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Dissecting erosion corrosion control case studies

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Just the other day I was out at my boat dock. I had some guide poles for my Jet Ski lift and the section that was always in the water corroded quickly in just over two years. It amazed me how bad it was and how bad it looked. The end pieces looked as if I dipped them in acid and it just ate away. As it turned out, for this application at my boathouse, I simply had the wrong stainless steel pipe. This costly exercise got me thinking about all of the industrial applications I have worked on, and I "blew" the design at my own home.

What I am primarily concerned about in this article is erosion corrosion control. Now what is erosion corrosion? Well, no matter how you might look at it, it involves the degradation of the material by some mechanical action in conjunction with a chemical interaction between the material and the media it is in contact with. There are many forms to express erosion. One way can be as follows (and there are many other ways). Some chaps have been spending a lifetime coming up with the equation, but the point I am trying to make will be clear as we go along.

$$L = \frac{C v^n \dot{m}_p t}{p A}$$

L — Linear loss of material
v — Impact velocity
m — Mass flow rate of particles hitting sample
p — Density of material making impact
A — Impacting area
C — Pre-exponential erosion corrosion constant
n — Power-law erosion constant
t — Time of exposure to erosion

The first principle in using third-party data is it may have significant errors that could affect the accuracy of the end result. For example, in the equation above, the constants C and n greatly affect the results. These constants are dependent on specific experimental conditions and can vary greatly. Notice how significant velocity can be to the problem if it builds up to a high level. The rest of the parameters in the equation are relatively "hard numbers" one can have some level of confidence in. Remember it is the number of particles hitting the sample and not the number of particles in the flow field.

The best test is one that considers the exact application and where samples can be put in an actual operating environment. However, in the real world, that is not always possible when failure occurs. Sometimes the actual failure conditions cannot be duplicated or determined without great difficulty and cost.

One way to determine C, m_p or V^n is to perform what is called a reverse analysis. In such a situation, you have had a failure and there is a desire to determine what the corrosion erosion rate was. A computational fluid dynamics (CFD) model can be developed and sensitivity studies can be performed to extract reasonable values for the constants. There is typically enough data available in the problem such that one can set an "anchor" on one or more of the critical parameters that will enable one to extract through the simulation what the other values may be. Using this approach is remarkably more accurate than using third-party data and information.

Case study mixer erosion

One of many successful case studies involved erosion in a mixer. For this piece of equipment, the internals were eroding out in a much-localized area. The bulk internal flow rate was designed to be high. A special weld overlay was used to protect the "wetted areas." However, even with all the protection, some areas would wear through to other critical components and a catastrophic failure would occur. It was also decided to increase the weld overlay in the area that failed, but that failed as well. Matters were further complicated because the fluid followed a Bingham-plastic model and was non-Newtonian. This fluid flow field is where a fluid shear stress is dependent on shear rate and temperature.

Several things were known that were contained within the carrier fluid, such as flow rate and particle composition. Through the CFD studies, we found the failures were occurring at locations of high velocities. Since we knew the component of erosion was a function of $V^{2.5}$, we knew what the target velocities had to be. The following methodology was executed to solve this problem:

1. A Bingham-plastic model of the fluid was developed.
2. The model's behavior was tested against known solutions.
3. The existing design was run and the model was compared to actual test data. In this case, there was good correlation between the actual flow conditions and what the model predicted.
4. The geometry of the internals of the burner was changed until the velocities were down to an acceptable level.
5. A prototype design was put in and tested, and worked the first time.

We did anticipate the particle impact would be the same. We just wanted to keep the velocity down. The project was successful and the erosion was no longer a problem because we reduced the velocity by streamlining the mixer.

Case study: Inlet flow to a transfer line exchanger (TLE)

In the ethylene industry, it is common to run feedstock in coils through a furnace to crack it to make ethylene. After the product comes out of the furnace, it must be quenched. One piece of equipment used for this is called a TLE. It is essentially a high-pressure and high-temperature heat exchanger. One of the challenges with the design is a low residence time is required on the gas side, which is the tube side in the heat exchanger. A typical inlet temperature is 1,575 F. The water side is typically about 1,500 psi, and the temperature is at the saturation point. In the process, when the gas side is quenched, heat is recovered and steam is made.

It is typical for vendors of this equipment to install all sorts of "hardware" on the gas side to prevent erosion. However, the KnightHawk team went to the base physics that govern the process to solve the problem. The problem was essentially coke particles travelling at high speed, and they would impact the inlet tube sheet and cause erosion.

Again, we find a situation where the erosion is a function of velocity to $V^{2.5}$, so KnightHawk once again employed CFD and went to work. The first discovery had no hardware and clearly showed what the problem was. The industry got a low residence time in the inlet piping at the cost of causing jet flow toward the center of the TLE. Even though the inlet flow diverged from a pipe to the size of the diameter of the TLE, it still had jet flow. It was as if the diverging cone was not there.

OEM would simply put impact plates, and this would stop the erosion but would cause coking in low flow zones that were created in the inlet to the TLE.

KnightHawk determined by going back to the base physics the best solution was to have an even flow field throughout the entry. This was accomplished by reshaping the inlet of the cone to the TLE and adding what we call inner flow body (IFD). KnightHawk patented the design, and it has worked successfully at Chevron Phillips for more than 10 years. KnightHawk has learned through years of research there are optimum velocities to prevent coking yet achieve uniform flow. In this process, we have also discovered TLEs that are oversized with too low of velocities that require more advanced techniques to address.

Summary

Both of these problems prove complex erosion problems can be solved by going back to the base physics and equations that govern the problem. In these cases, it was velocity. So, the velocity was reduced at critical points to achieve problem goals and objectives. Critical points for success are as follows:

1. Determine if experimental data by third parties is sufficient for the constants in the erosion corrosion rate equations. If not, you need to conduct your own experiments or reverse calculate from an actual problem.
2. What is the best fluid model to characterize the flow field? Is it a simple compressible Newtonian model or is it a complex non-Newtonian model?
3. The area of concern is impacting of particles and the number. Usually the total particle count is known but not the amount of impact. CFD sensitivity studies can help on this.
4. Temperature effects can be a problem in high-temperature erosion corrosion situations. Sometimes this is referred to as "hot erosion."
5. It is best to run models of the existing design and compare to a newly proposed design to make sure all of the modeling makes sense.
6. Make sure there are no corrosion aspects that can bite you. An example would be where the protective magnetite layer is lost off of high heat flux equipment. If this happens, corrosion will govern, and no matter how you tweak the flow field, you will still lose the ball game.
7. Run test cases to validate anticipated results. One aspect not discussed in detail is time of exposure. This relates directly to the erosion corrosion rate to determine if the design will be acceptable.

Finally, here is a small plug about the IFD above. It is an effective device that solves problems in a unique way. There are many applications for it and it is quite cost effective. KnightHawk will model your exact application and put in a device that meets your requirements for the application. Usually, it is made of a high alloy material that can take the temperature, and it is anchored into the refractory inlet cone. Contact KnightHawk and we can discuss how this equipment can help you.

As with many of these complex systems, this analysis should be led by a professional engineer competent to do the work using a multidiscipline approach.

For more information, visit www.knighthawk.com or call (281) 282-9200. ●