Chapter

18

Cavitation

Locations

Cavitation is favored anywhere low-pressure regions form in water. Abrupt pressure changes and turbulent flow promote attack. Damage may occur only where water contacts surfaces. Pump impellers, and other pump components, are the most commonly attacked boiler component. Blowdown lines and valves are also frequently affected. Pump impellers are usually damaged on the suction side, and valves show wastage on discharge sides. Less commonly, condensate lines and turbine components are attacked.

General Description

Cavitation is a process whereby small vapor spaces rapidly form and collapse in a fluid. Pressure differences in the liquid cause vapor-bubble formation. The liquid actually boils at the reduced pressure. The steam bubbles quickly collapse, producing microjets that impinge on metal surfaces. The damage may affect only the normally protective oxide layer, or in severe cases, may directly attack the underlying metal, physically dislodging less resistant alloy phases.

Energy is required to form a cavitation bubble. Part of that energy is consumed in creating the bubble surface. Since it takes less energy to form the bubble on a preexisting surface, cavitation bubbles form most readily on existing surfaces. Pressure may be lowest and turbulence highest at or near moving surfaces. Further, surface discontinuities afford easy bubble-nucleation sites. Bubble formation and collapse may occur in just a small fraction of a second. Each bubble collapse produces a relatively small amount of damage. Damage accumulates during thousands of cycles. Once surface irregularities are formed, attack will tend to concentrate at damage sites, eventually producing deep, localized attack.

Critical Factors

Pump cavitation is often caused by too high a pressure differential between suction and discharge sides. Insufficient head pressure is usually the precipitating cause. Throttling on the suction side of pumps promotes a large pressure differential. Gas entrainment due to leaking packing, decomposition of water chemicals, and gas effervescence can also promote bubble

Figure 18.1 Longitudinally split blowdown line with severe localized metal loss caused by cavitation.

formation. In a surprising number of cases, incorrectly sized impellers and other pump components cause difficulties.

Blowdown lines are especially susceptible to damage if flow is excessive and the discharge direction abruptly changes. Attack usually occurs during intermittent manual blowdown when flow direction is severely changed in pipe tees and elbows. Attack can be intense if blowdown rate is high and lines are undersized (Fig. 18.1).

Alloy composition also influences attack. Soft, ductile metals and brittle, low-strength alloys such as gray cast iron are easily attacked (Fig. 18.2). Alloys such as chromium stainless steels are resistant to attack in many environments.

Turbulent flow and abrupt pressure changes promote attack. In many cases, cavitation is a threshold phenomenon. Cavitation does not simply gradually decrease in intensity, but ceases altogether below some critical turbulence level.

Identification

Cavitation damage produces localized areas of jagged metal loss. Undercutting is usually pronounced. Close visual inspection reveals surfaces having a spongy, honeycombed texture. Attacked regions may or may not

Figure 18.2 Pump-housing section severely attacked by cavitation. Material of the pump-housing section is gray cast iron.

Figure 18.3 A cast steel feedwater-pump impeller severely damaged by cavitation. Note how damage is confined to the outer edges of the impeller where vane speed was maximum.

be covered with corrosion products. However, if attack is active shortly before the section is inspected, corrosion products will be minimal. Although corrosion usually accelerates metal loss, attack can occur in its absence. Even glass can be attacked by cavitation.

A striking feature of cavitation damage is the localized nature of attack. Wastage is most severe on pump impeller vanes near the outer periphery where impeller speed, and presumably turbulence, is highest (Fig. 18.3). Attack is most severe on trailing vane edges, where low-pressure areas are formed (Fig. 18.4). Pump shafts, for example, can be attacked locally where surfaces are exposed to turbulent conditions (Fig. 18.5). Adjacent surfaces are usually only lightly polished or apparently totally free of damage. Edges, corners, and projections all intensify turbulence, provide bubble-nucleation sites, and become preferred damage regions.

If components are vibrating, damage may be present on all surfaces in contact with water. However, vibratory modes involving movement in a single plane are more common and produce attack on opposite sides of the component.

Cavitating pumps can sometimes be recognized by the sounds they

Figure 18.4 Vane damage on low-pressure sides of small, special-purpose, bronze feedwater-pump impeller. Some vanes have been penetrated.

Figure 18.5 Highly localized cavitation damage on steel feedwater-pump shaft. Adjacent regions are free of metal loss.

make. Active cavitation can sound like the impact of stones against metal surfaces. However, pump noise and vibration usually mask these sounds.

Elimination

Cavitation damage can be reduced by design, alloying, coating, and/or surface finishing. Design strategies concentrate on reducing turbulence, vibration, and rapid pressure changes. Maintaining sufficient head pressure, preventing packing leaks, and discharge-side throttling all reduce pump damage. Smoothing of impeller surfaces and use of elastomeric coatings prevent damage by reducing nucleation sites and by absorbing the implosion energy of bubbles, respectively.

Hard, resistant alloys including 18-8 stainless steels are often recommended. Plasma-coating and surface-hardening techniques have had limited success in reducing attack.

Cautions

Cavitation damage resembles acid corrosion. Although somewhat similar to other impingement and erosion phenomena, cavitation produces distinctly different wastage. Because of the unique characteristics of this damage, microscopic observations often conclusively show that cavitation has occurred.

Related Problems

See also Chap. 7, "Low-pH Corrosion during Acid Cleaning," and Chap. 17, "Erosion."

CASE HISTORY 18.1

Industry:	Chemical manufacturing
Specimen Location:	Blowdown line threaded into a tee
Specimen Orientation:	Horizontal
Years in Service:	6
Water-Treatment Program:	Phosphate
Drum Pressure:	1200 psi (8.3 MPa)
Tube Specifications:	2½ in. (6.4 cm) outer diameter, mild steel
Fuel:	No. 6 fuel oil, natural gas

Severe, localized wastage on internal surfaces caused a blowdown line to fail. A perforation occurred near the attachment of the pipe to a tee (Fig. 18.1). Attack was confined to spongy, jagged patches of loss; surrounding surfaces were free of significant deterioration.

Failure occurred during manual blowdown. Blowdown had been increased due to feedwater contamination from the preboiler system.

CASE HISTORY 18.2

Industry:	Pulp and paper
Specimen Location:	Boiler feedwater-pump impeller
Specimen Orientation:	Vertical
Years in Service:	1
Water-Treatment Program:	Phosphate
Drum Pressure:	1200 psi (8.3 MPa)
Impeller Specifications:	10½ in. (27 cm) diameter, 7 vanes, cast steel
Fuel:	Black liquor

Feedwater supply could not meet boiler demand. The feedwater impeller was severely wasted, and the vanes were almost gone. Attack was confined to the periphery of the impeller (Fig. 18.3).

Wastage was apparently caused by cavitation induced by insufficient head pressure.

CASE HISTORY 18.3

Industry:	Steel
Specimen Location:	Condensate line
Specimen Orientation:	Horizontal
Years in Service:	3
Water-Treatment Program:	Polymer
Drum Pressure:	900 psi (6.2 MPa)
Tube Specifications:	4½ in. (11.4 cm) outer diameter
Fuel:	Natural gas

A condensate line developed several small perforations. When opened, the line was riddled with many irregular pits (Fig. 18.6). Some pits mutually intersected, forming more general areas of metal loss. Close visual inspection of pits revealed jagged, irregular internal-surface contours.

Pits strongly resembled oxygen corrosion (See Chap. 8, "Oxygen Corrosion"). However, microscopic examination showed evidence of severe plastic deformation and mechanical shock within, and only within, pits. Further investigation revealed a history of steam hammer and other mechanical vibration of this line.

It is possible that oxygen pits were present before cavitation became severe. However, it is clear that cavitation played a role in deepening these pits and causing final perforation.

Figure 18.6 Heavily pitted condensate line. Attack resembles oxygen pitting, but was caused (at least in part) by cavitation.