Cavitation Erosion

Cavitation erosion (and the related erosion or impingement corrosion) is an infrequently discussed yet frequently misunderstood phenomenon that can lead to metal damage and failure. It can afflict everything from engines and generators to plumbing systems and propellers.

Cavitation is the formation of voids or bubbles in a liquid that are a result of forces that act upon the liquid. It's important, however, to distinguish these voids from common bubbles as the latter contain a gas, often air, while the former contain nothing. That is, they are vacuum bubbles. Interestingly, the formation of the cavitation void is tantamount to boiling because the boiling point of a liquid drops as the pressure drops. (It's why mountaineers use pressure cookers; at a high altitude and therefore lower atmospheric pressure, water boils at a temperature lower than 212°F.) Thus, cavitation bubbles are essentially a result of low temperature boiling induced by low pressure.

Cavitation may occur as liquid moves swiftly around constrictions and through orifices, particularly when such orifices change shape from small to large, as in water moving past a gate valve, or worse, through a partially opened valve. These conditions create a Venturi effect and the rapid change in pressure is conducive to the formation of cavitation bubbles.

Cavitation also occurs when a liquid is placed under a high vacuum. This can occur if the supply of fuel or hydraulic fluid to a pump (including high-pressure injection pumps) is restricted, creating a high vacuum. Cavitation erosion also occurs on the back (the forward-facing) face of propeller blades when the propeller is overloaded, i.e., when the surface area of the propeller is insufficient for the size or weight of the vessel. A similar form of cavitation erosion occurs inside cooling systems when impellers or circulation pumps turn more quickly than the fluid can readily move. The speed of the impeller "tears" the fluid, creating a void or bubble.

Yet another area where cavitation erosion occurs, and perhaps the one that causes the greatest degree of grief and expense, is on the outside of a diesel engine's wet cylinder liners. Engine pistons operate inside cylinders that fall into one of three categories: parent bores, dry liners, and wet liners.

Parent bore cylinders are essentially bored directly into the cast-iron block. They are rugged, reliable, and have no issues with cavitation. Coolant circulates around the outside of this casting, removing heat from the cylinder. However, they are less easily repaired or rebuilt, especially in place, because the bore can only be repaired by, well, re-boring in a machine shop, which requires engine removal.

Dry liners are similar to parent bores except the bore in the block is oversized and a liner is then pressed into it, enabling it to be replaced relatively easily, affording the engine a higher degree of serviceability.

Wet liners essentially take the place of a parent or dry liner in that they are inserted into the block; their outside surface makes direct contact with the coolant. These liners are supported by, and seal with, the top and bottom of the block alone. In the middle they are free standing, and as such, they must be especially rigid. The advantage of this design is, again, that in-place replacement of liners is possible. However, their advantage over the dry liner is that because they are in direct contact with coolant, they transfer heat more efficiently. This, in turn, allows engine designers to extract more horsepower from the same size block and displacement when using a wet liner. As a result, a smaller, lighter engine can deliver more power.

As advantageous as wet liners may be, they are susceptible to cavitation erosion. As the fuel mixture in the cylinder is ignited, it sends a shock wave through the wet liner's wall. That shock wave momentarily pushes coolant away from the outside surface of the liner, creating a void or vacuum bubble. This process occurs with every ignition cycle, thousands of times per minute. At 2000 rpm, a 6-cylinder engine experiences 12,000 shockwave events.

You now have a clear picture of how and where cavitation occurs; however, the real issue is the damage it causes. How damaging and destructive is it? Imagine what it would be like to repeatedly and cyclically subject a metallic surface to 10,000–15,000psi shocks. Some studies show that this is precisely what occurs in a cavitation erosion environment. The real destructive power isn't in the formation of the cavitation void; it's in its demise. As the pressure around the void increases, at the end of the shockwave cycle in the wet liner or as fluid leaves a low pressure zone in a fuel injection pump or on the surface of a propeller, the void collapses violently, wherein high pressure and often heat are generated, albeit on a microscopic scale. As this occurs, metal is scoured away, molecule by molecule. Remember, this occurs over a long period of time through repeated exposure to tens of thousands of void implosions. Eventually, a pit forms, which acts as a catalyst for future formation of cavitation voids, accelerating the process.

The good news is cavitation erosion is relatively easily avoided. In pump applications such as hydraulic and fuel systems, keeping vacuum or suction effort to a minimum is usually all that's required, which means keeping filters clean, along with good engineering of the system to prevent restrictions in high-pressure plumbing.

For engine cooling systems, the preventive action is multi-pronged. Ensure that you are using the proper, manufacturer-approved, diesel-rated coolant, particularly if it's a wet liner engine. Coolant that is specifically formulated for diesel use often includes cavitation inhibitors. Additionally, you can add manufacturer-approved SCAs, or supplemental coolant additives, that form a film on surfaces, reducing cavitation. Also, make sure your coolant and cooling system are clean. Old, contaminated coolant whose additives have been depleted will do little to prevent cavitation erosion, and deposits inside an engine's cooling system (these often occur as a result of failing to replace coolant or flush the system often enough) also increase the likelihood of cavitation erosion in that cavitation bubbles form more readily at or on these deposits.

Finally, make absolutely certain that your cooling system is operating under pressure—and under the correct pressure. Pressurizing a cooling system, and virtually all are pressurized, serves two functions. One, it raises the boiling point of the coolant, making overheating less likely. Two, because cavitation is a form of boiling, raising the pressure also makes this less likely to occur. Thus, you should inspect the pressure cap and seat on your engine's and generator's cooling system to make sure the gasket and seating surfaces are intact and free of any damage that might prevent it from retaining pressure.