The ABC of Radiant Heating reads PEX

Why PEX?

Previous articles in this series have described the success story of Radiant Panel Heating with PEX tubing. Why is PEX the only alternative, and are there different kinds of PEX tubing? This article will look at the history behind today's situation, and review some differences between the materials used.

The PP era (in Europe)

Radiant floor heating started to revive in the late 60's in central Europe. The typical installation included a few hundred feet of tubing per loop installed in the concrete slab. A minimum of one foot of tubing per square foot is required so each project typically consists of thousands of feet of tube. Installing stiff pipes would require a lot of labor to connect and fit into the floor. Additionally, fittings or couplings are considered to be weak points; the potential for leaks is thought to be larger there, and codes often require all fittings to be accessible.

In order to install the tubing in an efficient and practical way, the tubing had to be flexible. This requirement considerably reduced the number of polymer candidates. The material selected in the late 60's was Polypropylene. Since “pure” Polypropylene (this is called a Homopolymer, PP) is comparatively stiff, it was somewhat cumbersome to install and it was easily kinked. Installation instructions soon included recommendations to warm the tubing before installing it, or even to fill it with hot water. While these recommendations were acceptable to users - it was another issue that became critical.

Trade magazines reported an increasing number of failures of the tubing in the early to mid 70's These happened typically in the bends of the concrete embedded tubing. The additional stresses caused by bending the comparatively stiff tubes initiated cracks that propagated through the tubing wall. Suppliers then developed Polypropylene copolymers (PPC) that included some Polyethylene groups in the material (that’s why it’s called copolymer) to make it more flexible and more resistant to stress cracking. Although these improvements were made, the market had become suspicious of the material, and it never regained its early popularity. PPC is still successfully used for radiant panel heating in several markets, but the market share remains small. There is virtually no PP tubing available on the North American market. Since the material Polybuthylene was developed here during the late 60's and early 70's, raw material manufacturers did not see a large potential in PP tubing, so standards were not developed, and it was not promoted. The situation remains the same today.

PB Made Inroads - For a While.

Polybuthylene (PB) tubing was introduced to the US market in the early 70's and a few years later in Europe. It was flexible and more stress-cracking resistant than PP, so it worked well for radiant floor applications and later for plumbing. In Europe, the standards for pressure rating are strict and the tubing wall was made comparatively thick. This, combined with a relatively high material price made the tubing somewhat expensive. As a result, the market share in Europe has remained limited, around 5% with swings 2-3% up or down over the years.

In North America, PB became virtually the only alternative for radiant floors until the mid 80's, when PEX was introduced. The material price was lower than in Europe, and the US rating system allowed a smaller wall thickness. But radiant floors were not well promoted and the market penetration was slow during the years between 1971 and 1985. Also, the public remained somewhat skeptical of PB, because there were major failures of regular cold water lines. (The reason was that batches without antioxidants in them were mistakenly released. Those pipes had begun to degrade already during extrusion). The next development was fitting systems for PB tubing made out of acetal plastics intended to make plumbing systems more affordable. This material degrades when it comes in contact with water at increased temperatures (so called hydrolysis) and it turned out to be another disaster for PB. Class action law suits came as a result and PB was withdrawn from the US marketplace.

The success of PEX

Crosslinked Polyethylene (PEX) tubing was introduced during the early 70's in the European marketplace. The material was flexible and installed easily, it was stress-cracking resistant, and could hold up to high temperatures. There were no failures and the market began to trust PEX tubing. Rather than selling only plastic tubing and fittings, complete systems were developed. These included manifolds, controls, tools, accessories, and design methods. Contractors could concentrate on installing systems instead of figuring out what components to use and how to build the systems. The design of radiant floor heating systems is somewhat complicated, making the manufacturers’ system approach a major success factor. Market penetration was rapid and the volume increase approached 100% per year over several years during the late 70's and early 80's In the early 80's there was a debate regarding oxygen diffusion through the plastic tubing (see the article: “The Oxygen Diffusion Debate - Defused”) which slowed down the increase. The issue was resolved with a barrier layer applied to PEX tubing, and the increase rate has since remained at about 20% per year in Europe with the beginning sign of a market saturation.
In the US, PEX sales for radiant panel heating systems started in the early 80's, but the real expansion and penetration began after an ASTM standard was published (1984) and European-inspired complete systems were introduced in the mid and late 80's. PEX tubing with a barrier for oxygen took increasing market shares.

The ABC of Radiant Heating reads PEX (continued)

Since then, the market has continued growing steadily by around 30% per year, and with an increasing number of competitors present, price pressure resulted.

During the 90's, composite tubing consisting of aluminum between two layers of PEX (PEX-Al-PEX) was introduced, but is mainly used for other heating and plumbing applications, rather than for radiant panel heating. During the late 80's until recently, increasing volumes of reinforced rubber hoses were used for radiant floors. Several of those suppliers have now disappeared from the market, and after major hose failures in the 90's, sales of radiant rubber hose is rapidly decreasing.

Are all PEX the same, or are they different?

In the US, virtually all tubing used for radiant floors is now PEX tubing. It has proven to be a winner and a reliable alternative. There are several commercially utilized crosslinking methods, and they can produce different kind of crosslinks, crosslinking density, and crosslinking distribution leading to significant variations in properties. Let's look closer at the different PEX processes to better understand the differences.

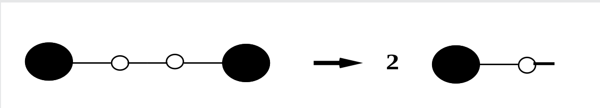
The commercially important crosslinking methods are the chemical methods using Peroxides (PEX -a) or Silanes (PEX-b) and Beta radiation (PEX-c).

Peroxide Crosslinking

Polyethylene is mixed with an organic peroxide (plus Antioxidants and possible other additives). The compound is poured into an extruder that heats the material until it melts and then extruded as pipe. The X-link reaction takes place either inside the extruder (Engel) or immediately after the extruder for other peroxide crosslinking methods. The reaction temperature/extrusion temperature is dependent on what peroxide is utilized. After crosslinking, the pipes are pulled through calibration tools into a cooling water bath.

The chemistry of the peroxide crosslinking reaction is easy to understand:

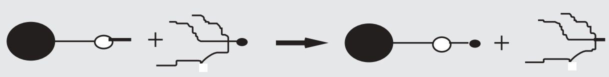
Step 1.



R - O - O - R + heat -> 2 R - O°

A peroxide is affected by heat so it splits up into two aggressive radicals.

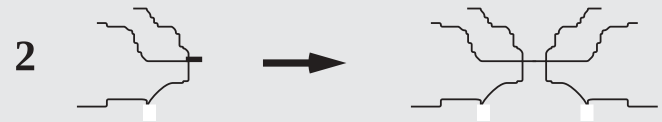
Step 2.



R - O° + P - H + heat -> R - O - H + P°

Each radical reacts with a Hydrogen in the Polyethylene (PE) making the peroxide radical stable while the PE turns into a Polymer radical.

Step 3.



2 P° -> P - P

Two polymer radicals react with each other, forming stable Crosslinked PE.

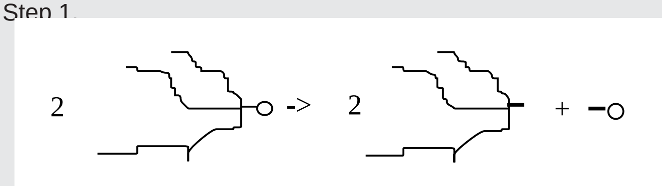
Beta Radiation Crosslinking

First, a suitable PE raw material blend is selected, with stabilizers and possible colorants/other additives included. It is then extruded into tubing onto large spools, perhaps 30,000 ft. on each. This tubing is then run under an electron beam many times. It is twisted and turned by large wheels and is "tanned" from every angle.

Electron beams, or beta radiation, are fast moving electrons from an electron accelerator. In a TV tube, high electrical potentials - 10,000 volts or more - are used to guide and speed up electrons until they hit the screen generating the picture. For crosslinking of PE, potentials of millions of volts are necessary to penetrate the material and generate crosslinks.

The energy of these electrons is selected so it corresponds to the bonding energy of Hydrogen atoms to the PE molecular chain. Hydrogen atoms are shot loose, forming pairs to become Hydrogen gas that is vented away. The PE chains now have open ends (known as radicals), but as these meet their “twins” they are bond together into a three dimensional network. The dose - the number of electron shots - will determine the degree of crosslinking.

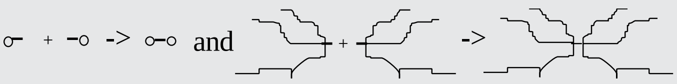
Step 1.



2 P - H + energy -> 2 P° + 2 H°

Radiation splits up 2 polymer molecules into polymer radicals and hydrogen atoms.

Step 2.



2 P° + 2 H° -> P - P + H_2

Two Hydrogen atoms form a Hydrogen molecule and the two polymer radicals merge together (they crosslink).

The ABC of Radiant Heating reads PEX (continued)

As we can see, both above methods result into the same kind of crosslink bond, a strong carbon-to-carbon bond between the original polymer molecules. This is not the case with the following method.

Silane “Crosslinking”
The Silane process includes several steps. The PE raw material must first be grafted in a separate extrusion process before the pipes are extruded. Raw material manufacturers often make this. Alternately, special extruders can allow injection of chemicals during the extrusion, eliminating the need for two extrusion steps. Generally, this is called the “Monosil Process” although there are a number of variations utilized in the systems.

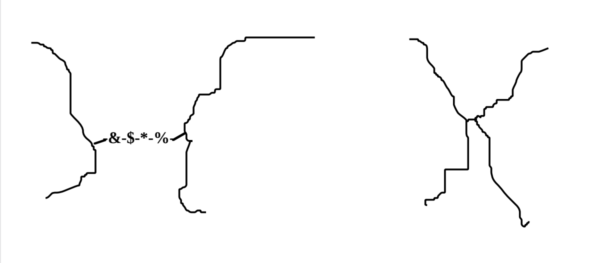
After pipes are extruded, the degree of “crosslinking” is very low, most of the bridges between the polymer molecules are formed afterwards when the material is exposed to humidity. When storing the pipes at room temperature and normal humidity, it could take months before final crosslinking is reached. This may be decreased to hours by storage at high temperatures and high humidity (“Sauna treatment”), or by circulating hot water inside the tubing. For larger wall thickness, many hours of hot water exposure may be required.

There are many variations to the chemicals that are called Silanes. They have somewhat different properties, and several different types can be utilized for building bridges between molecules. The example below is representative since the principal is similar to other Silanes. The chemistry is somewhat complex and not as easy to display as those above.

(CH2)n + RO° + CH2=CH-Si(OCH3)3 ->(CH2)n-CH2-CH2-Si(OCH3)3 + RO°
Vinyltrimethoxysilane is first grafted to PE with help of a peroxide.
Then, by treatment with hot water (add H2O to above), methanol is split off:
-> (CH2)n-CH2-CH2-Si(OCH3)2-OH + CH3OH (Methanol !!)

Two of these merge to form the crosslink, giving off water. The bridge between the two Polymer chains in the Silane “crosslink” looks like this:

-CH2-CH2-Si(OCH3)2-O-Si(OCH3)2-CH2-CH2-



Silane, a bridge **"real" PEX - a crosslink**

Some people (including myself) think that the Silane reaction should be called a vulcanization rather than a crosslinking since there is a bridge between the polymer chains - not a Carbon to Carbon crosslink.
The saying is: "The strength of a chain is equal to its weakest link"; the Silane bridge includes many different kinds of bonds between chemicals connecting the polymer chains. Each kind of bond has its unique bonding energy level and can be accordingly affected...

The last step in the crosslinking reaction described above is the step when water is released and the link is formed. This reaction can be reversible when moisture is available and the temperature is comparatively high. For each grade of Silane vulcanization the possible effects of hot water to the vulcanization bridge should be studied.

The health effects of Silanes, and/or their reaction by-products, and/or solvents used should be studied for each Silane composition when used for potable water. There are currently no Vinylsilanes in the list of chemicals in materials approved for contact with food and water in the “Official Journal of the European Communities # L 61/26 EN (European Norm) of March 12, 1996”.

The ABC of PEX
In the short overview of the three kinds of PEX tubing materials commercially available, we saw that Chemical Crosslinking (or Engel) with the acronym PEX-a and Radiation Crosslinking, PEX-c, have the same kind of crosslinking bonds while Silane Crosslinking, PEX-b, has a different bond. We can see corresponding differences in the materials, for example when heated up to release the thermal memory of the materials. There are other differences between them, and I may revisit this in future article(s). However, the most important property is the long-term strengths of the materials. They must be able to withstand the exposures in their intended applications. Long term testing has been ongoing since 1961 for radiation crosslinking and since 1972 for chemical crosslinking, and I must believe that long-term test results are being developed also for Silane crosslinking.

From the history (in the first part of this article) we have learned that some hot water plastic tubing materials have come and gone. Those disappearing did not meet the requirements. They survived for many years but finally they failed to provide what was expected or demanded. PEX tubing has proven to sustain in all its' applications and the growth continues all over the world. We must hope and rely that all PEX manufacturers continue to maintain the PEX history of success.

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℉ 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.

The Oxygen Diffusion Debate - Defused (continued)

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℃ (158℉) and 20℃ (68℉) for 28 days while tightly coiled, and a final permeability measurement then carried out at 40℃ (104℉) (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℉ (40℃). 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℉ - and even more (read “staple-up applications”). At 160℉ the diffusion is approximately 2.5 times higher than at

The Oxygen Diffusion Debate - Defused (continued)

104℉ and at 180℉ 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.

The advantages of selecting a low temperature heating systems

Radiant floor heating systems can provide substantial heat output at surprisingly low water temperatures. Since radiant floors provide the optimal temperature distribution for human comfort, an average air temperature of around 67°F will provide adequate comfort for most people. At that room temperature an average floor surface temperature of around 79°F will generate a heat output of 20 Btu / (h. x sq.ft.), which is adequate to maintain the indoor temperature for a reasonably well insulated building even during the coldest winter days. With a Vinyl or Tile floor on top of concrete, the temperature the circulating water would only need to be 88°F to provide this output.

In a conventional heat loss calculation, the designer will calculate how much heat is required to maintain adequate room temperatures in a building. Even though there are reasons for adjusting this calculation somewhat for radiant floors - the result will be similar. So when we know how many Btu's are required, why does it matter at what distribution temperature the heating system delivers this heat?

There are many arguments in favor for systems utilizing low water temperatures, and this article will discuss some of them.

Heat sources - when water temperatures are low

With increasing energy costs people are becoming more interested in using alternative energy sources, and low temperature systems can make that be a viable possibility.

- Hydronic solar collectors are able to provide much more energy at a low water temperature. Even during mid winter, simple constructions are able to provide water temperatures in the lower 100° F.
- The efficiency of a heat pump is greatly increased when low delivered temperatures are adequate. COP's in the range of 3 are commonly reached in such cases. (COP = Coefficient of Performance; Energy output divided by Energy input).
- The efficiency of a district heating system is greatly improved when low water temperatures can be utilized. There are numerous cogeneration plants and other power stations that currently waste huge amounts of warm water.
- Many industrial processes generate water warm enough to heat the building where they take place, when radiant floors are the selected distribution system.
- There are many examples of grocery stores using the warm water generated by their refrigeration system to heat their floors.
- Geothermal wells can provide much more heat, when low water temperatures can be utilized.

But there are also many possible benefits when more conventional heat sources are used.

- Boilers using wood or coal are typically equipped with storage tanks so they don't need to be fired up so often. A low temperature distribution system will also be able to "squeeze out heat" when the temperature has fallen quite low in such tanks. The result is longer time between charges, and/or smaller storage tanks can be utilized. Undesired heat losses will of course be much lower. These advantages are valid for any system utilizing storage tanks (not only wood or coal fired).

Energy savings by lowering temperatures

Energy saving is another major advantage with low water temperature systems. One rule of thumb says: "You save 1% on fuel consumption for every 3°F lower water temperature required." The exact figure may be challenged, but the fact is:

- Undesired losses from boiler, distribution piping, and other equipment will be greatly reduced at lower water temperatures.
- When low water temperatures are adequate, use of condensing boilers will provide a considerable reduction of flue gas temperatures. Less fuel is wasted heating the outside air. The efficiency gain is in the range 10%-12% at condensing operation.
- Where off-peak rates are available, the thermal mass of radiant slab floors will keep warmth for extensive periods of time. Combined with storage tanks, such systems should never need to be fired at prime rates.

Save the materials - at low temperatures

- All degradation processes go faster at higher temperature. The rate is often increased to the double per each 10°F temperature increase. Corrosion rate increases, life-span of gaskets and O-rings, etc. decreases, sensitivity to slight UV exposure increases, oxygen diffusion through polymers go faster, most corrosion inhibitors are faster degraded, and possible antifreeze need earlier replacement.

Select the low temperature system!

The benefits of heating systems that operate at low water temperatures are staggering! Where concrete slabs are poured it seems irresponsible to not install tubing that can provide heat. Right away - or in a future when its energy cost reduction will require it to be utilized.

Floors with wood joists construction will require higher heating water temperatures than slab and other poured floors. However, the utilization of efficient heat transfer plates or fins can substantially decrease that difference. Simple staple-up of tubing under the floor will require substantially higher water temperatures, and I must believe that such a system selection must be based on lack of knowledge. Energy savings will quickly offset the investment in transfer plates.

Since radiant floors by definition are warm, unhealthy carpeting can be avoided or at least minimized. Each 1/8th of an inch of carpeting thickness may increase the water temperature required by 10°F at design conditions. The benefits of low water temperatures described above should make carpeting thickness decisions to be a simple process.

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