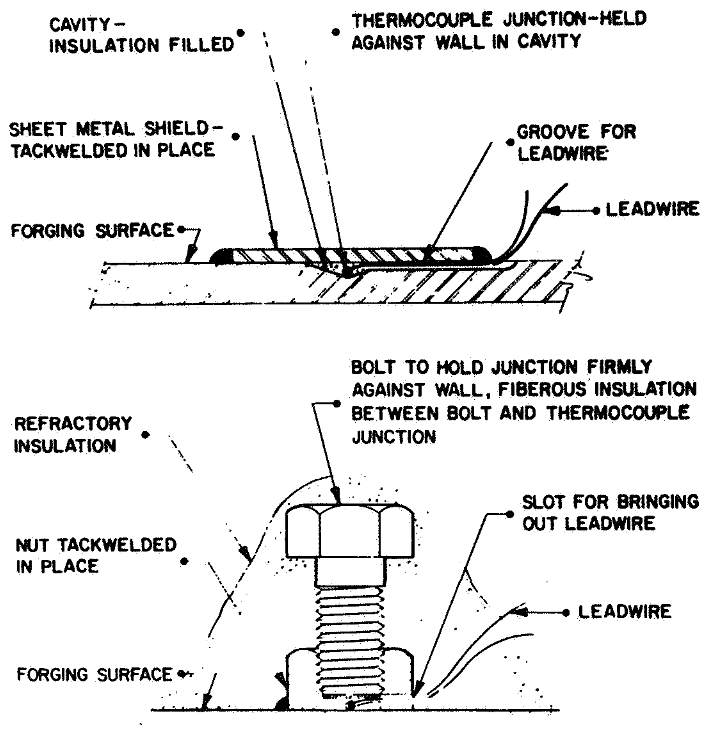


Figure 5. Typical surface thermocouple installations.

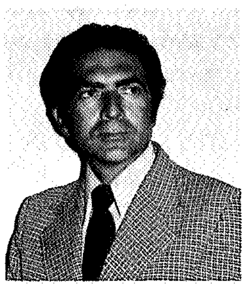
metal is locally insulated from the cooling air which does not affect the junction temperature significantly.

A number of measurements have been made on the decarburization on the lower forging since this installation of new insulation in June, 1972. No further decarburization has taken place. Decarburized areas remain in the lower forging, but the progression of decarburization was stopped completely. Current operating procedures call for at least bi-monthly ultrasonic inspections as well as daily monitoring of the temperatures of the forging. #

Literature cited

1. Nelson, G.A., *Hydrocarbon Process*, 45, 201 (May, 1966).
2. Amer. Petr. Inst. Pubn. 941, "Steels for Hydrogen Service at Elevated Temperatures and Pressure in Petroleum Refineries and Petrochemical Plants," July, 1970.

SHORT, G.R.



GUNDZIK, Richard M.