Special Report:

The Oxygen-Diffusion Debate

by Paul Hanke

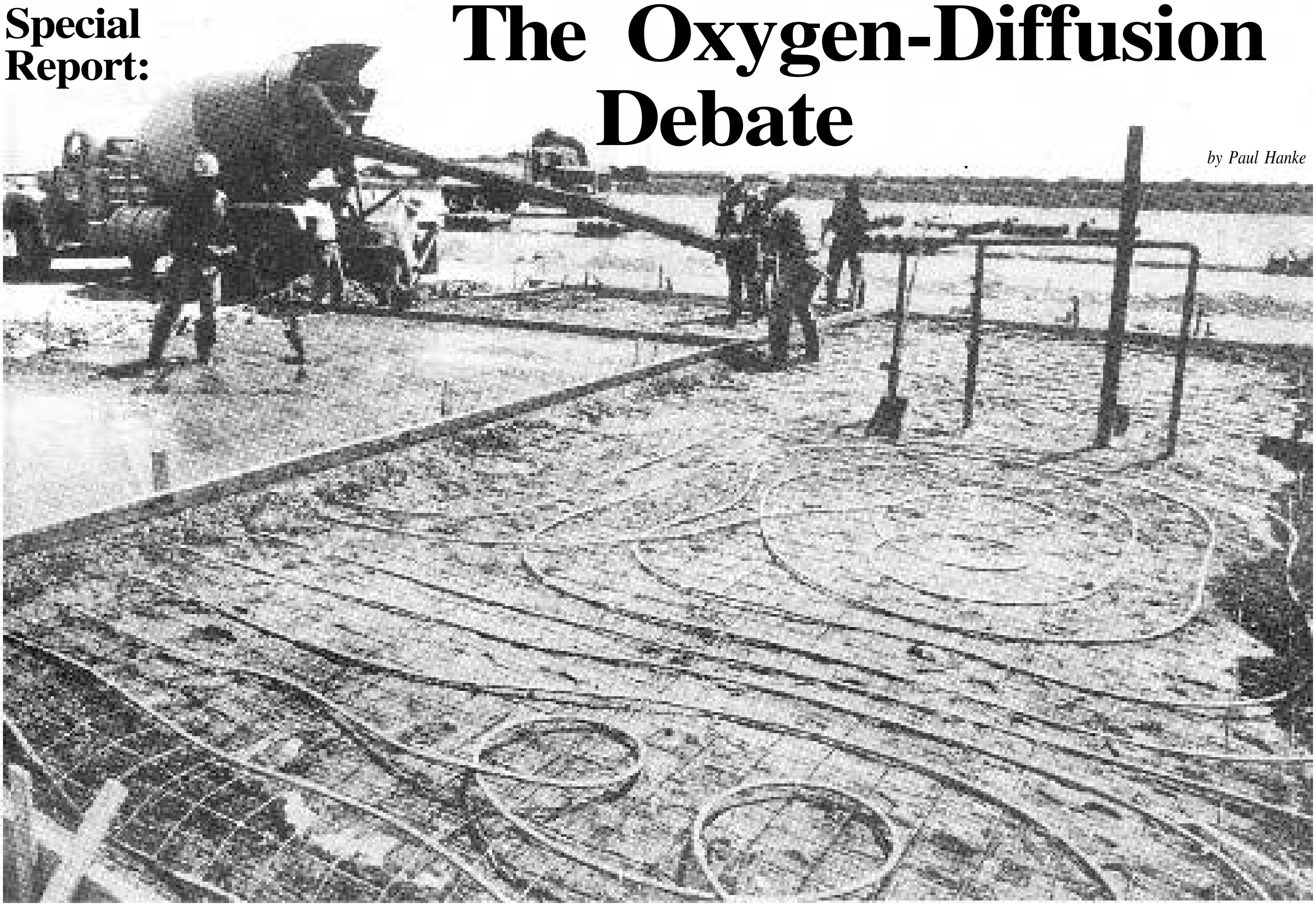

Photo courtesy of Shell Chemical Co.

In January's article on radiant heating, Paul Hanke discussed the use of polybutylene (PB) plastic, cross-linked polyethelene (PEX) plastic and EPDM rubber tubing as alternatives to copper pipe in hydronic radiant slabs. As he mentioned, each of these products is susceptible to the phenomenon of "oxygen diffusion," which can cause corrosion elsewhere in the system.

This month, Paul expands on the issue with this special, in-depth report. He explains how the problem arises, its extent, and what can be done about it during the design and installation of radiant heating systems.

Most readers probably are aware that water in the form of gas (i.e., vapor) can pass through the solid walls of a house. It also is true that *oxygen* gas can pass through the walls of non-copper *pipes,* combining with the water inside to cause corrosion elsewhere in radiant heating systems.

Only steel and iron components—not the pipes themselves—are affected by this "oxygen diffusion" —the term used to describe the migration of oxygen molecules through surrounding materials.

While poly (plastic) sheets in house walls resist the diffusion of *water vapor,* not even pipes made of plastic are immune to *oxygen* diffusion.

The problem of oxygen diffusion is relatively unknown in the U.S., but it has been recognized for some time in Europe, where at least one country is considering code changes in response.

The European experience has spurred extensive research—and controversy—in the industry, prompting the development of at least one new piping product specifically designed to resist oxygen diffusion.

Just how serious is this oxygen-diffusion problem? That remains a subject of much debate. The fact that manufacturers here and abroad are making extensive efforts to find a solution, however, indicates that the problem deserves serious consideration.

The Problem Discovered

Before other materials replaced copper tubing as the "pipe of choice" in hydronic radiant floors, corrosion related to oxygen diffusion had never been a particular concern, because copper is impermeable to oxygen.

Any corrosion that may have occurred in the pumps or boilers was attributed to oxygen, that entered through joints or leaks in the system. Some sources believe this is still the major source of oxygen entry in systems with non-copper pipes.

The oxygen-diffusion issue apparently first came to light in Europe in the early 1970s, when large amounts of corrosion sludge were discovered in the radiator heating systems of a relatively new apartment complex in Sweden. Leaks developed in the metal radiators soon afterward.

A Swedish testing institute, Studsvik Engergiteknik, was called in to investigate and determined that the problem was caused by oxygen diffusion through the walls of the rubber-based EPDM tubing connecting the radiators. EPDM is one of the products now used in hydronic floors as an alternative to copper.

As a result of Studsvik's findings, Wirsbo Bruks AB (the Swedish parent company of Wirsbo Co. in the U.S.) asked the lab to test a new product of its own—PEX, a plastic pipe made of cross-linked polyetylene—for the same problem. Wirsbo had begun marketing PEX two years before the discovery of the EPDM-attributed failure in the Swedish apartment building.

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PEX was found to be significantly less permeable to oxygen than EPDM, according to Tomas Lenman, vice president and general manager of the Wirsbo in the U.S. (1)

But apparently the difference wasn't significant enough. According to Lenman, Wirsbo had begun receiving PEX-related liability claims at a rate of about 5 percent in four years—a level the company deemed unacceptable.

As a result, in 1979 Wirsbo withdrew its original PEX tubing from the hydronic-heating market in Scandanavia and began seeking a solution to the problem of oxygen diffusion.

In the process of searching for a solution, Lenman says, the firm tested about 100 different possibilities. The search ended in 1981, when Wirsbo developed a pipe that reduced permeability to what the company felt was an acceptable level.

The solution involved the incorporation of a tight polymer barrier within the wall of its PEX pipe—in effect sandwiching an "oxygen barrier" between inner and outer layers of the pipe wall. This new pipe was dubbed "pePEX" to distinguish it from ordinary cross-linked polyethylene.

Meanwhile, in 1979, the German trade press had begun publishing articles on the subject of oxygen diffusion, focusing primarily on the use of plastic pipes in underfloor radiant-heating systems. The result of this the debate was a proposed 1985 draft standard for underfloor heating pipes in the German national building code, commonly known as DIN. (More on this later.)

Others in the industry—including Shell Chemical Co., a major manufacturer of polybutylene (PB) plastic tubing in the U.S., and the British Gas Corp. —also had begun looking into the problem.

After investigating PB, PEX and chlorinated polyvinyl chloride (CPVC) piping for radiant-heating applications, the Research & Development Division of British Gas presented its preliminary findings at the "Plastic Pipes VI" conference in York, England.

As a result, British Gas withdrew its support for the use of plastic pipes in its gas-fired radiant systems, based on the risk of corrosion, the cost of preventive measures and the relative costs of plastic and copper pipes.

Following the move by British Gas, Shell issued a recommendation in June 1984 that PB pipe *not* be used in radiant heating systems involving mild steel or cast-iron radiators. (The recommendation did not apply to copper fin-tube radiators, which were not considered to have the same degree of risk.)

Shell then stepped up its own research into the matter, which led it to revise its original recommendation nearly a year later. According to an April 15, 1985, article in *Contractor* magazine, Shell advised BOCA (the Building Officials and Code Administrators International, Inc.) and others in the industry that oxygen diffusion through PB pipes was so low as to be negligible. The company did recommend that rust inhibitors be added to the water in the systems as a safeguard, however.

The EPDM Debate

At least one U.S. supplier of tubing for radiant-floor systems—HydRadiant, Inc., a subsidiary of Gyp-Crete Corp. —withdrew its EPDM product from the market after the company "experienced corrosion of cast iron" in the field, according to marketing manager Lawrence V. Drake.

Although it "can't be 100 percent proved" that the problems were related to oxygen diffusion, Drake says, HydRadiant believed "the evidence warranted a switch."

Since the withdrawal of its EPDM product in 1984, HydRadiant has undertaken an extensive investigation aimed at developing its own tubing specifically for radiant-floor applications. The company plans to unveil the new product as a component of a complete system this April.

In the meantime, HydRadiant recommends the use of either PB or Wirsbo's new generation of pePEX tubing until the Midwest company gets its own product on the market.

On the other hand, George Peteya of BioEnergy Systems, Inc. (BESI), the Ellenville, N.Y. -based manufacturer of the "Radiant Roll" tubing mentioned in January's article, says there are "no problems that I know of with his firm's EPDM tubing.

Noting that BESI's product has been in use since about 1977 and estimating that there are "thousands of systems in place," Peteya says his firm would have heard about any corrosion problems by now.

If the potential for corrosion with EPDM is such a concern in *other* countries, why are we so unaware of it here in the U.S.?

Lawrence Drake of HydRadiant suggests one explanation: The earliest applications of EPDM often involved open-loop solar systems, many of which also used bronze pumps and copper heat exchangers—which meant there was little cast iron or steel in the system. As a result, the chance of corrosion would have been greatly minimized.

This indeed may explain BESI's experience in this regard. Much of the company's early marketing did involve solar applications, and its "SolaRoll," a product similar to that used in radiant-floor applications, originally was developed for use in solar collectors.

Peteya offers another possible explanation: Because corrosion is accelerated if the circulating fluid is heated to temperatures above 140 F—the maximum temperature at which radiant systems should be operated—any alleged corrosion problems in the field probably can be attributed to operating the systems at too high a temperature. He emphasizes the importance of stepping down temperatures from the typical 180 F boiler output to minimize the risk of corrosion.

Bill Chalmers of Shell Chemical agrees with Peteya about the effect of temperature and notes that too much oxygen may be present in the system during start-up, or that oxygen may be sucked in through fittings as the fluid in the system cools.

Nonetheless, HydRadiant's Drake maintains that permeability-related corrosion is a "big problem" with EPDM, and Lenman of Wirsbo agrees.

What About PB and PEX?

As noted earlier, Drake's firm currently is recommending the use of either PB or pePEX tubing in radiant-floor systems. Of the two, he says he would choose PB over Wirsbo's new pePEX, which is a relatively recent European introduction in the U.S. market, for reasons of cost and availability.

While acknowledging that oxygen in a system conceivably can cause corrosion, Shell's basic position—based on its experience here and in Europe—is that diffusion is a very minor problem compared to oxygen leaks through fittings and the like.

Citing an Austrian technical paper to back up this position, Scott Elstad of Shell's Polybutylene Business Center told NEB that there should be "no problem with PB in the first 50 years of service." (This very well may be an acceptable lifespan.)

But the report also concluded that "oxygen diffusion through plastic underfloor heating pipes undoubtedly reaches proportions that cannot be ignored." It also should be noted that corrosion-related problems such as blockages caused by scaling could occur before any steel components themselves actually rust through.

Shell's advice to recipients of its PB marketing guide remains that they add a rust inhibitor compatible with PB pipe to the system. (2)

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Even Lenman of Wirsbo, Shell's competitor, acknowledges that "if the plastic material has a permeability in the range of TB, you're not in the completely unsafe area, as with EPDM, but you are still in a grey area."

Drake of HydRadiant prefers not to take a definite position on the PB issue. "I truly don't know if there is enough diffusion to create a problem," he says, adding, "Your guess is as good as mine." He does say that chances of having a problem are "very good" if EPDM is used, however.

Lenman agrees, noting that problems with EPDM systems could show up "in as little as six months, and very likely within the first heating season." At the same time, however, he also admits that problems may not appear for up to five years—or perhaps never for some systems.

All of which raises the question of how serious the problem actually is.

How Big a Problem?

This much can be said for sure: Everyone agrees that oxygen gas can enter heating systems through the walls of plastic- and rubber-based pipes, and that this can cause corrosion in steel or cast-iron parts.

The question is whether diffusion-related corrosion is a *significant* problem, or whether there is merely a remote likelihood of encountering problems severe enough to cause failure or require repair. The answers differ depending on whom you talk to.

The question actually has three parts. First, how do the different types of plastic and rubber tubing compare in oxygen permeability (and therefore their susceptibility to harmful corrosion). Second, what is the risk of corrosion assoicated with the use of these products as opposed to copper? And finally, what can be done to prevent corrosion in existing systems that use plastic or EPDM pipe?

Studies by Studsvik give us a relative measure of the permeability of PB, ordinary PEX (without the special diffusion barrier) and polypropylene-based products like EPDM. (See the accompanying chart.)

PB and ordinary PEX are roughly the same in oxygen permeability, with PB performing slightly better over the entire temperature range tested. According to Wirsbo, its enhanced pePEX pipe with a built-in oxygen barrier is 100 to 1,000 times less permeable than ordinary PEX or PB.

The corrosion question, however, remains a grey area. At this point, no firm answer can be given, and the risk of corrosion apparently cannot be determined simply by studying the permeability data for each product.

This is because many other factors must be considered in addition to the permeability of the pipe—including the quality and mineral content of the water, the existence of sediments, the temperature of metal surfaces (heat accelerates corrosion), the presence of rust inhibitors, the diameter of the pipes, and whether there are any leaky valves or joints.

Theoretical calculations can be made, but they alone are not reliable.(4) Models or field studies are better guides to predicting actual behavior.

Corrosion in the field generally is caused by two main mechanisms:

First, slow oxidation of iron in the system forms black "magnetite" particles, which usually develop uniformly on all steel surfaces and pass into the circulating water. While relatively harmless, this process can produce localized deposits of sludge, which can clog pumps and breed the more dangerous "pitting" type of corrosion. The solution to this problem involves periodic flushing to remove the sludge.

Second, and more serious, is red rust, which is especially dangerous in regard to scaling and possible blockages. Red rust generally is attributed to the presence of higher levels of dissolved oxygen in the system.

The relative amount of plastic pipe compared to the amount of iron or steel in a system also affects the rate at which corrosion will form. The greater the surface area of plastic relative to steel, the greater the risk of corrosion.

What to Do?

Since apparently no one can tell you for sure when or if oxygen diffusion might cause corrosion in your radiant system, precautions are in order.

First, you may select a pipe that has a low permeability rating, such as Wirsbo's pePEX with the built-in diffusion barrier, but you will pay a premium for such materials. Next in order of preference would be PB, with EPDM coming in third.

Next, try to minimize the amount of plastic relative to steel or cast-iron components in the system. (Of course, this advice is fairly easy to follow if you have a bunch of free-standing radiators and a boiler connected by a few short lengths of pipe, but it may be very difficult to adhere to with typical radiant-slab applications, which involve hundreds of feet of buried plastic pipe.

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Opinions vary on whether the addition of rust inhibitors in circulating water can help. As noted earlier, both Shell and and HydRadiant now recommend the use of rust inhibitors as a precaution. (Drake says that a properly flushed and cleaned EPDM system with an inhibitor should last at least "20 to 30 years" before corrosion presents a problem, which is about the same potential lifespan as earlier copper systems.

On the other hand, Wirsbo investigated—and rejected—this option in the course of developing its new-generation pePEX piping. According to Lenman, the use of inhibitors "turned out to be a disaster." He cites more than 1,000 pre-fab Swedish homes using inhibitors in their radiant systems, 50 percent of which were found to have "corrosion disturbances due to oxygen diffusion" within a year and a half.

In fact, Wirsbo's research indicates that the improper addition of corrosion inhibitors actually could compound the problem by increasing pitting corrosion. (5) Wirsbo has yet to find an inhibitor that satisfies all the criteria the company has set for the product, Lenman adds.

If you do use a rust inhibitor, be sure it's compatible with the piping, as Shell advises. Drake recommends periodic maintenance as well. This should be done once or twice a year by either a home owner with a test kit or by a HVAC professional on contract. The process is similar to checking the antifreeze in your car.

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According to Drake, the inhibitor itself does not lose effectiveness, but make-up water can dilute it. Lenman, meanwhile, says the problem is that most inhibitor ingredients on the market can lose their effectiveness over time by chemical breakdown or other mechanisms. Either way, regular maintenance is important.

Regulations and codes offer another potential safeguard against corrosion. The proposed German standard noted earlier for underfloor heating pipes (DIN 00 4726) specifies at least one of the following:

- The use of corrosion-resistant materials, such as stainless steel and copper, for parts that come in contact with the water flowing through plastic pipes,
- The use of plastic pipes with "reduced oxygen permeability," or
- The use of corrosion inhibitors for hydronic heating.

In the U.S., there are applicable ASTM standards for plastic pipe (as cited in January's article), and Drake predicts it won't be long before a standard comes along specifically for radiant floors.

In the interest of avoiding potential problems and liability claims, it seems prudent that designers and installers of radiant floors should proceed cautiously on the limited information we have available until such time as an ASTM standard is developed. ■

We welcome contributions on this subject from readers and manufacturers in the field. We're particularly interested in hearing from HVAC *contractors, boiler and tubing manufacturers and chemical or hydronic engineers who know of corrosion problems in the U.S. related to the oxygen diffusion.*

Footnotes

(1) "Oxygen Diffusion in Plastic Pipes and Related Corrosion Problems," by Tomas Lenman, May 21, 1985. Rockford, Ill.: Wirsbo Co.. page 2.

(2) Letter by A. H. Schroer, Manager of Sales Development, Polybutylene Business Center, Oct. 17, 1984.

(3) Lenman report cited above, page 6; and Sept. 15, 1985 "Amendment," page 2.

(4) British Gas Corp. Report to Plastics VI Conference, by R.N. Britton and Dr. L. Houseman, circa 1984 (exact date unknown).

(5) Lenman report cited above, pages 3-4.