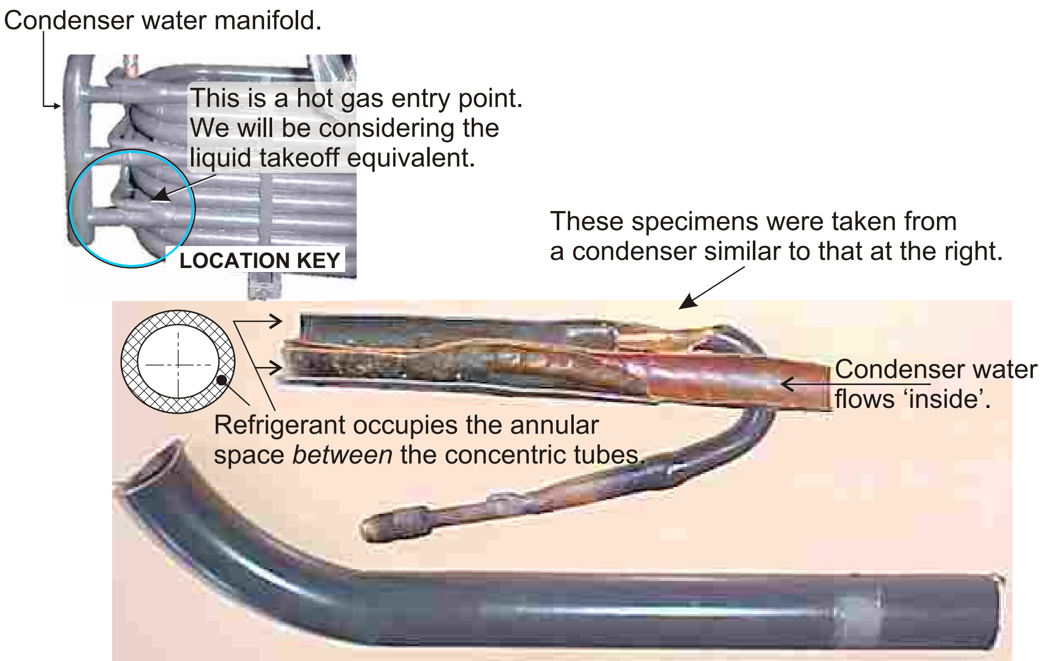
RETURN

OUR INDUSTRY : MAY 2006

A CONDENSER FAILURE "WHAT WENT WRONG?"

Possibly you have the same fascination as me in various television series such as 'What Went Wrong?'. These will start with something like an air crash, and then dig into and sift through all available evidence in order to establish, and learn from, the event. Today we have lined up something of that nature.

A couple of years back I was invited to an equipment supplier's office. He handed me two 'exhibits', which you can see here as Fig. 1. These had been cut from a failed tube-in-tube condenser. From the inset in the illustration you will get an idea of where in the equipment the samples came from, except the picture shows the hot gas entry points, and we are considering the far end, at a 'liquid takeoff' point, buried behind and lower down on the condenser. The construction detail at each end is similar.



THE SORRY "EXHIBITS"

Fig. 1.

The fellow asked me what I thought had caused the failure. I said 'freezing'. His reaction was: 'Can't be'. The pressure which had caused the fault had occurred from the *hot gas* side. Compression had taken place *into* the water side. So he considered freezing had to be a non-starter.

The events had taken place many months before I had been called in. The equipment was almost out of its guarantee period when the failure took place. Now an insurance wrangle had emerged. I asked for a description of the installation. The unit was equipped with two condensers, and these were both served from the same cooling tower, located some six metres above the unit. There was nothing outside of this to the condenser water system. Refrigeration circuits inside the unit were entirely separate. *Both* condensers strangely had suffered the identical failure at practically the same time. Was this a remarkable coincidence?

I asked about the compressors, and was told that both had been found to be 'shot', and had been bundled off to the scrap yard without first having been opened and inspected. At this stage they probably had already become steel reinforcing rods in the beams of some building. Gas charge? My friend had got to site the day following the report of the failure. He had checked the Shraeder valves of the refrigerant circuits. When he had pressed their little pippies he had been puzzled to find drips of low pressure *water* coming out where he would have expected a blast of high pressure gas.

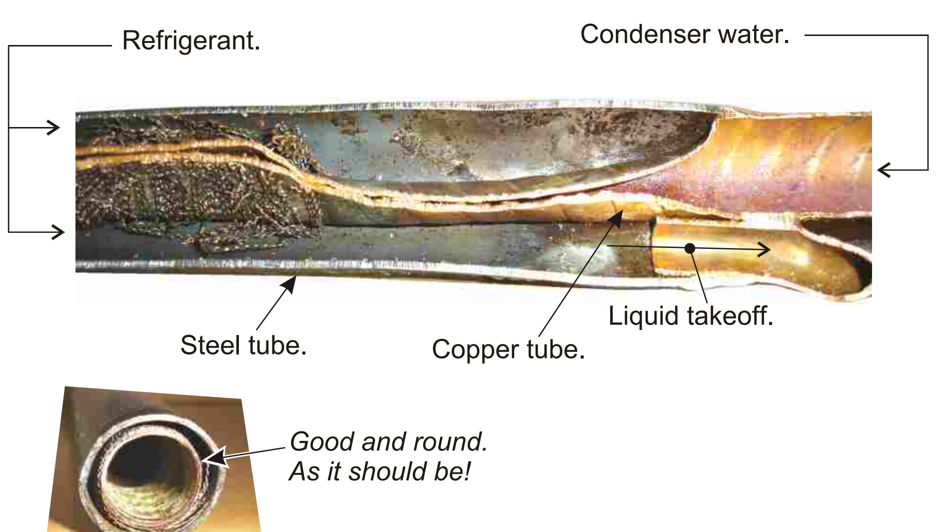
Me again: 'What about the condenser water? Did you take a sample?' Another strange thing. The system was *dry*! Bear in mind, the cooling tower stands six metres above the pair of condensers we are discussing. Given a mains water failure, the sump will evaporate to a low level, the pump will start pumping air, and unless there is advanced flow protection, the unit will go out on high pressure. Even if the tower sump had been completely drained, the piping legs would have remained filled with water. So this draining would plainly have been a deliberate action. Reference information for filing!

Must have been freezing!

I returned home convinced that freezing had been the cause. It is good not to close your mind too early in the day, before weighing up every possibility. But this looked so open and shut, although the reason for such a cause was very obscure. Years of experience have shown me that superficial logic does not necessarily play any part.5

Report writing has been a cornerstone of practically my entire working life. Just write! If it becomes apparent that garbage is coming up, hit the 'delete' button. If a green shoot which has the promise of growing into something fruitful emerges, work on that. Vigorously help it to grow. **But just keep the show moving.** You will so often find, two hours later, that you have moved into a totally unsuspected area, but all, for some unexplained reason, has plainly become *rational*! If you stop to think, you will be dead in the water!

The focus of the investigation was to explain the collapsed tube. Fig. 2 provides a more detailed picture of this, for your scrutiny. The collapse was limited practically to the bit in view. Most of the copper tube had retained its manufactured cylindrical shape, as you will see from the inset of Fig. 2.



DETAIL OF THE COLLAPSED TUBE. Fig. 2.

Back home, I plumbed the possibilities. *Two* totally independent circuits, developing the exact same fault, practically within minutes of one another. There *had* to be a common denominator. Both in the same box? Nothing there. Both sharing a common power supply? Needed a moment of thought. But how could this possibly be electricity-related?

Other possibilities

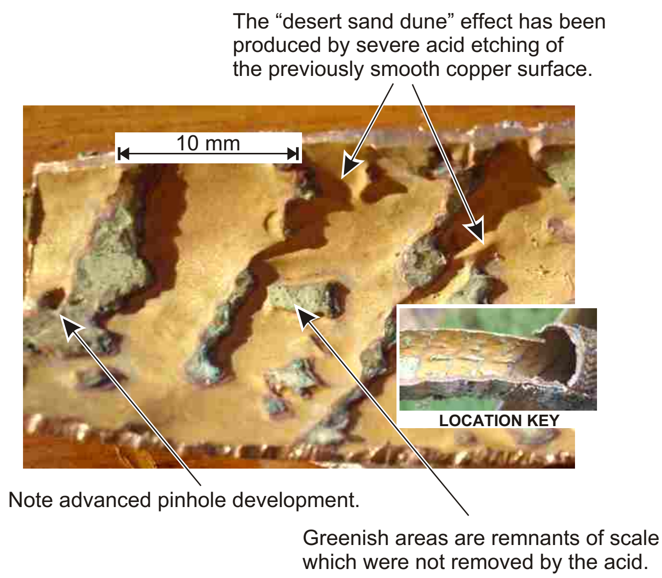
My client was considering extreme temperature and extreme pressure as possibilities. Of course, to thoroughly investigate these would require destruction testing. That was not a practical option. So rationalisation had to suffice. Copper starts becoming reasonably soft as it approaches being red hot. We could perhaps guess at 500^{o} C as being critical in this regard. How could any temperature of such magnitude be encountered in the condenser of an operating system? Furthermore, there were flecks of scale visible. (These would become important)! But any elevated temperature such as this would have caused these pieces to break away from the copper? This was definitely one for the scrap bin!

The 'pressure' issue… As said, without conducting destruction testing, it was impossible to know at what pressure such a failure would have occurred. But certainly it would have been many dozens of megapascals. The compressor itself would have broken long before being able to generate sufficient pressure to even remotely approach this. At such pressures, the hot gas line would have bulged like a balloon. That doesn't happen elsewhere in millions of other jobs, and it hadn't happened here. Additionally, the bellows of the high pressure switch would certainly have exploded with a deafening 'bang' very much earlier, thereby providing a very messy safety valve function.

Condenser water was the only common denominator. Hound-dog had to sniff in that area! When in doubt, I take photographs! As it was dingy inside the tube, I took my specimen out into the early morning sun, and carefully rotated the tube for best sunlight penetration. This effort yielded the picture of Fig. 3. (Please see Footnote 1). This step provided a most unexpected break! In Fig. 3 you will see a series of 'hills and valleys' on the inner surface of the copper. These became obvious as I was setting up for the photo, and most definitely should not have been there. Out came a high-powered magnifier. There were caps of a pale material, which certainly had the appearance of being isolated specks of familiar condenser scale, although harder than usual. One difference however was a green hue. (Calcium carbonate scale, in itself, is a chalky Marie biscuit colour).

FIRST CLOSE INSPECTION. Fig. 3.

Out now with my hacksaw! More exposure of the affected copper to oblique sunlight allowed me to take the photo given here as Fig. 4. On this, you will see a great likeness to an aerial photograph of dunes in the Kalahari Desert. Bear in mind, this earlier on had been the smooth inner surface of the copper tube. This provides graphic evidence of the extent of this extremely severe acid attack.



CLOSE-UP OF COPPER REMOVAL BY ACID ETCHING Fig. 4.

So, we would be on pretty strong ground by anticipating there had been a powerful *uninhibited* acid present, and this under the disturbing conditions of an active water flow. I have been present when folks from the Water Treatment fraternity have dumped dozens of litres of inhibited hydrochloric acid into a cooling tower sump as a quick-fix to sort out whatever they had failed to achieve by the best ongoing efforts of the dosing pump. That stuff is powerful! You are glad that your legs! But this acid is *inhibited*, (See Footnote 2) it goes in with a careful watch on pH, and it your nose is in your head, and not on your right ankle! The heavy acid fume in the air down at knee level is so aggressive that you get the feeling that there are droves of ants crawling on is flushed out and the neutralising water which at this stage should go into the system is heavily dosed with an alkali, such as soda ash. This latter serves to penetrate all the nooks and crannies, to render impotent residual traces of the acid.

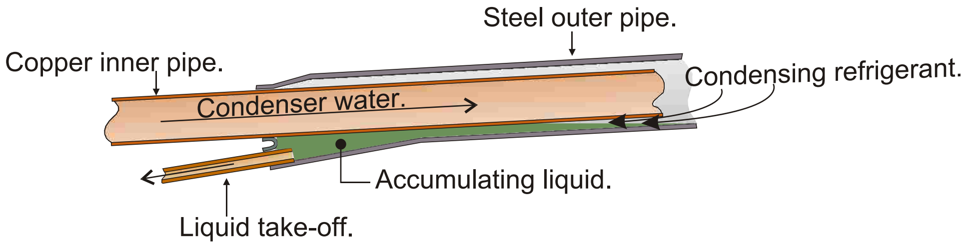
But I felt that what was emerging in our present situation was a case where acid had been placed into the sump, and had simply been abandoned in the system as the pump circulated! It might have been uninhibited hydrochloric acid. This is commonly available as pool acid, obtained from the hardware shop. But, given the severity of the attack, I have wondered whether it was in fact *sulphuric acid* that might have been dosed. It was an industrial application of a nature where sulphuric acid is used routinely in on-site processes, and this acid could well have been freely available on site.

Right! We have developed a very likely scenario for the damage to the copper tubing of the condenser. But we still have to position this to where ice-build conditions could occur *inside* the refrigerant side of the condenser. Please look again at Fig. 4. You will see some pretty deep furrows which have been scoured into the copper, as well as one point which is well on its way to developing into a full-blown pinhole. And all we have seen is just one very small sampling of the condenser tubing. It would certainly be realistic to presume that at least one fully penetrating pinhole developed in each of the condensers.

Hydrostatic head

As mentioned, the cooling tower stood six metres above the unit. Hydrostatic pressure at the condenser, due to this extent of elevation would be a mere 60 kPa. To this, we would require to add an unknown amount of pump pressure. The condenser water, so far, would still be well below the condensing pressure of the R-22 in the system. So, the advent of a pinhole would result in a blow of R-22 into the condenser water, with this being lost to the atmosphere at the cooling tower. As internal pressure in the refrigerant circuits tumbled, the remaining refrigerant would cool down substantially, especially if the unit tripped through lack of refrigerant, or until traces of water entered the refrigerant and froze to temporarily plug the liquid feed restrictors.

Under this new condition, condenser water pressure would be sufficient to drive a limited amount of water *into* the refrigerant circuits. Take a look at Fig. 5. This gives us an insight into what will be taking place at the lower reaches of the condensers. In the normal course of events, this is where refrigerant will accumulate by gravity, in readiness for being fed into the liquid lines. There will be a small amount of liquid still present down here, at this stage. As water now enters the circuit, this will mix in with this refrigerant accumulation.



LIQUID TAKEOFF OF THE TYPE WE ARE CONSIDERING. Fig. 5.

Emergency action!
Now it occurs to our mysterious Mr. X that possibly he has not been any too wise, and ditching the evidence would be smart under the circumstances. He gets himself to a drain point at the lowest spot of the condenser water piping, dumps that down a drainage gully and without further ceremony takes off from site like a rocket. Now the refrigerant system is relieved of its last containing pressure. Refrigerant boils off, freezing that water which had taken up residence in the lower part of the condensers. As this freezes it has nowhere to expand, and so promptly flattens the copper tube, as we saw in Fig. 2. The only straw remaining for those involved to grasp onto is to point at the equipment, and label this as 'defective'!

Of course, it is impossible to say whether this is precisely how the events unfolded. But I consider it paints a very realistic scenario of the possible progression of affairs. The residues of a firmly attached scale, remaining on the samples to this day showed that there was a severe scaling problem, which undoubtedly must have been causing periodic high-pressure faults. Someone would have complained, and someone would have responded. I cannot for the life of me perceive of any manufacturers' inbuilt deficiency which could have precipitated the collapse of these tubes. And I cannot believe it was anything but ice that physically wrought a near simultaneous flattening of tubes in two condensers which were totally independent of one another, other than jointly being served by one condenser water circuit.

Oh! We mentioned an unusual greenish hue to the residual pieces of scale. I am no chemist, but wonder whether this was an outcome of *copper sulphate* forming in the circulating acidified water, and that tinting the unremoved part of the scale? One of the basics of acid cleaning is that you <u>do not</u> aerate the descaling solution. (Another basic is to avoid using sulphuric acid, which could have produced the copper sulphate, if that is indeed what stained the scale residues green). You take care to assure that the hose carrying the solution being circulated is immersed well under the liquid surface in the holding tank, and that no air entrainment can occur. But there appears to be indication that the *system cooling tower*, and not a tank, was used. What better way could a person find to aerate the solution, if that was what was wanted, than to pass it on a continuous basis through a cooling tower? If this was indeed highly aerated sulphuric acid that was being circulated, it is no wonder there occurred this extreme extent of damage!

The insurers agreed with the picture painted much as you have just seen it and through this decided that my client's equipment itself was not at fault. The final outcome was settled to the contentment of my client.

I am sure you will agree that, serious as the undertones concerning practises within this industry of this saga might be, it makes for a fascinating study to draw events and observed indications together and structuring them into some sort of rational scenario. Having the opportunity to be able to do this is a great bonus for me now. When you are under pressure of the clock and time sheets in a work situation, this just does not provide the environment and circumstances essential for working these things through to a measure of conclusion. In my happy retirement, it provides a welcome break from watching the lawn grow. Until next time, please stay very well!

Footnote 1: If you think you have seen Fig. 3 before, you are perfectly correct. It served, although without it being connected to this present situation, to get the ball rolling in order to fire up an article of a couple of years back, entitled 'Don't Destroy That Condenser!' At the time of that writing, there was a wrangle going on, concerning this issue. But subsequently, the issues have been settled, time has moved on, and now with us still remaining reticent about revealing identifiable installation specifics, the cushioning of elapsed time makes it OK to pass on some technical details of this rather interesting sequence of events.

Footnote 2: Hydrochloric acid is usually used at 27% to 30% for descaling. At this concentration it is highly aggressive, both to scale and to metals. We wish for it to soften up scale, not to dissolve metals. Inhibitors are added to buffer up the metal, preparing it for its ordeal in the face of the acid.

It remains necessary still to flush the acid from the system *immediately* it has completed its descaling function. You determine this point in time by monitoring pH of the now extremely dirty water. The acid, when sufficiently concentrated for the task at hand, will pull pH down to about 2. As it dissolves, the alkaline scale will move pH back upwards. You add further inhibited acid. Once the pH remains low, you conclude there is no further scale to be shifted. *Now* is the time to get the acid and gunge out of the system, flush, and to very rapidly introduce the alkaline neutralising agent. The original corrosion inhibitors themselves become spent as they do their work. If you drag your feet about getting the acid back out, the inhibitors will have become ineffectual. Now, instead of dissolving scale the acid will direct its activity to dissolving metal!

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