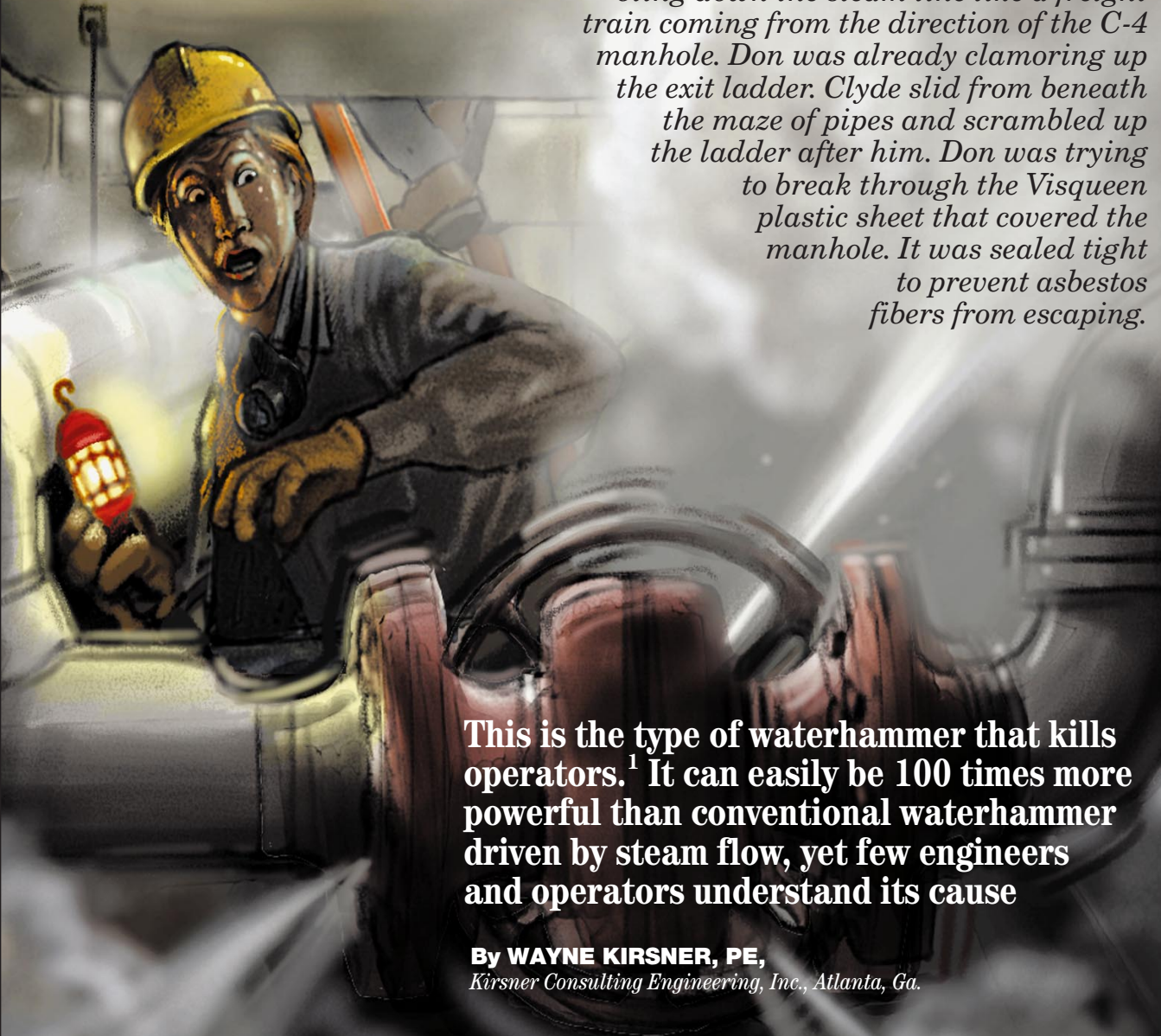




Condensation-Induced

The steam pipe started to vibrate and shake. Don yelled to Clyde — “Let’s get the Hell out of here...this thing’s going to blow!” Clyde stuck his head out from where he was removing insulation beneath the steam pipe. He heard a loud roar rumbling down the steam line like a freight train coming from the direction of the C-4 manhole. Don was already clamoring up the exit ladder. Clyde slid from beneath the maze of pipes and scrambled up the ladder after him. Don was trying to break through the Visqueen plastic sheet that covered the manhole. It was sealed tight to prevent asbestos fibers from escaping.



This is the type of waterhammer that kills operators.¹ It can easily be 100 times more powerful than conventional waterhammer driven by steam flow, yet few engineers and operators understand its cause

By WAYNE KIRSNER, PE,
Kirsner Consulting Engineering, Inc., Atlanta, Ga.

Waterhammer

A white steam cloud rolled down the utilidor from the direction of C-4 and began to flood the manhole. Another worker fleeing the encroaching steam crawled up behind them. Together, they desperately tore at the stubborn Visqueen seal until it finally gave way, shoved open the steel hatch above, and tumbled out into the fresh air. The swelling heat from the utilidor rose around them. Up top, there was pandemonium. Steam was billowing out the C-4 manhole as well as the manhole they'd just exited. Fire engines were arriving. Men were shouting and trying to figure out who was still down in the utilidors. Two other workers, Bobby and Wayne, had not gotten out.

Moments earlier, before the accident, Bobby had opened the 10 in. gate valve at Manhole C-4 a second incremental turn. He thought, "This is strange; the valve's handwheel spun freely." Just 15 min earlier, he'd "cracked open" the 10 in. cast iron valve to admit steam into the 2200 ft steam line to begin warming it up. For three weeks now, he'd been energizing the G-Line at the end of the asbestos workers' shift and had never had the system warm up this quickly. It usually took about 30 to 45 min. When the handwheel spun freely, he understood the lack of friction to mean that steam pressure on either side of the valve had equalized, so the warm-up was complete. He could open the valve the rest of the way. This seemed too quick though. He'd better check with his supervisor before spinning the valve all the way open.

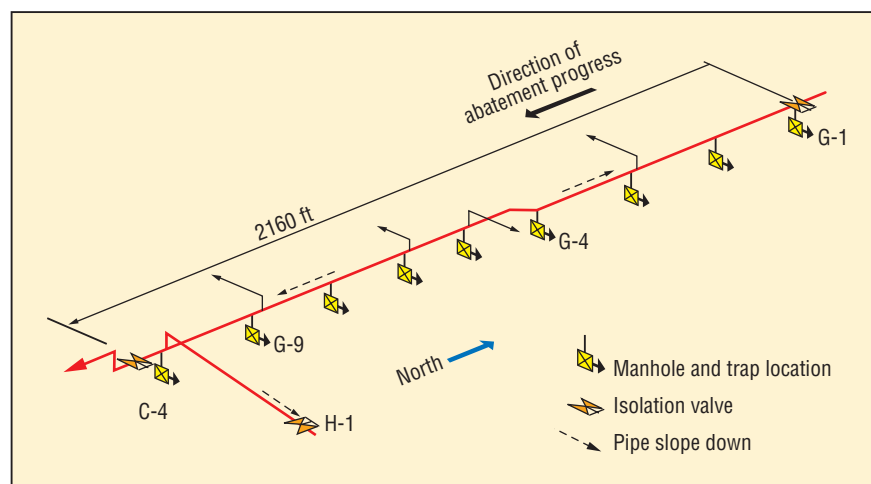
¹ Mr. Kirsner wrote the July 1995 HPAC article "What Caused the Steam Accident that Killed Jack Smith."

Bobby nudged past his co-worker, Wayne, as he made his way over to the material passout and yelled up through the plastic flaps to his boss — "She's spinnin' freely. Is it okay to open her up all the way?" The supervisor was puzzled, too. "No," finally came the muffled response. "Better continue to open her a little at a time like we were told to do." About a minute had elapsed since Bobby had opened the valve enough to lift it off its seat. As Bobby turned back to the valve, a "pop" was heard. Then a moment later, "KA-BOOM!" Hot water and steam exploded from the 10 in. valve. A white cloud of flashing condensate and steam filled the utilidor with a suffocating wave of heat. Wayne was knocked down and stunned by the scalding water spraying from the valve. Egress via the manhole exit was cut off by steam spraying from the valve. The only way out appeared to be through the material passouts constructed into the roof of the utilidor. Bobby clambered up on top of the pipes and jumped up catching his armpits above the opening. From

there, he was able to hoist himself through the plastic-covered opening. He emerged with second and third degree burns, but otherwise, he was okay.

Wayne stumbled through the piping to the other material pass-out. His first jump was too weak, and he fell back onto the piping, which by now was becoming slippery with condensing steam. Air temperature in the utilidor was approaching 200 F. Wayne desperately collected himself. He knew that this might be his final chance. He groped his way back up onto the slippery pipes, took a breath of the searing air, and leapt up again into the plastic-covered opening. This time he was able to hook one elbow above the rim and, with his life on the line, kick up through the opening.

Clyde and Don saw Wayne crawl out through the plastic flaps of the material passout. He rose to his feet and started screaming for help. His protective clothing was shredded. Loose skin was sloughing off his exposed arms and legs. He was badly burned. Clyde yelled at passers-by to call an ambulance as they ushered Wayne away from the steaming manholes. Soldiers with a knowledge of first-aid rushed him to a barracks across the street and started to apply cold packs to his burns and gave him cold drinks. Wayne's throat was beginning to constrict. An ambulance arrived to rush Bobby and Wayne to the hospital. As the injured workers were being cared



1 Isometric view of G- and H-Lines (no scale).

STEAM ACCIDENT

for, Clyde turned his fury on his supervisor and screamed, "We told you this would happen."

What happened

For four weeks, asbestos workers had been removing asbestos insulation from the 2200 ft section of steam main known as the G-Line and the 120 ft H-Line (Fig. 1). Like all steam mains at Fort Wainwright, Alaska, the G- and H-Lines ran underground in narrow utilidor²s filled with pipe. Originally, the contractor had tried to abate the steam main with the lines energized. This proved to be near impossible for the workers. Utilidor temperatures reached 160 F as insulation was removed from the 325 F pipe carrying 80 psig steam. Laborers who had to be suited-up and masked to work in the asbestos-laden environment were passing out from the heat and/or were quitting. The contractor was forced to seek relief from the owner. A compromise was negotiated after the first week—steam would be de-energized at midnight before each workday, and asbestos abators would start work at 4:00 AM and finish by noon at which time steam would be restored. The asbestos removal contractor would be responsible for de-energizing and re-ener-

² Shallow underground utility tunnels capped with removable concrete lids.

gizing the steam line daily. For the three weeks before the accident, this was the procedure. By the beginning of the laborers' workday, temperatures in the utilidors were still around 120 F, but with frequent breaks to cool off and re-hydrate, conditions were tolerable.

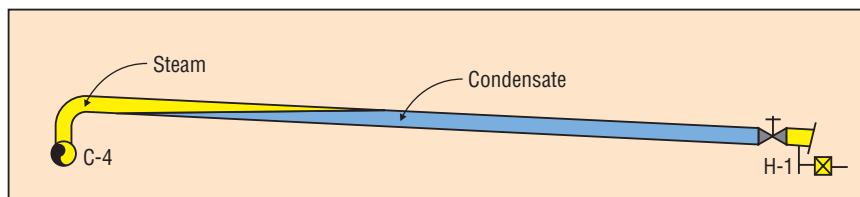
Unfortunately, discomfort to the workers was not the only consequence of removing the insulation from active steam mains that had gone unforeseen. There was also the effect on the steam traps. At each manhole, a $\frac{3}{8}$ in. thermodynamic trap was installed, except C-4, which contained a $\frac{1}{2}$ in. trap. At the system's operating conditions, the $\frac{3}{8}$ in. traps could remove 295 lb of condensate per hr.³ With 3½ in. of insulation, 300 ft of 12 in. pipe generates 41 lb of condensate per hr. Thus, for a typical pipe segment, the traps had better than a 7 to 1 safety factor for condensate removal *with the line insulated*. With the insulation removed, however, heat loss increased by almost a factor of 18 so that condensate formation jumped to 729 lb per hr over 300 ft of pipe. At this rate of heat loss, the $\frac{3}{8}$ in. traps had less than one-half the capacity needed to keep up with the condensate production. This was not good.

³ Trap conditions were 80 psig with a 10 psig backpressure.

Abatement began at Manhole G-1 and headed south toward C-4 at the rate of 125 ft a day. As abatement proceeded down the G-Line, local traps serving the uninsulated portion of the line were overwhelmed with condensate during the period that the lines were energized each day. In the first two weeks, however, this did not cause a problem. Excess condensate merely rolled down to C-4 on the south end and G-1 on the north end. Traps on the south end, still serving insulated portions of the line, had adequate capacity to remove the excess condensate. On the north end, the steam valve was left closed, so trouble was avoided. After two weeks of daily startups without a serious incident, save some minor waterhammers, asbestos crew operators grew confident that startup of the steam line was no big deal.

By the beginning of the third week, insulation removal had reached Manhole G-9. Calculations showed that at this point the rate of condensate being generated in the southern section of the G-Line began to exceed the net capacity of the traps to remove it. Condensate accumulation during steam operation is potentially destructive. But even so, as long as condensate is religiously drained everyday before startup, a catastrophic waterhammer accident might still be averted. The problem was that condensate wasn't being drained religiously. The asbestos workers given responsibility for energizing the steam main daily didn't fully anticipate the danger inherent in starting up a high-

continued on page 116



2 H-Line full of condensate to overflowing.



3 Conditions before C-4 valve opened.

STEAM ACCIDENT

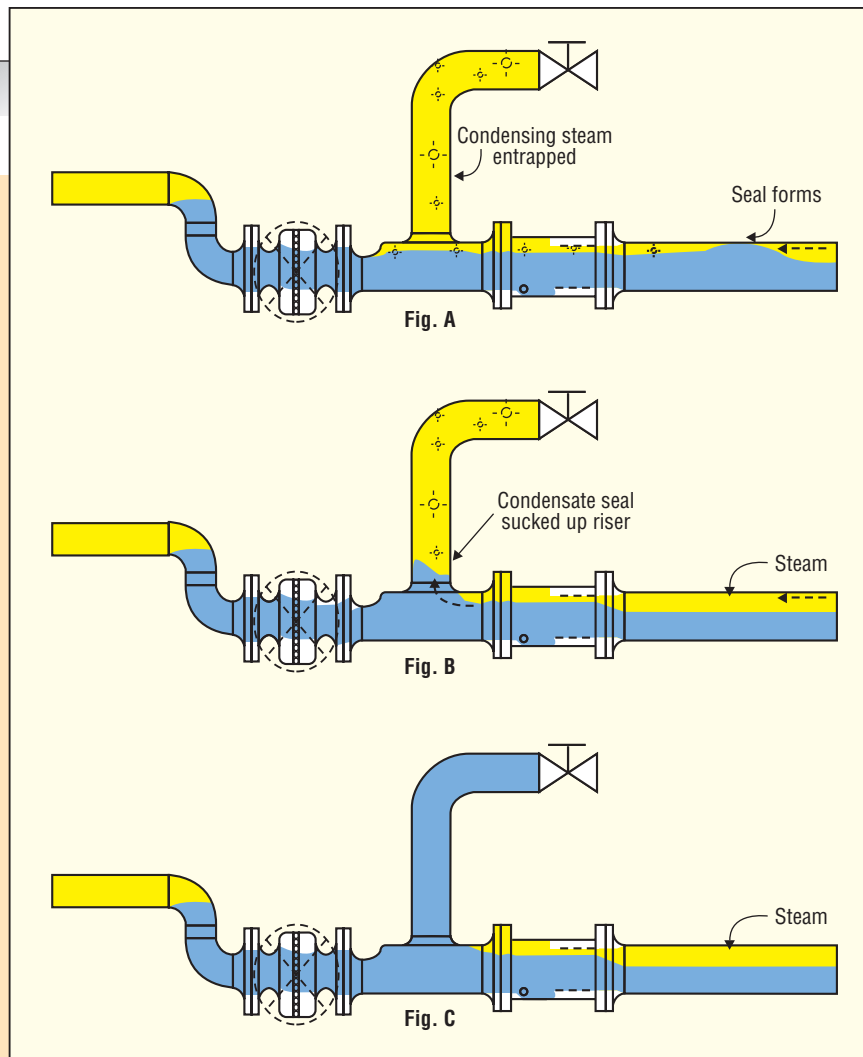
continued from page 114

pressure steam system with condensate in it. They did not routinely open drain valves to bleed the system of excess condensate either at night, when they shut down the system, or at noon, when they re-admitted steam through the C-4 valve to re-energize the steam main. Their belief was that steam admitted through the C-4 valve would blow condensate to the far end of the main at G-1. Thus, in their view, only the drain at G-1 “really” needed to be opened at startup. Accordingly, there was a tacit understanding that the bleeder valve at G-1 would be opened daily by the quality control supervisor for the prime contractor, and any condensate that wasn’t drained at startup, they apparently thought, would be mopped up by traps after startup.

As the third week began, the severity and frequency of water-hammer began to accelerate. Residual condensate accumulated in the steam pipe at C-4 due not only to operation of the uninsulated steam main but also due to condensate formed at startup that went undrained. Early in the third week, heavy banging forced workers to evacuate the utilidor. Clyde, one of the more vocal evacuees, warned the abatement supervisor, “This thing sounds like it’s ready to explode . . . What are you going to do about it?”

By Wednesday of the third week, all the insulation had been stripped from the G- and H-Lines. The lines were completely bare. By the next morning, the day of the accident, calculations showed that sufficient condensate had accumulated at C-4 to fill the line adjacent to the valve completely and extend over 300 ft up the steam line toward G-9.⁴ In addition,

⁴ Before the line completely filled, however, much of the condensate blocking the steam entrance at C-4 would be swept downstream toward G-1 by the steam entering through the valve. Later, it would be swept back as explained later.



Condensate Collection in Vertical Lines

Condensate will fill a vertical take-off like the H-Line against gravity if the horizontal line beneath it becomes filled or nearly filled with condensate. To illustrate this point, I have exaggerated the rise of the H-Line in the figures below. Fig. A shows steam flowing into all open portions of the steam line and condensing. The condensing steam causes a reduction in local pressure that induces steam movement to flow in to replace it. If the horizontal section of steam pipe fills or becomes nearly full, a “condensate seal” forms that isolates the steam downstream of the seal. Condensing steam in the pocket causes the pressure to fall. The falling pressure in the isolated steam pocket will then suck up condensate into the pocket to fill the void. The result is shown in Fig. C.

tion, condensate accumulated in the 120 ft long H-Line. Due to a design oversight, there was no drain or trap upstream of the gate valve at H-1. The contractor, not comprehending the pitch of the H-Line, did not realize that condensate would accumulate against the H-1 valve during the three weeks of on-off steam operation. Hence, the line filled with condensate as depicted in Fig. 2.

Condensate also accumulated each night in the double-elbow riser to the south of the C-4 valve (Fig. 3). During the period after midnight when the C-4 valve was closed, steam condensed in the uninsulated double-elbow riser and came to rest against the south side of the closed valve. From midnight until noon the following day, enough condensate accumulated to almost fill the riser.

Condensation-Induced Waterhammer vs. Conventional “Steam Flow” Driven Waterhammer

On the day of the accident, there was a change in the startup procedure. To isolate another steam main for repair work, the contractor needed to energize the G-Line early. The asbestos crew was instructed to start up the G-Line 1 hr and 15 min before their quitting time. In addition, but unbeknownst to the asbestos crew, the contractor’s quality control supervisor decided to expedite warm-up in the G-Line by admitting steam through the G-1 valve at the far end of the G-Line as well as through C-4. The G-1 valve was opened as much as 30 min before Bobby first cracked open the C-4 steam valve. This had the likely effect of sweeping the undrained condensate residing against the G-1 valve on the north end of the line south to C-4, and *completely* filling the H-Line as shown in the sequence of figures in Sidebar 1. The situation, then, as Bobby prepared to crack open the C-4 valve 15 min before the accident, is shown in Fig. 3.

Subcooled condensate filled the steam line on both sides of the C-4 valve in addition to filling the H-Line completely. High-pressure steam admitted through G-1 had pressurized the steam main and was sitting atop the condensate on the north side of C-4. The south side of the valve was also under steam pressure, which based on testimony, was likely slightly less than that on the north side.

Now, put yourself in Bobby’s place, *except* assume you know all the information described above. In your mind’s eye, you can visualize the build-up of condensate shown in Fig. 3. You figure out, based on the ease with which the valve’s handwheel spun, that there is full steam pressure atop the condensate. Ask yourself two questions:

■ *Is this situation dangerous?* — Some steam people would say, “No, as long as there is no fast-moving steam, there’s no danger of waterhammer. Opening C-4 slowly and incrementally should prevent steam or condensate

Waterhammer, according to a major steam trap manufacturer’s engineering guide, is “the impact caused by a sudden stopping of a rapidly moving slug of water.” The guide goes on to explain that:

“[Unless] condensate is removed from low points...ripples form on the condensate surface...until condensate so restricts steam flow that a slug of condensate is carried down the main by the steam. The slug of water travels at the speed of steam (which may be in excess of 100 mph) until some obstruction is reached...[and]...the slug of water is suddenly stopped often with disastrous results...”¹

The waterhammer described above is but one type of waterhammer. I term it *steam flow driven waterhammer*. It describes an impact event where a slug of fast moving water strikes a stationary object and gives up its momentum much like an ocean wave striking a sea wall. The formula for the maximum impact pressure over the target area is:

$$P_{\max} = \rho v^2 \quad 1$$

where

ρ = fluid density

v = slug velocity

For water at 60 lb per cu ft and $v = 100$ mph, $P_{\max} = 279$ psi. Lab experiments indicate that peak pressures for actual events are typically less than the maximum theoretical value.²

Condensation-induced waterhammer is a different animal. The pressure pulse generated by a con-

densation-induced waterhammer is due to the compression of water by a piston formed by a moving plug of water. This is the same phenomena that generates waterhammer in a hydronic, single-phase system, *i.e.*, plumbing. The formula to calculate the magnitude of the maximum pressure pulse is:

$$P_{\max} = \rho c v \quad 2$$

where

c = the speed of sound in water (about 4300 fps)

Note that Equation 1 is similar to Equation 2 except that c replaces one v . What’s the relevance of the speed of sound? The sonic speed squared, c^2 , is in essence a shorthand notation for the ratio of the stiffness of the material, represented by Young’s Modulus E , divided by the density of the material, *i.e.*,

$$c = \sqrt{E/\rho}$$

Clearly, the magnitude of a pressure pulse reverberating through, for example, a piece of steel compressed upon collision, would in some measure be a function of the stiffness of the steel. The same is true for water. Hence, the dependence on c is really a dependence on E .

At 4300 fps, c is roughly two orders of magnitude larger than v . Thus, the over-pressurization generated by condensation-induced waterhammer can be 10 to 100 times greater than that caused by steam-flow driven waterhammer.

¹ Sarco “Hook-up Designs for Steam & Fluid Systems,” 1981.

² Neumann & Griffith, “Forces on a Pipe Bend Resulting from Clearing a Pool of Liquid Upstream,” PVB-Vol. 224 / Fed-Vol. 126, Fluid Transients and Fluid Structure, 1991.

For more information, contact Mr. Kirsner at www.kirsner.org

from moving quickly and thus prevent a waterhammer.” This is wrong, dead wrong. High-pressure steam in contact with *subcooled* condensate is dangerous. It’s a recipe for condensation-induced waterhammer. Sidebar 2

explains why this type of event is 10 to 100 times more powerful than conventional “steam flow” driven waterhammer.

■ *What would you have done in Bobby’s place?* —If your answer is,

continued on page 119

continued from page 117

“I’d first open the C-4 bleeder valve to drain the condensate,” you’re toast. Although, this is the answer most steam operators would give, it will trigger the accident. Neither the bleeder valve nor the steam valve can be opened without provoking this accident. To understand why, it’s crucial for steam fitters and operators to understand the mechanism of condensation-induced waterhammer.

Condensation-induced waterhammer

A condensation-induced water hammer is a rapid condensation event. It could also be aptly termed a *rapid steam bubble collapse*. It occurs when a steam pocket becomes totally entrapped in subcooled condensate. As the steam gives up its heat to the surrounding condensate and pipe walls, steam changes from a vapor to a liquid state. As a liquid, the volume formerly occupied by the steam shrinks by a factor ranging from several hundred to over a thousand, depending on the saturated steam pressure. Likewise, the pressure in the void drops to the saturated vapor pressure of the surrounding condensate. (For example, the saturated vapor pressure of condensate at ambient temperature is less than 1 psia.) This leaves a low-pressure void in the space formerly occupied by the steam that the surrounding condensate, under steam pressure itself, will rush in to fill. The resulting collision of condensate generates an over-pressurization that reverberates throughout the portion of the pipe filled with condensate. How severe is the over-pressurization? Remember that water is virtually incompressible. In a collision, it does not give.

Think of the last time you did a belly flop off a diving board—the water felt pretty “stiff,” didn’t it?

The specific factors that influence the severity of a condensation-induced waterhammer are:

- The steam pressure
- The degree of condensate subcooling
- The presence of non-condensables left over in the void
- The size of the void

If the steam pressure is high, the condensate is subcooled, non-condensables are absent, and the void is large enough for a slug of water to pick up some velocity. The over-pressure resulting from an event can *easily* exceed 1000 psi. This is enough pressure to fracture a cast iron valve, blow out a steam gasket, or burst an accordion-type expansion joint. And, in fact, failure of each of these components in separate condensation-induced waterhammer accidents has resulted in operator fatalities.

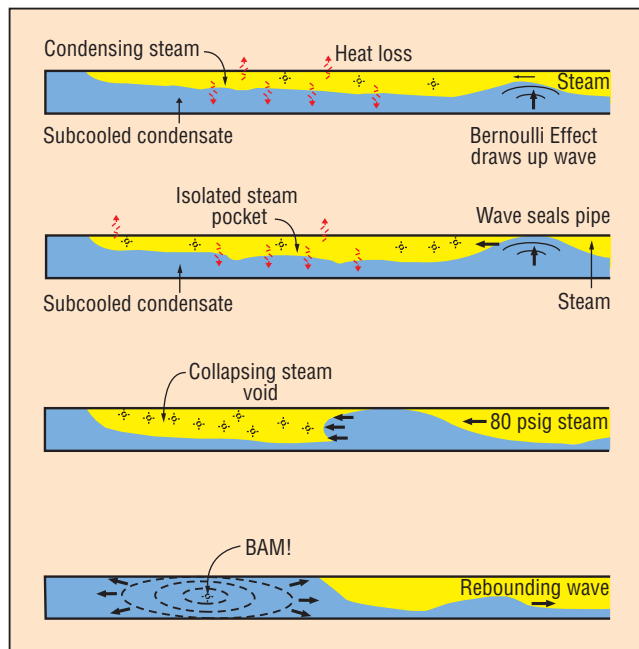
One might ask at this point, “But wait, isn’t it common for steam and condensate to come into contact in a steam system?” Good design and operating practice aim to avoid mixing high-

pressure steam and excess condensate by making sure steam mains are properly trapped, and live steam is kept out of condensate-return systems. Nevertheless, it does happen. Condensate lines, for instance, are often heard to pop and bang when steam squirts into them through traps. Why don’t the collapsing steam bubbles destroy condensate pipes? They can over time. But, the shock waves generated are not catastrophic because the pressure in a condensate system is generally low—on the order of just a few psi, subcooling is not great, and the steam bubbles are small. Of course, high-pressure steam can contact subcooled condensate in steam lines when something goes wrong—for example, when a trap assembly becomes plugged with scale causing a drip leg to fill with condensate. Why don’t situations like this result in destructive, condensation-induced waterhammer? One reason is pipe geometry. A steam bubble must become entrapped for there to be a collapse. In a vertical pipe such as a drip leg where steam is above the condensate, it’s difficult to entrap the steam because natural buoyancy tends to keep the two fluids separate.⁵ In fact, research experiments show that it’s difficult to entrap a steam void in any pipe sloped downward in the direction of steam flow more than 1/2 in. in 1.0 ft.⁶ At slopes less than this, however, and in upwardly sloped pipes, it’s a different story.

At Fort Wainwright,

⁵ A condensation-induced waterhammer is possible if a vertical pipe is drained extremely fast.

⁶ Griffith and Silva. “Steam Bubble Collapse Induced Waterhammer in Draining Pipes,” PVP-Vol. 231, ASME, 1992.



4 Steam entrapment and slug formation in a horizontal line.

STEAM ACCIDENT

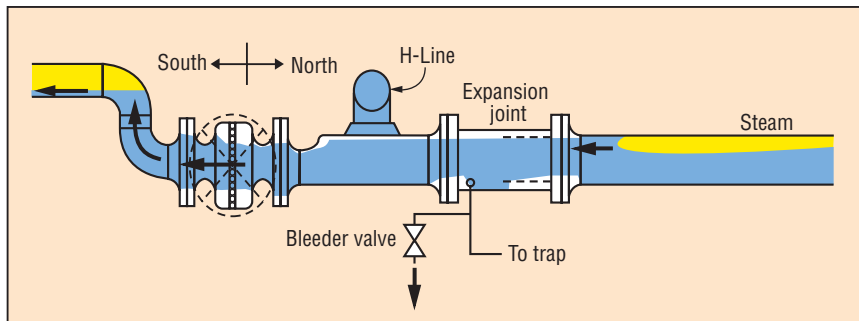
the pipe slope to C-4 is $\frac{1}{4}$ in. in 10.0 ft—normal for a steam line. Thus, the line is nearly horizontal. How does steam become entrapped when resting atop subcooled condensate in a nearly horizontal line? The sequence below explains how (Fig. 4).

- Steam residing over subcooled condensate loses heat to the condensate and the surrounding pipe, which causes the steam

stream supply creating a steam pocket. Ongoing condensation in the isolated steam pocket drops the pressure, causing a slug to accelerate into the void.

The formation of a condensate bridge or seal is a necessary condition for a rapid condensation event in a horizontal line. Often, however, heat transfer is not rapid enough to induce sufficient steam flow to seal the pipe and to

boundary layer insulates the steam void. On the one hand, the layer prevents rapid condensation, but on the other, it can allow a steam void to grow in magnitude and potential energy like an over-expanded balloon. Often times, there will be no rapid condensation event if the layer goes undisturbed. Steam will fill a pipe atop subcooled condensate without incident. Minor collapses may occur, but due to the lack of rapid heat transfer, they will be mild and go unnoticed. If, however, the insulating layer is disturbed in such a way that the layer is breached at some point, then the local intrusion of subcooled condensate can result in a chain reaction, which shatters the entire insulating layer. In a millisecond, the rate of heat transfer can increase a thousand fold, inducing a rapid steam influx that seals the pipe and sets off a rapid condensation event, resulting in condensation-induced waterhammer. The key, then, to whether or not an event is initiated depends on the occurrence of a trigger to cause interface shattering.



5 Steam encroachment as condensate is drained.



Photo 1 The model pictured was constructed to simulate the accident.

to condense. The continual loss of steam induces fresh steam to flow in to replace it. Steam flow over condensate will tend to draw up a wave in the condensate via the Bernoulli effect.

- If the rate of heat transfer is rapid enough for a given condensate level, the induced steam velocity will draw up a wave high enough to bridge the pipe.

- The formation of a bridge immediately isolates the downstream steam pocket from the up-

cause a rapid steam bubble collapse. In fact, generally, a “trigger” is needed to initiate a condensation-induced waterhammer in a horizontal line where neither steam nor condensate is flowing through the pipe. That’s because in a non-flowing situation, heat transfer between the steam and condensate is retarded by a stagnant layer of hot condensate and non-condensables laid down by steam as it condenses atop cooler condensate. This interphase

Back at the accident

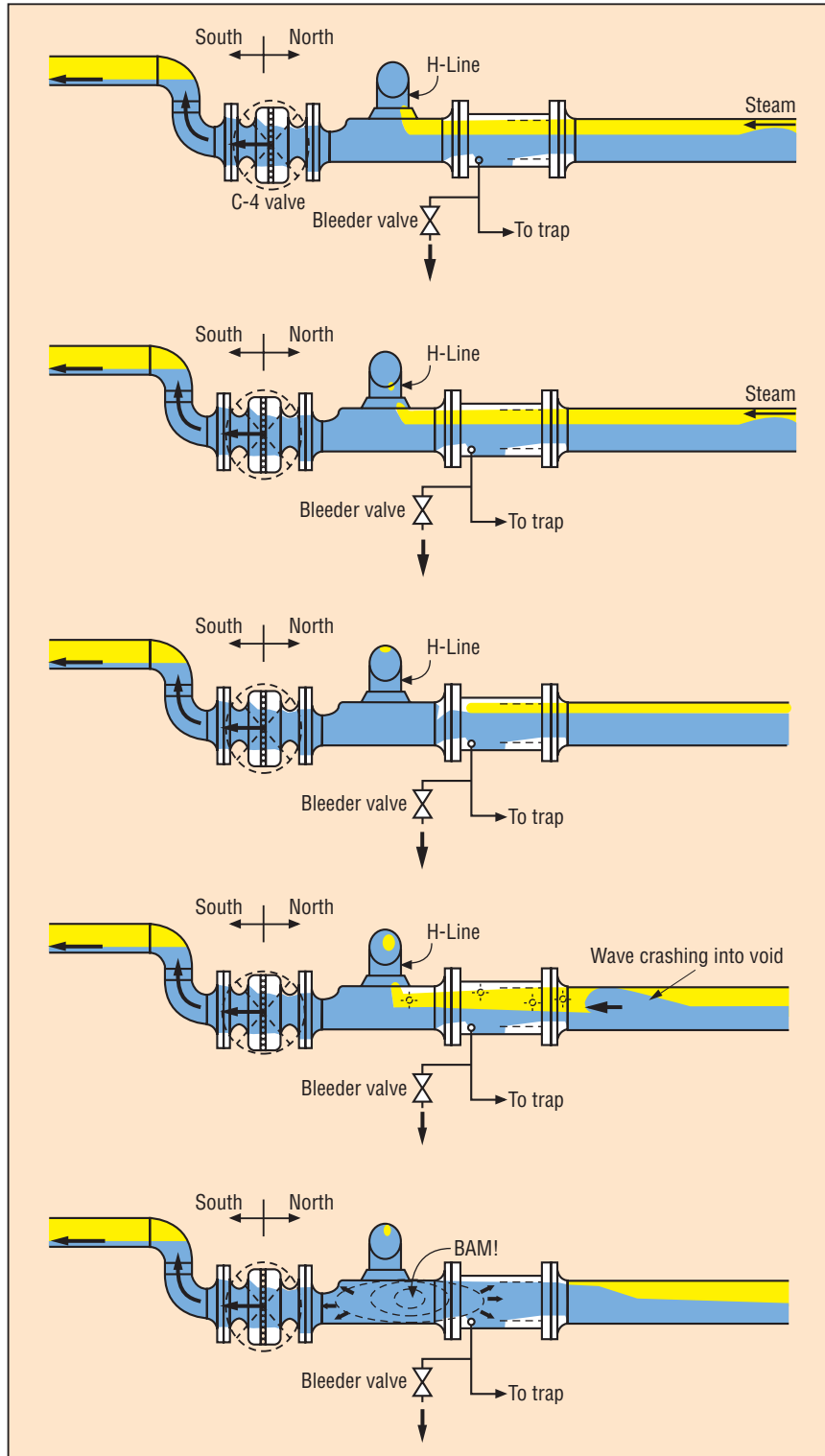
Now, return to Manhole C-4 15 min before the accident. Bobby had opened the bleeder valve at C-4 for the first time per a special instruction from the quality control supervisor. He then proceeded to crack open the C-4 steam valve. Both of these actions presumably resulted in condensate draining from the system on the north side of the C-4 valve. The pipe volume vacated by the draining condensate at C-4 drew in steam along the top of the pipe from the north to replace it (Fig. 5). Fifteen min after the first crack, Bobby opened the C-4 valve again—this time lifting the disk $\frac{1}{2}$ in. off its seat. This action accelerated the removal of condensate and the advance of steam along the top of the pipe toward C-4.

The model pictured in Photo 1 was constructed to simulate the

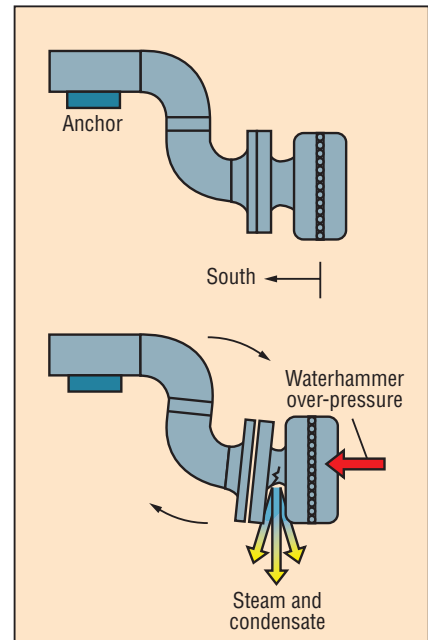
accident. From this point on, I'll describe what we understand to have occurred based on tests with this model and others used to investigate the accident (Fig. 6).

As the tongue of steam reached down the nearly horizontal line toward C-4, it probably collapsed several times as seals developed, but the collapses were not violent

enough to be termed *waterhammer events*. When the steam finally reached the vertical opening to the H-Line, the steam licked around the corner seeking to flow up into the H-Line riser. This was the trigger necessary to set off the event. The tip of the tongue distended, then detached, releasing a bubble containing steam and non-condensables that rose up into the vertical H-Line while an equal volume of subcooled water spilled down into the G-Line. The remainder of the steam tongue quickly snapped back into the G-Line after releasing the bubble. The release of the bubble and the exposure to the cool condensate assaulted the stability of the boundary layer. It caused a ripple to reverberate down the length of the steam-condensate interface—perturbing it and accelerating heat transfer. This could have been sufficient to trigger the event. It depends on how much air had seeped into the system during cooling. As condensate continued to drain, steam ad-



6 "Frame-by-frame" animation of a condensation-induced waterhammer event.



7 Illustration of a valve's deflection during the waterhammer event.

STEAM ACCIDENT

vanced toward the H-Line opening a second time, again peeking around the corner, and again releasing a bubble of steam and non-condensables. This time the interface shattered. The entrapped steam pocket collapsed hard, whipping a slug of water from the north into the collapsing void at C-4 with a load snap. The collision of the slug with the condensate at C-4 created an overpressurization that rebounded throughout the water-filled portion of the system, including up the H-Line where Clyde and Don would have been working.

At Fort Wainwright, the overpressure caused the double-elbow riser at C-4 to compress as shown in Fig. 7. The pipe and valve flanges twisted in response to the deflection of the double-elbow riser. The twisting flange caused the cast iron valve body to crack at the flange neck, causing first condensate, then steam to spray from the valve. The actual damage to the valve is shown in Photo 2.

Could this accident have been prevented?

Of course. Numerous procedural blunders should be obvious to experienced steam operators and their supervisors as they read this article—not the least of which is assigning responsibility for startup of a high-pressure steam system to untrained asbestos workers. But, I'm most interested in putting the question above to the guy who's in the last line of defense—the steam operator standing in Bobby's shoes with his hands on the valve's handwheel just moments before the accident. Suppose from the feel of the valve's handwheel, he surmises that there already must be full steam pressure on the steam line, and he believes not only that the line contains

subcooled condensate, but that it is FULL and resting against the valve he is about to open. The question is—*Is it possible, given the circumstances with which he's confronted, to avoid this accident?*

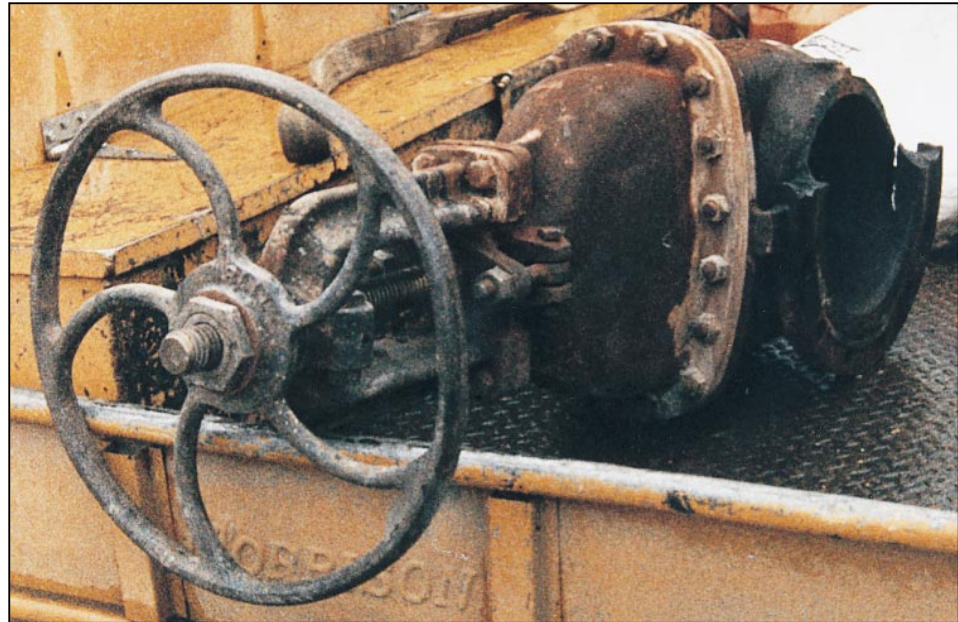


Photo 2 This shows the actual damage to the valve.

The answer is YES. But, there's only one way. Cut the steam off. Don't open the C-4 steam valve. Don't open the bleeder valve. You've got to exit the manhole and close the G-1 steam valve, *then* drain the lines to empty the condensate. This is what must be done to avoid a condensation-induced waterhammer in the situation described. Trying to drain the condensate with high-pressure steam atop the subcooled condensate will trigger a rapid condensation event.

In conclusion...

Here's what I want steamfitters and operators to know:

■ High-pressure steam in contact with subcooled condensate is an unstable and potentially explosive mixture.

■ Don't admit steam into a line filled with subcooled condensate. In fact, always be wary of admitting steam to any cold steam line

if you cannot be absolutely certain that the line has been completely drained.

■ Allowing subcooled condensate to flow into a steam-filled line is more dangerous than admitting steam into a line with subcooled

condensate.

■ If you suspect that a pressurized steam line is filled with subcooled condensate, don't attempt to drain the condensate. Shut the steam off first; then, drain the condensate. If you do open a drain and the line hammers, close it and get the steam off. The line may continue to hammer until you get the steam off.

■ A mixture of steam above subcooled condensate can sit dormant in an isolated steam line like a loaded gun awaiting a triggering event. Opening a valve to admit steam or opening a bleeder to drain condensate can trigger the event. Don't let yourself or those you supervise inadvertently pull that trigger without first making sure the gun is unloaded.

HPAC