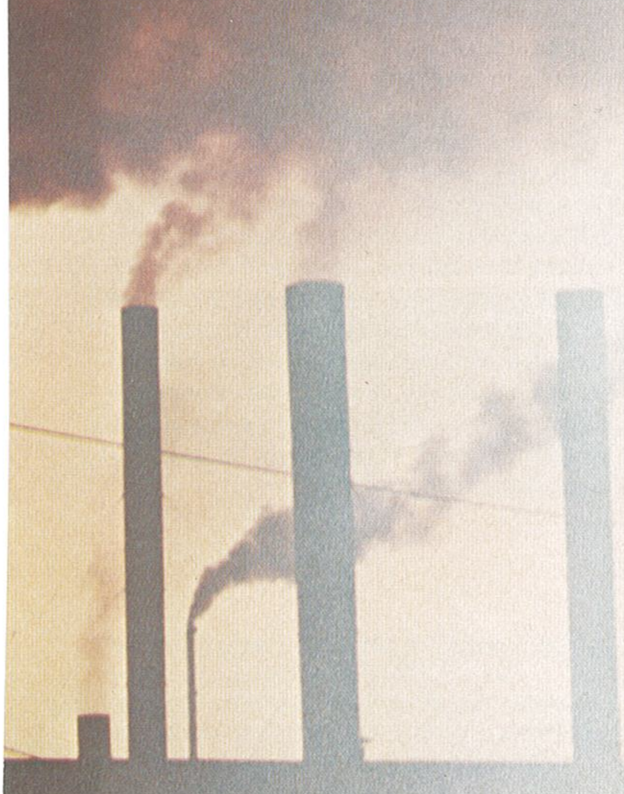
Thoughts on Selecting a Material



NO MATTER HOW THE QUESTION concerning the selection of a piping material is approached, the question concerning the condition of the water will always be of critical importance.

Impure Water – Water Under Stress

In the following discussion we will limit our comments to systems installed in buildings for drinking water (cold), for general use (warm) and for hot-water heating. In all these areas there are a whole list of national standards and recommendations that must be taken into account when choosing a material. The demands that are found in them all differ to a certain degree but these differences need not concern us here. The differences in the condition of the water that is to be carried do concern us.

There is no doubt that the very ones who need the water – humans – are also the ones who present the greatest danger to its purity. With the help of technology, we are able to transport water to almost any place we want. But what does the water that we transport look like? To tell the truth, somewhat murky! And the situation gets worse from year to year.

When fossil fuels are burned, sulfur oxide is given off. It then falls down with the rain mainly in the form of sulfurous acid and turns the water acidic, that is, it lowers its pH value. In spite of laws to the contrary, we are still treating nature as our dumping ground. Industry often stores or disposes of chemicals in a careless way. The agricultural and forestry industries continue to use fertilizers and pesticides without restraint. In winter we keep our streets and highways free of snow and ice by using an enormous amount of salt. We could go on and on. Every instance we have mentioned puts the ground water into further danger. We now notice that the water is no longer as it should be. Finally, in our zeal to undo some of the harm that has been done to the water, we add new chemicals to this life-sustaining substance. What is it then that finally comes out of our faucets?

Water that is loaded with harmful substances presents a risk in more ways than one. First, it presents a risk for the health of the people who use it. Second, it presents a risk for the metal pipes which, as they are destroyed, can also add more harmful substances to it.

PLASTIC PIPES WITHSTAND CORROSION. Plastic pipes that have been in use extensively for cold water supply since the middle of the fifties have not displayed any corrosion. This is the case no matter what the quality of the water has been. After undergoing extensive testing, pipes made of cross-linked polyethylene (Wirsbo-PEX pipes) have been officially accepted for drinking water in Belgium, the Federal Republic of Germany, Denmark, Finland, the Netherlands, Norway, Sweden, Switzerland, Spain, Italy and the United States.

No Starting Point for Calcification

Another factor that has a direct impact on the choice of the kind of piping material to be used is the lime content of the water. When the lime content is high and metal pipes are used, it is necessary to install a larger pipe than would normally be required just to achieve some sort of reasonable life span for the system. Plastic pipes, on the contrary, are known for their smooth, even walls. This means that there is no need to be afraid of the formation of lime deposits that can eventually lead to clogging. Because the inside diameter of the opening remains practically the same, the size of the pipe can be chosen without allowing for clogging that might occur after they are installed. That makes them much simpler and, above all, less expensive to install. As a bonus, the smaller diameters lessen the amount of water that has to run through the pipes to get hot water.

Synthetic Plastics – Still Undergoing Synthesis

The reason why plastic pipes have not yet made the decisive breakthrough into home water systems might lie mainly in the bad reputation that plastics have in many places. The manufacturers have only themselves to blame for that.

The technology of plastics is not only young; it is also complicated. It demands of the manufacturer a knowledge that is not only broad but also deep. It demands both perseverance and creative thinking. Finally, it demands a proper sense of responsibility. There are enough stories about production line failures of plastic products to provide material for several books. If there had been more conscientious testing done on some of the products, plastics would surely be seen in a much better light today.

***High demands** are placed upon materials chosen for uses other than piping systems. Flying machines as different as the super-light Gossamer Albatross and the space shuttle Columbia put the most extreme qualities of plastics to the test.*

Plate 6:1

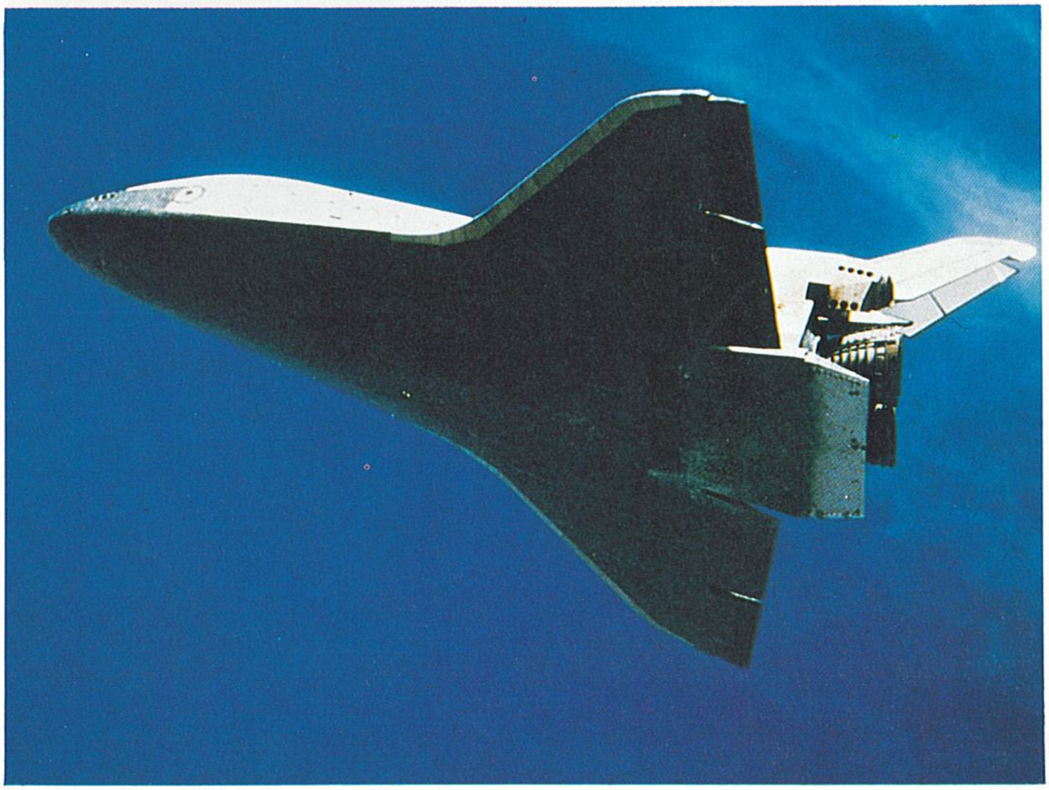


Plate 6:2

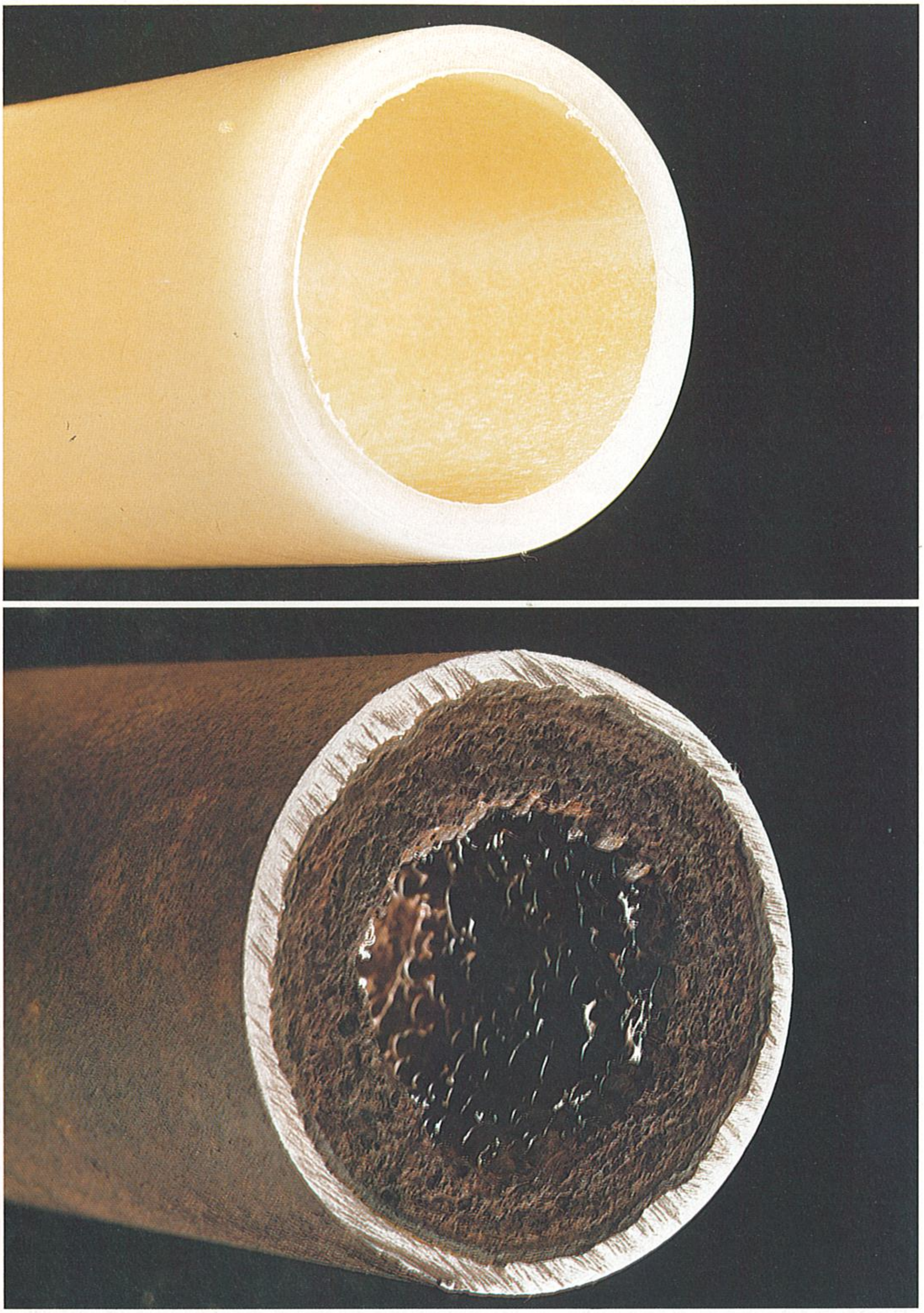


Plate 6:3

Any unevenness *on the internal walls of pipes promotes the formation of deposits. In this respect as well, plastic pipes have an advantage over metal pipes. The bottom picture shows a metal pipe with an advanced case of sediment buildup.*

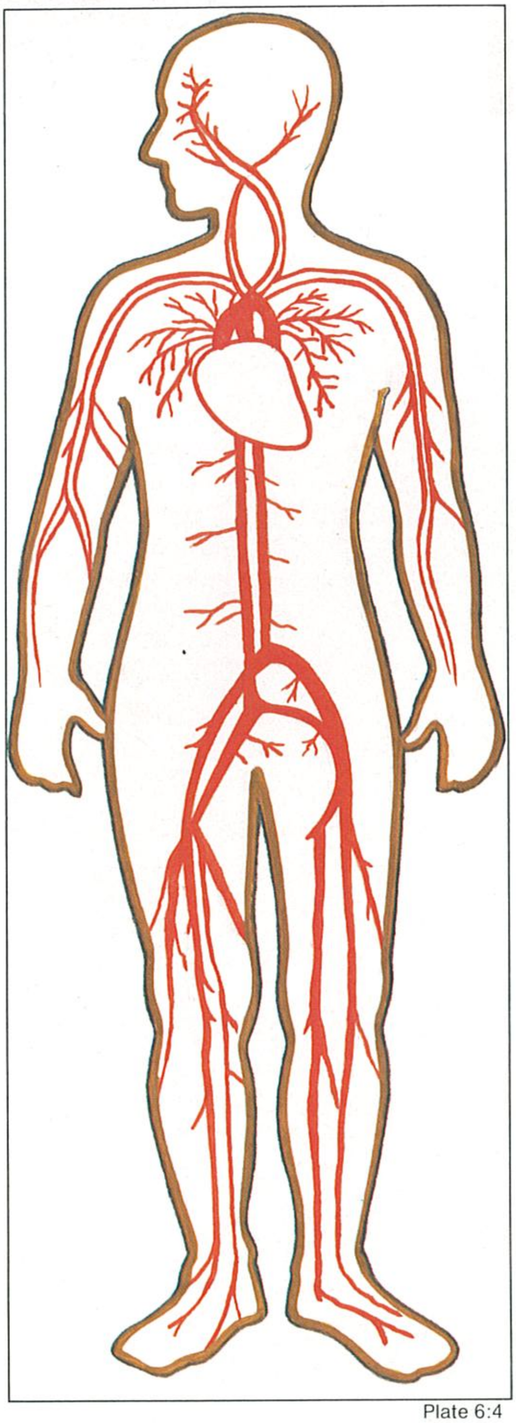


Plate 6:4

If the blood vessels and capillaries of the human body were placed end to end, they would stretch out for a distance of 56,000 miles (90,000 km). The heart continuously pumps about five quarts (5 l) of blood throughout this many-branched pipeline network.

56,000 Miles of Pipes

When properly manufactured, processed and installed, plastic products offer unimaginable possibilities. In a manner of speaking, nature has actually done it already. In the human body, the heart pumps about 5 quarts (5 l) of blood through a total of about 56,000 miles (90,000 km) of pipelines that are made of "synthetic" materials.

Not all customers are skeptical. For example, the car manufacturers are convinced of the value of synthetic plastics. In the United States, the amount of plastic materials in passenger cars doubled from the year 1977 to 1981 and it is estimated that this amount will increase another 50 percent by 1985. The announced goal of this change is the lowering of the production costs and the decrease of the cars' weight in order to reduce fuel consumption.

The spectrum of uses for plastic is very broad. It covers everything from airplane parts, such as the rotor blades of helicopters, all the way to replacement parts for the human body, such as plastic valves for the heart. Synthetic resins served as binders for the heat shield tiles on the space shuttle. In 1981, a human "pedalled" across the English Channel in an airplane made of plastic.

The future will bring us an ever-increasing number of plastic products. Canning containers, electrical wire, bicycles with only a few remaining metal parts. All of these are plastic products that can actually be made today. The actual limits exist more in our own imagination than in the material itself.

A NEW OIL CRISIS? What kind of impact would a repetition of the situation which caused the two oil crises of the 70's have. A new oil crisis would surely be a world crisis that would affect all types of industrial production. Still, the plastics chemical industry withstood the past tenfold increase in the price of oil quite well. This is reflected in the fact that, during the same period of time, the raw materials used in the production of plastic products increased only threefold in price.

Through the implementation of new production methods and other efficiency mea-

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sures, the cost of manufacturing plastic tubing has remained relatively stable. The prices for finished tubing are usually the same for about one year. This is not true in the case of copper tubing whose prices are at the mercy of the daily metals-market quotations. Depending upon the events that take place in the copper producing countries, the quote can shoot up hundreds of dollars per ton from one day to the next.

Cost of Completely Installed Systems

Actually, a comparison of the unit purchase price between plastic and metal pipes is not really that important. What is really important in the long run is the cost of the completely finished system. This is an amount that takes into account not only the material that is used but also the cost of the labor to install it.

In general it is true that, for example, rigid copper tubing and the necessary fittings often cost less than a system consisting of Wirsbo-PEX pipes when the system is used for drinking water supply. But price is not everything. Wirsbo-PEX pipes are not only lighter (328 feet (120 m) of 3/4 inch (20 mm) plastic pipe weighs about 31 pounds (14 kg) and copper 240 pounds (110 kg)) but they can also be cut, bent and connected much more easily. It takes less time to install plastic pipe and that has an especially large effect on the overall cost of the piping system.

Plastic tubing, *the true "featherweight". A 400-foot (120 m) coil of 3/4-inch (20 mm) tubing weighs just 31 pounds (14 kg).*

PLASTIC HAS ITS OWN CHARACTERISTICS. Even a layman would notice just by touching them that metal and plastic are two completely different types of materials. Anyone who is going to install plastic tubing should know what is different and what is better about it and should take those facts into account when working with it.

Normally, someone who is used to installing metal pipes can adapt quite easily to installing plastic pipes. In fact, he will probably notice quite quickly that plastic pipes make his job easier. With well-designed educational materials, anyone who is not a complete stranger to the industry will learn quite quickly how to work with plastic piping materials.

That is true for all types of uses whether it is for drinking water, hot water or surface heating systems, although laying out heating pipes

Installation *of under-floor-heating pipelines. The less resistant the tubing is to bending, the easier it is to install.*

Plate 6:6

does demand some basic knowledge of another sort.

Take the Change in Length into Account

Plastic pipes are prone to constant movement. That is part of their nature. Depending upon the temperature change, they either expand or contract. The increase in length is, for the most part, only an aesthetic problem. It can be handled easily by concealing it in soffits and other hollow spaces or in conduit or by building it into floors, walls and ceilings. Flexible plastic pipe that is installed in conduit can be replaced with little effort. Especially in the case of remodeling jobs but also in new construction, there are various plumbing situations that call for hidden installation.

Another characteristic of plastic tubing that is less well known than its tendency to expand is its tendency toward shrinkage. It appears in all types of plastic tubing to a greater or lesser degree after a certain period of use. The reason for this can be found in the influence of water pressure and temperature on the molecular restructuring of the tubing material from an axial direction (parallel to the axis of the tubing) to a tangential direction (perpendicular to the axis).

In the worst case, polyolefin pipes shrink up to about 0.5 percent. The tensile stress that is created by that contraction can be withstood quite handily by technically well-tested pipe connectors without having to be afraid that the plastic tubing will slip out of them. If it is possible to foresee that the piping system might have to be taken apart at a later date, equalizers (compensators) should be built in from the start.

High Temperatures and Pressure Surges

Compared with metal pipes, plastic pipes are more sensitive to high temperatures and strong pressure surges. Piping networks used for industrial water are often subjected to a temperature of from 195° F. (90° C.) to 205° F. (95° C.) and a water pressure of 145 psi (10 bar) including a pressure safety factor of 1.3 to 2.

Unfortunately, the possibility cannot be ruled out that a mistake during construction or installation or the failure of safety valves or thermostats could lead to excessive temperatures (perhaps even as high as 248° F. (120° C.)). The high temperatures might even be accompanied by a sharp rise in pressure. In such cases, it is not completely certain whether the plastic tubing could withstand such a strain especially when there are short lengths of tubing in the system. Long portions of tubing, on the other hand, produce an effect similar to expansion tanks and so can even prevent the bursting of a boiler.

Wirsbo-PEX tubing can withstand an excessive temperature of up to 248° F. (120° C.) for a short period of time without being damaged. But to avoid the undesired effects of

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any prolonged excessive temperatures, the first 6 to 10 feet (2 to 3 m) of pipe leading out of the heat source should be made of metal.

Even surges up to 1000 psi (70 bar) can be cushioned by a piping system that consists of longer runs. The ability of plastic tubing to stretch and, by doing so, to dampen the pressure peaks, leads to a smaller amount of strain upon the pipe fittings than would be the case with metal piping.

An extended period of high pressure, on the other hand, will lead to a rupture in plastic tubing. An excessive amount of pressure can be caused, for example, by pumping water into the system when the faucets are closed and the air cannot escape. The internal pressure in such situations can build up to almost the square of the actual pressure on the water being pumped or forced in. This means that under an actual pressure of about 80 psi (6 bar), it could rise up to about 600 psi (35 bar). The fact that the air is compressed also causes the excess pressure to remain. (For more information on the changes that take place in the tubing in such circumstances, see the information on "creep" on pages 79 and 120.)

__Flexible__ plastic tubing can be manufactured in just about any length.

THE MODULUS OF ELASTICITY. In order to benefit from a lower cost in both time and money when installing a piping system, the plastic tubing must be pliable and relatively soft. If this is the case, the tubing loses some of its apparent bulkiness. It even becomes unnecessary to use elbows in most cases.

The flexibility of tubing depends upon both its thickness and a certain property that it has which is known as the modulus of elasticity or, as it is sometimes called, its E-modulus.

Expressed in a more scientific way, the modulus of elasticity describes the relationship between a stress (σ measured in psi or N/mm^2) that is placed upon a certain piece of material, here a piece of tubing, and the extent to which it is stretched (ε) measured in fractions or percentages. The amount of the elongation is arrived at from the equation:

$$\varepsilon = \frac{\Delta l}{l} \cdot 100$$

where l = the original length and Δl = the increase in length.

If the stress-elasticity curve were straight, it would mean that the material being tested is completely elastic. The E-modulus would then be equal to the slope of the σ curve:

$$E = \frac{\sigma}{\varepsilon} \qquad \%$$

Up to now we have presented the generally accepted mathematical facts. When it comes to the question as to how the test results are to be interpreted and presented, there is already less agreement.

The conditions during testing, such as the temperature and the rate of stress, are of great importance. For example, a high temperature and a low rate of tension will lead to a low E-modulus. The comparison of the E-modulus of two plastics tested under different conditions is, considering those facts, very misleading if not downright indefensible.

Even the starting or reference point of the E-modulus is not always the same. One manufacturer places one of the tangents through the zero point of the coordinate system (at 0% tension). Others take into account a 1% or a 10% tensile stress.

The conclusion that can be reached based on the E-modulus is that the smaller the E-modulus of a plastic pipe, the softer and less restrictive it is during installation. But an objective comparison is only possible when the method of determining the E-modulus and its point of departure are the same. Table 6:2 presents the E-modulus of Wirsbo-PEX tubing under various conditions.

Unbiased Comparision

UNIFOS Kemi AB, one of the leading manufacturers of polyethylene in Europe, conducted a test comparing the E-modulus of various kinds of tubing used for under-floor heating. Each of them was subjected to four tensile tests during which they were stretched at the rate of 2 inches (50 mm) per minute. The length of the samples tested was about 2-1/8 inches (55 mm).

The secant modulus was measured when the sample had been stretched 10%. That is an amount close to what would be encountered in actual use. Table 6:1 presents a summary of the results of that test.

Tubing material	A	B	C	D
Secant modulus (psi where ε = 10%)	23,061 +/−435	30,168 +/−725	26,107 +/−1015	31,038 +/−435
(N/mm^2 where ε = 10%)	159+/−3	208+/−5	180+/−7	214+/−3
Secant modulus (relative)	1	1.3	1.1	1.3

Table 6:1

Tubing material A: PEX (Wirsbo PEX)
B: Polypropylene copolymer (PP-C)
C: Polybutylene
D: PEX (radiation cross-linking)

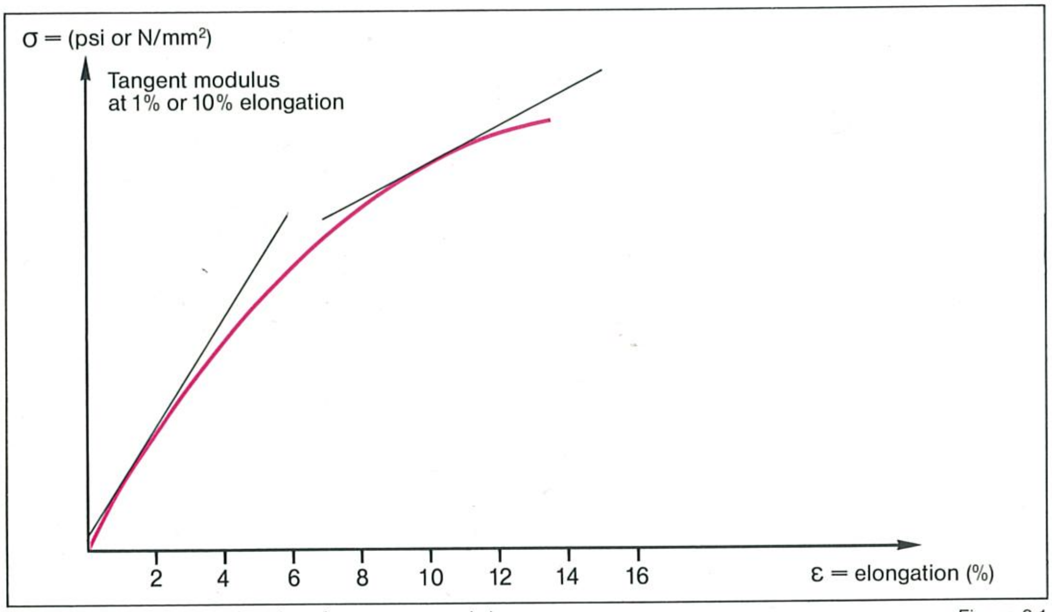
Flexural stiffness (absolute and relative) of various tubing materials.

As the table shows, the types B and D are the stiffest and so are also the hardest to work with. The manufacturer of type B also recommends that the tubing be heated up to 120° to 140°F. (50°C to 60°C.) to lessen the amount of the stress and so also the danger of breakage sometime after it is installed.

Modulus	Elongation ε (%)	Elongation Speed (100%/min)		Elongation Speed 1%/min		Temperature °F	(°C)
Secant	1	124,009	(855)	73,245	(505)	73.4	(23)
	10	28,283	(195)	18,855	(130)	73.4	(23)
	1	26,832	(185)	18,855	(130)	176	(80)
	10	10,153	(70)	7,252	(50)	176	(80)
Tangent	1	84,848	(585)	41,336	(285)	73.4	(23)
	10	7,252	(50)	2,901	(20)	73.4	(23)
	1	20,305	(140)	13,053	(90)	176	(80)
	10	2,900	(20)	2,175	(15)	176	(80)

Table 6:2

***Elasticity modulus** E (psi or, in parentheses, N/mm²) of cross-linked polyethylene (Wirsbo-PEX tubing, cf. Chapter 12, page 109).*



***Stress-elongation** graph using the tangent modulus.*

Figure 6:1

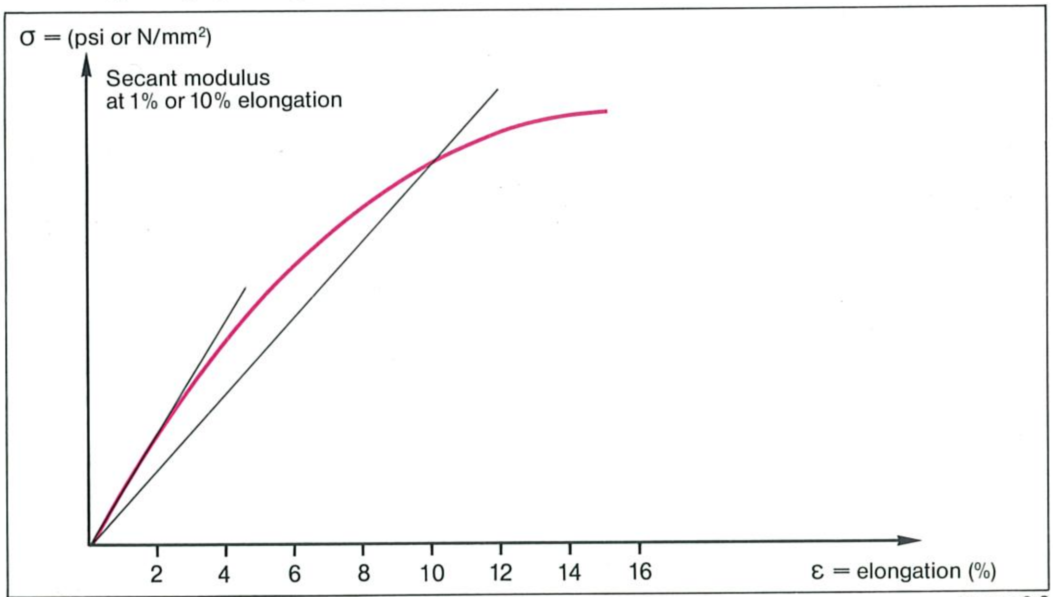


Figure 6:2

***Stress-elongation** graph using the secant modulus.*

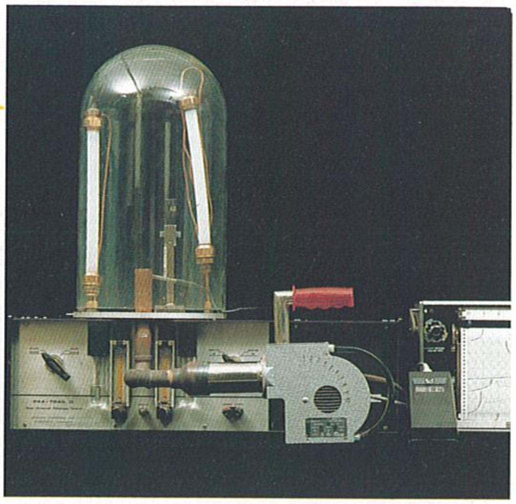


Plate 6:8

Equipment for measuring oxygen permeation. The machine (Wirsbo-Mocon) works with either gas-filled or water-filled tubing.

OXYGEN PERMEATION. Is it a problem? Plastic tubing made of PE, PEX, PP and PB can all be permeated to a certain, degree by gases. The reason lies in the molecular structure of these types of plastics.

The difference in the permeability of the various materials is measurable. However, the degree of difference is negligible in terms of long-term use.

Whether this characteristic can lead to problems in tightly enclosed areas (such as in under-floor heating) is dependent upon a variety of factors. The temperature must be given the strongest consideration as a determining factor. The internal system pressure and the speed of flow are less important.

Permeation leads to a minor increase in the oxygen content of the water that is contained in the system. This, in turn, poses the danger of general corrosion for the system's metal components. The quality of the water used in the system is the determining factor as to whether, and to what degree, corrosion occurs.

In the case of surface heating using plastic pipes, we already have more than ten years of practical experience that we can use in evaluating the corrosion problem. The number of under-floor heating systems that are in operation today in Europe must be in the millions. Despite the large number of systems, there have only been a few cases where problems have developed in which oxygen permeation could not with certainty be ruled out as a contributing factor. Instead, most of the problems were caused by circulatory difficulties. These were eliminated by flushing out the system.

At this time there are several possibilities being discussed to lessen the risk of possible damage due to oxygen permeation. They include:

1. addition of corrosion retardants to the heating water,
2. separation of the heat source and the under-floor heating system by using a heat exchanger,
3. using plastic tubing with a sheathing that is impervious to oxygen.

Anticorrosion Agents

Through the addition of certain chemicals (inhibitors), the oxidation of metal components can be lessened or even prevented. Anticorrosion agents, which are also called "inhibitors", can be distinguished according to their functions.

- Oxygen absorbents. They react with the oxygen that has entered the water and, in that way, keep the amount of oxygen that could actually cause corrosion at a very low level
- Agents that prevent corrosive action on the surface of the metal components by electrochemical means. Depending upon the way they work, a distinction is made between anodal, cathodal and those that use a combination of both.

When we are dealing with chemical protection in floor-heating systems, the items that generate the greatest amount of interest are inhibitors. Their job is to prevent the corrosion of steel surfaces. The manufacturers of such protective inhibiting agents are, naturally enough, the ones who have the best knowledge in this field. They can say which material might be best suited for each particular installation.

Among other characteristics, one should require the following from a corrosion inhibitor:

- anodal protective action for general corrosion prevention.
- cathodal protective action for prevention of localized corrosion such as pitting.
- thermal stability, that is, the ability to withstand the temperatures to which the system is subjected.
- the smallest loss of effect possible based upon the particular characteristics of the water used in the system. (The behavior of the proposed inhibitor should be documented by the manufacturer.)
- no negative effect upon the seals and the plastic tubing.
- good ability for tolerating the environment.
- an easy method of establishing the quantity of the inhibitor in the water.
- protective action for metal components of the system as well as for the plastic tubing.

There should be a cautionary note added to this discussion. Experience with inhibitors is still quite limited. The selection and use of these materials should be undertaken with the utmost of care and only under the direction of the most reliable of dealers. The use of too little of the material or of a material that does not possess an adequate degree of the type of protection needed could lead to pitting especially in the case of steel components. If the intended effect is not achieved, the inhibitor could even have the opposite effect, that of increasing the danger of pitting. Just that very result has actually been observed in a few cases.

System Division

The division of the system into a boiler circuit and a heating circuit, both of which are connected by a heat exchanger, is a solution that holds out much promise for the future. In such a system, the heating circuit must, of course, contain only corrosion resistant components. We can expect to see this type of system on the market soon.

Plastic Tubing Impermeable by Oxygen

What we are referring to here is tubing that has already been coated with an impermeable layer of material. This deflective barrier prevents, or at least reduces substantially, the intrusion of oxygen through the walls of the tubing. There are various alternatives that could theoretically be used to accomplish this insofar as construction and material are concerned. But to insure its practical value, certain basic requirements must met. These include the following:

- The barrier must reduce the permeability of polyolefins (PB,PE/PEX,PP) to oxygen to at least one-tenth of the normal average amount for the particular material.
- The barrier layer has to adhere tightly to the tubing. That should prevent the surrounding air from entering between the tubing and the barrier layer in case the coating is somehow damaged.
- Temperature changes should not adversely affect the long-term reliability of the permeation barrier. This requirement is especially hard to fulfill when the plastic tubing and the permeation barrier have different elasticity coefficients (as, for example, plastic and aluminum).
- It has to be possible to produce elbows and branches without damaging the permeation barrier coating. The same must be true for transporting such tubing and for its handling at the installation site.

All these requirements reduce the risk of problems during the use of the piping system but also mean that the cost for the whole system will be higher. The fact that, according to experience gathered up to the present time, the risk from problems caused by oxygen permeation is minimal anyway, should also be taken into account when deciding upon the material to use.

One example of a tubing which has been designed to fulfill these demands is WirsbopePEX. It is a plastic pipe with an oxygen barrier made of a polymer layer.