How Hot Is Too Hot?

A temperature previously considered safe turned out to be anything but safe in a case of a catastrophic failure of the header in a superheated steam system

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Even short period, high-temperature operation of a 1,500 lb./sq. in. steam system results in catastrophic failure of the header, and many other undesirable side effects.

Perhaps this statement seems obvious, but what is not obvious is the ease with which 1,300°F can be generated from the Farmland Industries 1,000-ton/day ammonia plant (design capacity) at Enid, at operating conditions. In a catastrophic failure of this type, "Monday morning quarterbacking" always reveals a great number of things that should have been done differently. This failure is certainly no different from that.

At the time of the failure in December, 1974, the plant was smoothly operating at a 1,300-ton/day rate. Nothing in the system appeared over strained or pushed. On the 13 shutdowns and startups that the plant had gone through from its initial operation in July, there had been difficulty in controlling the 1,500-lb./sq. in. steam superheat temperature below 900°F from the high-temperature coil, and below 700°F from the low-temperature coil.

On each shutdown, some excursion in temperature had occurred; certainly nothing as out of control as the one on December 11. Many investigations show no damage from earlier temperature excursions.

Power failure upsets process

The Enid plant relies greatly on electric power for its operation. The cooling water system and the hot carbonate carbon dioxide removal system are on total electric drive, with the exception of the hydraulic turbine. A series of three power failures between 9:05 am and 9:25 am caused serious process upsets that resulted in the catastrophic failure of the 1,500-lb./sq. in. header at about 9:40 am.

To answer the major question of the report, "How Hot is Too Hot?" it is now apparent that the temperature of the steam was around 1,300°F, and caused ductile failure of the 1,500-lb./sq. in. steam header. Point of failure was in the horizontal run near the thermowells just ahead of the superheater header relief valve. Approximately 3½ ft. of line opened, dumping all steam from every pressure level in the plant.

In addition to the steam line failure, the high steam temperature warped the case of the topping turbine, requiring its replacement. If that weren't bad enough, and it wasn't discovered until resumption of operation on December 28, the sudden and immediate release of steam had caused catalyst damage in the primary reformer. Catalyst replacement was made in late January.

With no plant steam power of any kind, residual reformer heat caused pigtail insulation to catch fire and burn in the penthouse. Also paving, insulation, and instrument destruction in the immediate area was total. There were, fortunately, no personnel injuries, which is to say that no one was closer than 100 ft. from the rupture.

The repair required catalyst replacement, replacement of the topping turbine, and the condemnation and reinstallation of approximately 220 ft. of the steam header. Closer to the rupture, it was obvious that the pipe was distended and bulged. Farther down the line, condemnation was made easy by simply measuring girth. Toward the outer limits from the failure point, sonic thickness measurement of the header was used.

The exact length of header to be removed for repair was determined by measuring the pipe thickness until normal thickness existed in all measured points. All the fittings were of a higher alloy (1¼ Cr, ½ Mo) and were of a greater wall thickness than the pipe. As a result, none of the fittings were damaged; and because of delivery problems, a great number were reused.

Rupture sample examined thoroughly

A section approximately 20 by 8 in. was cut from the rupture. The outside surface was covered with mill scale with a white residue, presumably from the insulation around the piping. The mill scale measured 0.0086 in. thick and contained many small longitudinal cracks. The edge had thinned to 0.068 in. at the thinnest point along the fracture surface. The rupture surface was ductile in appearance with the angle of fracture being approximately 45° to the radial direction. In the thinnest section of the wall, apparently where the rupture initiated, a concave surface was noted similar to that of the cup and cone type fracture seen in tensile specimens.

Based on the metallurgical examination, the rupture resulted from overheating to the point that the tensile strength of the piping was exceeded. In effect, the failure was by tensile overload, not however due to an increase in load, but due to a decrease in tensile strength as the temperature rose.

Piping that bulged but did not rupture was also overloaded, but only to the point that its yield strength and not its tensile strength was exceeded. There was no evidence that the pipe that was salvaged and left in the line had suffered any damage due to overheating. Total time for the outage was 417 hr. not including the catalyst replacement time which occurred a month later.

On resumption of operation on December 28, the maximum rate attainable was 1,120 ton/day because of the 100-lb./sq. in. pressure drop across the primary reformer. The carbonization and attrition of the catalyst was atypical to normal catalyst carbonization. The point of most severe carbonization was 21-23 ft. from the top rather than 6-8 ft. down, as normally expected. Flow reversal could explain this phenomenon.

A number of modifications have been made to the plant to reduce its sensitivity to excursions in steam temperature during startups and process upsets. These modifications have largely been born out of our increased operating knowledge and increased knowledge of the cause of the failure.

The most important operating change was in the treatment of purge gas and the primary reformer fuel gas header pressures during the time that the purge gas is extracted from the fuel gas header.

At the time of the failure, the standard operating procedure was to reduce the fuel gas header pressure to compensate for the lower heating value B.t.u./std. cu. ft. of the purge gas. The procedure assumed that reduction in fuel gas header pressure would directly affect the process exit temperature from the reformer.

We have learned since that this is not true over the entire range of fuel gas pressures. What happens is that with a given draft condition, at the time of purge gas extraction, any extra fuel over the air supply simply goes unburned into the convection section and does not impart any change in process exit temperatures. The operator can therefore very easily misjudge the required pressure reduction by only monitoring process temperatures.

To correct this error in logic, an immediate adjustment to calculated fuel header pressure, based on purge gas flow, is made on extraction of purge gas. These values are posted at the fuel gas header pressure controller. The operator then downfires beyond this point to receive a 5°F drop in process outlet temperature. At this point the convection caps must be opened to cool the convection section to make up for loss in steam make from the ammonia converter boiler feed preheater exchanger.

Before the institution of this procedure and understanding of principles involved, opening the convection caps did not always give uniformly desirable results. Frequently, opening the convection caps resulted in raising rather than lowering the exit steam temperature because of ignition of the unburned primary reformer fuel.

Changing the procedure to drastically and immediately reduce the primary reformer fuel header pressure is the only major operating difference since the failure. Prior to the failure, reductions in process gas feed rate were made because the vent system at the suction to the synthesis gas compressor and the methanator vent will not tolerate vent rates above 1,000 standard ton/day.

Now, on abandonment of the loop, no change is made to process gas feed rate so that new process upsets are not introduced, and so that maximum steam generation can be maintained from the waste heat section. Maximum waste heat steam is needed to cool the steam superheater. Also, when the loop is abandoned, it is desirable to continue maximum heat removal from the firebox by maintaining full process rates. These are the only operation changes that have been made.

Design changes are made

The accident also pointed out a number of mechanical deficiencies with the unit operating in the 1,300-ton/day range. This unit is different from previous prototypes in that the superheater area is some 25% larger than previous units.

During normal operation, this extra area provides a steam system that is a great deal more stable and has more power flexibility than the earlier prototypes. However, in startup, control of superheat is very touchy. Because zinc oxide desulfurization is used and is integrally heated with the convection section, initial reformer warm-up frequently causes excess temperatures to be generated, even with the tunnel caps and convection caps wide open.

It has been observed that from the time steam is introduced to the reformer until closing of the loop, some difficulty is encountered in holding one of the superheater coils within alarm limits (881° and 700°F). The difficulty is more severe when 50% or more of the steam make is from the auxiliary boiler. On startups, the superheat problem does not disappear until steam is generated from the converter and the auxiliary boiler can be downfired. Obviously on shutdown the reverse is true; superheat sensitivity appears as soon as the converter comes off the line.

At the time of the failure there was insufficient horsepower to govern draft in an ideal manner at the 1,300-ton/day rate. The maximum speed at which the induced draft fan could be driven was 650 rev./min. By renozzling the turbine, any speed required up to 900 rev./min. can now be obtained.

A fan speed of 730-740 rev./min. is required at 1,300 ton/day to maintain correct draft for burner control and proper concentration of excess air. At the time of the failure, with the fan limited at 650 rev./min., the furnace was always operating in the threshold of afterburning. To make matters worse, it has also been determined that at time of the failure, two of the three louvers in the auxiliary boiler duct were detached from the operating shaft and under load conditions remained in the closed position. This naturally resulted in low draft in the auxiliary boiler and increased the likelihood of afterburning in the convection section.

Considering the induced draft fan and auxiliary boiler louver deficiencies, it was fortunate to have not scattered the unit all over the landscape. Because of this danger, continuous oxygen and combustible analyzers are being installed in the convection section. In the meantime, operation is based on fan speed corrected by laboratory analyses on the stack gases twice each week.

One additional recommendation has been made to install desuperheaters in the superheat coil section. These will facilitate startup and shutdown and reduce the difficulty of control.

Now, while this catastrophic failure is fresh in everyone's mind, it is not apt to recur. Since the heat exchange relationships are sometimes obscure to the operators because of the many variations, it is feared that some time in the future this knowledge will change as people change, and time will erode the memory of the catastrophe. To forever prevent a recurrence, it is strongly recommended that the desuperheater be installed. The desuperheater will normally save 8 to 10 hr. on each startup.

Conclusions

As the entire event is contemplated, anything above 900°F is too hot. It is possible to operate within this limit even though all of the recommended changes have not been installed. If the present state of knowledge had been achieved prior to December 11, the failure would not have occurred; it can be chalked up to lack of operating experience and incomplete mechanical diagnosis.

On the other hand, if a system that is so complex and integrally meshed as to require superhuman operators to constrain the process within safe limits, then it needs some modification. As the new generation of reformers with air-preheat is about to be born, steam temperature sensitivity is likely to continue unless some help is given the plant operators. #

J.D. Atwood

DISCUSSION

B.O. STROM, CF Industries: We are very concerned about the problem you mentioned in your paper in that superheat temperature even the old Kellogg ammonia plants, was always a problem. We struggled to control it. You are talking about time wasted. I think it's true. However, we feel at least that we should have a more positive control of this superheat temperature, because runaways will take place, and control by these caps is not the answer. You know that—I know that. It's never worked. It's nonsense.

Now more importantly, even though the ID fan is beefed up and has enough horsepower et cetera, we are still facing, on start up, with low capacity steam generation, by your auxiliary boiler because the caps are not functioning. We end up with a superheat temperature that's way up above 1000F or 1100 degrees. And we have suggested, at least I have already begun suggesting to Heat Research at M. W. Kellogg, that we look and attenuate the temperature as you call it, between the two coils.

Now they are telling me whether or not it's so I guess we have to take their word for it, that there's only five feet distance between the coils. So I'm suggesting that they look at control of the temperature at some reasonable level. The way it is now we are in difficulties and I don't think anybody is sophisticated enough to operate the plant safely.

ATWOOD: Certainly I agree with that, and one point that you bring out there is one of the things that lulled us into the failure. It is not uncommon in this particular kind of reformer for the high temperature alarm to sound during startup. This was certainly true prior to December 11th, and because it had always occurred, the operator was not nearly as aware of what could occur as what did occur. Certainly I think a thousand degrees is tolerable, but if the alarm point is actually 881, and once that point is exceeded, the operator can not be complacent about it. To prevent operator complacency, control must be added to the steam system.