The Oxygen Diffusion Debate - Defused

What is the "problem"?

In previous articles we have reviewed the features, benefits and principles of Radiant Panel Heating Systems with flexible PEX plastic tubing. These systems work extremely well, but require basic knowledge on compatible products and correct designs. During the 1970's, the first decade of the development of modern panel heating systems, knowledge was still limited and errors were made. One specific issue lead to a major debate. On one hand many believed that the matter could be disregarded, while others predicted major failures and the death of an industry. Neither of them were right. The issue was the diffusion of oxygen through the walls of plastics pipes.

Due to this “problem”, in the early 80's, extrusion techniques were developed to equip plastic tubing with suitable barriers to reduce oxygen penetration to a minimum. PEX tubing for heating is normally equipped with such barriers and this practice should have eliminated the issue. Even today, however, installations are made disregarding the known facts. Those new to this industry may challenge or proclaim disbelief. This article aims to provide relevant information on the matter.

First, a brief description of the issue at hand: plastic tubing is not impermeable - unlike metal pipes. Therefore, oxygen molecules will penetrate through the tubing wall and into the circulating water of “closed” hydronic radiant floor system. The amount of oxygen passing through the tubing wall and into the system is well known for all materials and increases with temperature. For a typical system with plastic tubing working at 100°F continuously, this oxygen diffusion leads to the generation of about 1 oz. corrosion products (Magnetite-Fe_3O_4) per 100 ft. of pipe each year (10 times more for EPDM rubber hoses). That is, if ferrous materials are present in the systems, such as steel pipes, steel pumps or steel boilers. If the quality of the water is good, general corrosion occurs. The resultant sludge consists of a fine grain metal oxide that normally is easily transported with the water. It mainly settles where the water flow rate is low. However, the amount of sludge builds up over the years and will lead to circulation disturbances and other corrosion-related problems. With more corrosive water qualities, problems due to pitting corrosion are likely to occur early.

This would seem to be a well known and well described occurrence, doesn’t it? Not! For years, and sometimes even today, there are those who challenge the facts and their implications. For this reason, it may be well worth to look at what history tells.

How it all started

This was the start of the oxygen diffusion debate:

In the major German trade magazine: “Sanitær und Heizungstechnik” (Plumbing and Heating Techniques) November 1979 issue, there was an interview with Mr. Hans Viessmann, CEO of Viessmann GmbH, one of the world’s leading boiler manufacturers. The article was titled “ Der Markt ist aufnahmefæhig fur moderne Einrichtungen” (The market is receptive to modern equipment). Here is a translation of the end of page 956:

Interviewer: “Problem related to Radiant Floor Heating: Today, we have finally understood that air has to be banned in heating systems, and we are meeting this requirement by having closed recirculating systems.
However, through the plastic tubing in radiant floor heating systems, oxygen reenters, and you, the boiler manufacturers, suffer from the resulting problem. How is the situation with warranties and guarantees, since your product is at risk?”

(Here follows a headline in boldface caption:) **The oxygen diffusion liability resides with the suppliers of radiant floors.**

Viessmann: “The situation is basically clear: In accordance with existing technical practices, there must not be any air - and thereby oxygen - let in into closed loop heating systems. Anyone that supplies heating products which load the water with oxygen, acts in contradiction with technical codes, and must be liable for consequentual claims. It is not only the boiler that is at risk, but all other ferrous parts like radiators, heating elements, and pipes.”

Research, and standards development started after this article, but the effects of oxygen diffusion and its' impact to heating systems had already been investigated in Scandinavian countries since 1974. However, this article generated a massive debate, and extensive research began in continental Europe. As radiant floor heating had gotten a major share of that marketplace, it was very natural that the issue took on such large proportions. Possibly major liability exposures had surfaced.

In early 1980, the Association of German Engineers issued Report Number 388 (VDI-Bericht Nr. 388, 1980): “Corrosion in hydronic heating systems resulting from oxygen diffusion through plastic tubing”. The main author was Dipl.-Chem. C.L. Kruse of the Governmental Material Testing Institute in Dortmund. The report provided information about practical experiences (failures) in heating systems, scientific background, measurements of oxygen diffusion (including test methods), and recommended ways of avoiding problems.

This report clarified a few points:

1. Oxygen diffusion through plastic tubing in closed hydronic heating systems can not be disregarded.
2. The magnitude of unacceptable oxygenation was described.
3. A standard for controlling the issue had to be developed.

The continued research in this field qualified Dr. Kruse to receive a Professor’s degree.

Although the work to prepare a standard was initiated already in 1980, a draft DIN 4726 was not ready until 1985 (i.e. the third draft of June 1985). The scope of the standard had by then expanded to include all general requirements on plastic tubing (PEX, PP & PB) for radiant floor heating. Draft and appeal periods lasted until 1987, when the final standards were issued. DIN 4727-29 are material specific (for PP, PB, and PEX, respective) standards and were amended to the general requirements for plastic pipes for radiant floor heating outlined in the standard DIN 4726.

What was the result?

What does DIN 4726 actually say?

The last page of the standard includes explanations, so the basis becomes clear. Following is a translation of the section describing their considerations: "Experience from heating systems have since long established that corrosion levels in hydronic systems with ferrous metals are acceptable at the level one exchange of the system water (to fresh water) per annum. This corresponds to an oxygen amount of 0.05g/(cu.meter * day). An "allowance" of doubling this amount is given (allowing for measurement inaccuracy) to make the "tightness requirement" to be 0.1 grams (per cubic meter and day). Plastic tubing shall meet this requirement after having been thermocycled between 70°C (158°F) and 20°C (68°F) for 28 days while tightly coiled, and a final permeability measurement then carried out at 40°C (104°F) (repeated 3 times). Typically, non-barrier plastic tubing allows about 5 grams to enter; 50 times more than allowable. For tubing that does not meet this permeability requirement either of following measures must be taken:

- corrosion-resistant components must be used either in the whole system or at least in parts which come into contact with water flowing through the plastic pipes
- anticorrosion additives must be used in the heating water."

The German DIN 4726 standard was soon adopted by the industry in Germany and all over Europe. Approval criteria for certification of plastic tubing typically included the requirements specified in DIN 4726. The first solution alternative: providing tubing equipped with an oxygen diffusion barrier, became the overwhelmingly most used alternative. Virtually all radiant panel heating tubing in Europe has been equipped with DIN approved oxygen diffusion barriers since 1985. The alternative methods, utilizing corrosion-resistant components, or adding and maintaining corrosion inhibitors are seldom used. The transition period in Europe from "naked" tubing to tubing with barriers took place during the period 1982 to 1986. Since that time there has been no "oxygen debate" in Europe. Oxygen diffusion became a non-issue. The trade, the experts, and the public accepted the DIN 4726 standard specification. Systems meeting this specification are performing well, and problems or claims are extremely rare.

What happened in the USA?

The use of radiant floors with polymer tubing started to revive in the US in the mid 80's. As is often the case with a young industry, information was scarce and often contradicting. Not very surprisingly, the oxygen diffusion became an issue, - again!

Although 15 years of extensive experience from Europe was readily available, the US trade had to suffer a new oxygen debate, and thousands of systems were installed not considering that corrosion would occur.

We may wonder what protection a home-owner has, when and if his system fails due to corrosion from oxygen diffusion. Typically, a manufacturer can be held liable, only if the general industrial technical knowledge at the time of sale, indicated that a material property could be improper to the intended application of the product. The industrial knowledge in the US seemed to be quite different from that in Europe on this matter...

Now, the oxygen permeability debate is basically over in the US. The Hydronics Institute adopted the text in DIN 4726 regarding oxygen diffusion in the summer of 1992. Other trade associations (such as RPA) subsequently adopted the same standard. There is no longer a question regarding what the general industrial technical knowledge is. We can congratulate the US home-owner to the right to have a radiant floor heating system that won't be prematurely consumed by corrosion.

What's up when all is not so normal?

The DIN standard 4726 specifies that tubing with barrier must be at least 50 times tighter than the average result for non-barrier tubing (PEX, Polybuthylene, Polypropylene). For a "normal" radiant floor heating system the amount of oxygen let in, corresponded to 50 times more than what all the experience to date had found reasonable. The "experience" in question is the following: Hydronic heating systems would normally survive for a long time even if all water in the system was exchanged once (or even twice) per year. More frequent exchanges or refills of systems, or corresponding addition of oxygen, had by experience lead to reduction in the lifetime of components due to corrosion. This was the experience and this was the reasoning that lead to the limit that all parties accepted.

The DIN standard aimed to cover most reasonable "normal" installations.

But many systems are not "normal", and the standardized limit for oxygen diffusion may not always apply. Let's discuss a few of these examples.

Temperature: The German standard identifies the diffusion allowance at 104°F (40°C). This is a common radiant water temperature for installations in concrete and gypcrete, etc. But many systems are installed where the temperature is considerably higher. Some designers approve of temperatures as high as 160°F - and even more (read "staple-up applications"). At 160°F the diffusion is approximately 2.5 times higher than at

104°F and at 180°F over 4 times higher. These installations should principally allow 2.5 resp. 4 times less tubing lengths than a "normal" system. Or a barrier that is 2.5 to 4 times tighter than the standard prescribes.

Amount of Tubing 1: What is a "normal" radiant floor heating system? It is not defined, but for a small boiler in a residential application, an average of 1,500 lineal ft. of tubing is fairly usual. Many of these systems may include several heat distribution methods, like baseboard, radiators, fan coils, etc. Say that we define the "normal" to be 1,500 lineal ft. of plastic tubing in the slab and we use 6 radiators for heating other areas. Let's compare that with a system (same house) using radiator heating in all but a 30 ft. bathroom floor section with radiant tubing. 30 ft. is 50 times less than the 1,500 ft. which means that the tubing in that floor would not need any oxygen barrier. It would still meet the intent of the DIN 4726.

Amount of Tubing 2: If in the same house we replaced all radiators with another 1,000 ft. of radiant tubing, do we then exceed the limit of allowable oxygen diffusion? Principally, yes (because of the way we defined the "normal" system). However, the barrier properties for most manufacturer's tubing exceed the limit of "50 times tighter", so we may still be OK.

Amount of Tubing 3: In the example above, we considered a steel boiler, pump and some other equipment made out of steel. Let's say that we now have a copper tube boiler, copper pipes and valves out of brass, so the only ferrous steel component is the pump. "Normally" the oxygen is consumed in general corrosion over the boilers steel surface, and the other steel components. Now the only component left for the oxygen attack is the pump! In spite of oxygen diffusion barriers, this component is doomed to fail due to corrosion attack. If the amount of steel surfaces is less, or much less, than the "normal" case, it is safer to use Method 2 of DIN 4726, making all components corrosion-resistant.

The relation between the amount of steel and tubing is obviously important. A "normal" system needs at least a steel boiler to absorb the oxygen that enters in spite of barrier protected tubing.
The opposite extreme would be when the system has a lot of steel and little tubing: there are a lot of steel surfaces available to absorb the small amount oxygen entering. The general rule is: if the total amount of steel surfaces are 5 times larger than the plastic pipe surfaces, tubing without barrier can be utilized.

Quality of water. There are wide variations in water chemistry. The concentrations of some 20 different chemicals decide the corrosivity of the water used. The result may be (for "bad" waters) that problems may occur where they shouldn't. But also the opposite (for "good" water qualities): long period of time with no problems occuring, although they should be expected. Generally, most water qualities in the US are quite "good"; corrosive waters are much more common in Europe. This partly explains the delay in rediscovery of the oxygen diffusion problem in the US. "Good" water quality means that there is little risk for pitting corrosion, but instead, general corrosion will consume the oxygen that enters a system. General corrosion means a very slow and even erosion of all the steel surfaces in the system. If there are few steel surfaces in the system, it could lead to failure of some parts over time, but this is not the "normal" case. Instead, the slow erosion will generate very fine rust particles forming corrosion sludge. This sludge will mainly settle in areas with slow flow rate or in pockets. If the amount of oxygen is small, as is the case when tubing with barrier are used, then there is little sludge, and there will be no system disturbances. If non-barrier tubing is used, considerably larger amounts of sludge are formed, and this may lead to plugged valves and pipes, pump problems and circulation disturbances. This does not happen immediately, but after some years, problems are very likely to occur.

Why Method 3 in DIN 4726 is less accepted

DIN 4726 suggests the use of corrosion inhibitors as a third solution to the oxygen diffusion issue. Corrosion inhibitors typically react with the steel surfaces and form a thin layer that can not be penetrated by the oxygen molecules. The oxygen level is low in systems without inhibitors, because most of the oxygen entering is quickly consumed by a general corrosion reaction. When corrosion inhibitors are introduced, the corrosion process stops and the oxygen level rises to comparatively high levels. Now it becomes extremely important to manage and maintain the level of corrosion inhibitors throughout the life of the system. If there are not enough inhibitors in the system, one spot will be the starting point for corrosion, and with the high abundance of oxygen available, the likelihood for failure increases. At high oxygen concentrations, the risk for pitting corrosion increases drastically. Pitting corrosion is very local; the process is directed into the depth of the steel, and a pinhole may be the final result.
I am not saying that "Method 3" can not be a solution, or that it does not work. But it is extremely important that such systems be very well maintained. Tests for the amount of effective inhibitors should be done frequently, more often than once a year. Since there is a risk that some systems will not be well monitored, this method should be used very selectively.

The debate on oxygen diffusion and its consequences was superfluous in the US. Wide experience existed in Europe for a long time. I hope above explanations will provide a general understanding of the relations and contribute to good system designs.