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Thermal shock and its challenges

It's the weekend. You are sitting at home watching your favorite team on TV. A call comes in from the plant about a heat exchanger that has just cracked. You are amazed because this exchanger has been the best performer in your unit.

How could it have happened? It is a thick nozzle with plenty of reinforcement. Then you remember the energy contest at the plant and how the winning team incorporated a recycle waste slipstream just ahead of where the nozzle cracked. However, you still wonder if that could have been the problem because it has been in service for six weeks. You do know this slipstream cycles in temperature several times a day.

The process group could not find anything wrong with the process. The operations group said they have always run the unit the same way. The engineering group said the design was good for the process conditions. The materials group took samples and found no defects. All of the bases were covered on the energy project, and everyone is certain it shouldn't have caused any problems.

When you are evaluating the system, you look at the flow and determine a cold stream is meeting a hot pipe. When this happens, the branch connection experiences thermal shock. The thicker branch section lags thermally more than the thinner pipe section. The local thermal gradient is high, thus causing high stresses. One way to validate the suspected cause is to instrument the affected area with thermocouples tied to telemetry to understand the variation in temperature and thermal lag.

As it turns out, the root cause of the problem was thermal shock. The engineering group had looked at the steady state conditions, but the transient thermal and stress conditions were not considered when the slipstream cycled in the process. The nozzle on the vessel was thick. There was a thermal lag in the mechanical response leading to high peak thermal stress. It took several cycles for the vessel to eventually fail, and it was diagnosed as low-cycle thermal fatigue.

The problem was solved with the following methodology:

1. Data acquisition was utilized to provide temperature profiles. The system was monitored on a 24-hour basis, and it could be easily seen how the affected area changed thermally.
2. A transient finite element model was developed. To execute this model, a finite element heat transfer model would first be developed. Then the nodal temperatures would be transferred to a finite element structural model. From that point, the stresses could be determined.
3. Once the finite element models were validated and matched what was going on in the field, a fix could be numerically tested in the model. To fix the problem was to illuminate the high local thermal gradient. Sometimes this could be done with insulation. More often than not a thermal sleeve has to be installed. This is simply an inner pipe that acts as a sleeve for the colder flow to enter the branch connection. A thermal sleeve was designed and implemented, and the problem was solved.

A few tips to consider for thermal shock:

- Look at the transient process conditions. In most cases, the steady state process conditions are looked at. In this particular problem, the failure occurred after a process modification. And compared to the overall plant life, it was actually pretty soon. Most problems involve some type of transient effect that is either overlooked or unforeseen. The code says the transient conditions should be looked at. This problem involved a higher level analysis that is not normally the case for design groups.
- Notice areas of thick transition. These areas often have high local thermal gradients that are detrimental to the overall design. When dealing with hot and cold conditions in the same line, the local thermal gradients are worse across thick areas.
- Take data acquisition readings whenever possible. Taking data will add confidence to the root cause of the problem. Today, with modern systems, the data can be transmitted anywhere on earth via the Internet. Remote monitoring systems can be quite helpful.

These types of problems should be reviewed and approved by a professional engineer competent in these problems.

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