Water and Pipes.

Publisher: WIRSBO BRUKS AB

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Forward

WHY WRITE A WHOLE BOOK ABOUT PLASTIC PIPES? In the past few years, plastic tubing has gained ever-increasing acceptance in home water-supply and surface-heating systems. This is true not only of Europe but generally of all western industrial countries.

This technical development has, to be sure, not been completely free of misunderstandings and setbacks.

It should be said at the outset that it is not at all easy to arrive at a clear definition of what plastics are. Not even any of the particular types nor any individual kind of plastic can be defined exactly insofar as its characteristics are concerned. The variations that are caused by the different manufacturing methods and the technical background and knowledge of the manufacturer are just too great to make this an easy task. Although these characteristics are beyond what can be predetermined by mathematical and theoretical means, they can still be ascertained by means of testing and experimentation. But some manufacturers are tempted to substitute results that are not based upon tests conducted for the required amount of time. This, of course, makes it impossible to arrive at an objective conclusion.

In spite of these facts, it is still true that we have an adequate amount of knowledge about the types of plastics that are being used for home piping systems. This knowledge, which has up to now been the preserve of experts in the field, is beginning to become more widely disseminated.

That development is to be greeted wholeheartedly. Even more than that, it is an unavoidable necessity if plastics and all the different types of tubing with all their advantages are to really come into their own. Saying this does not in any way imply that every contractor, architect, dealer, installer and everyone who has anything to do with pipes that are made of this new material has to be retrained as a plastics chemist. But in our opinion, it is indispensable for everyone who uses plastic tubing to gain a minimum amount of knowledge so that each one can form his own opinion concerning it and the decriptions that accompany it.

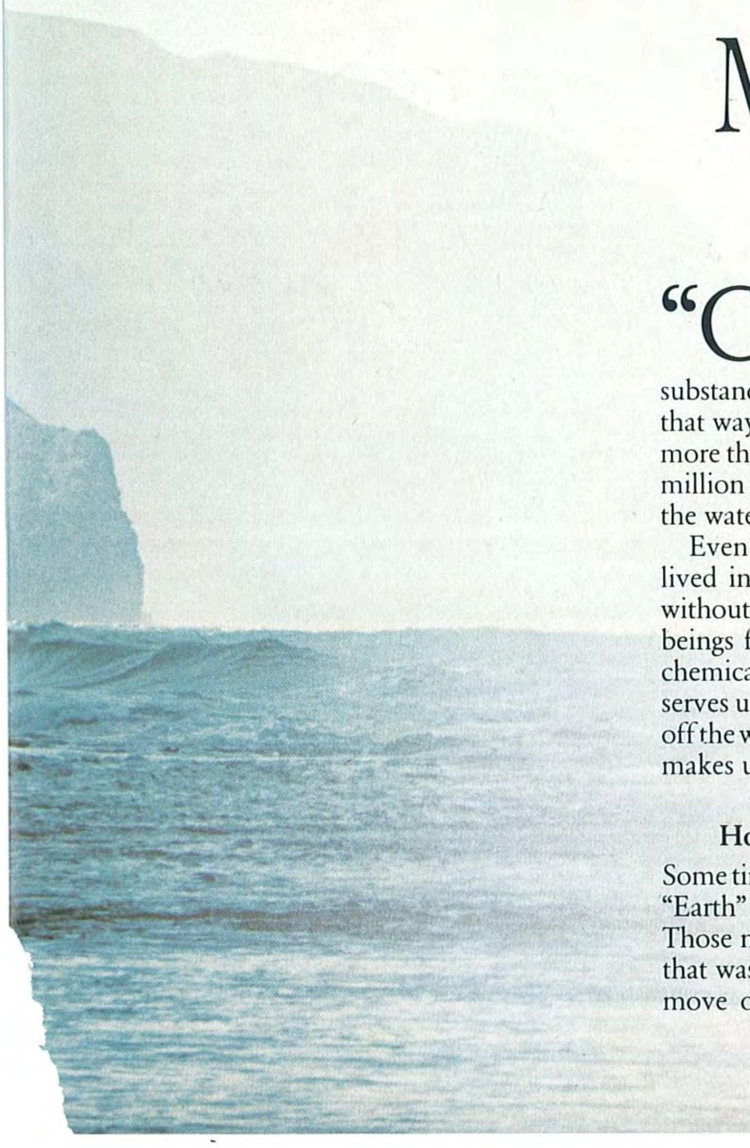
That is enough reason for WIRSBO BRUKS AB to publish this handbook.

This book covers a broad spectrum all the way from the source of the materials used for manufacturing plastic tubing to the actual use of the finished pipes. It affords insights into the world of the researcher and tester. It should, stated simply, awaken a new understanding of just what kind of product plastic tubing really is.

The authors have also written this book in the hope that it will serve as an impetus for increased care and objectivity in the presentation of test results. This is needed because without reliable documentation, no dependable judgements can be made concerning any tubing that is being evaluated.

The final goal is a reliable system that has a long life expectancy. It is our expressed hope that we will be able to contribute toward this goal through the publication of this book.

Yours sincerely,
WIRSBO BRUKS AB
Founded in 1620



Water Means Life

"OH, IT'S JUST WATER!" You have probably heard people say something like that. But does this wet substance really deserve to be put down in that way? After all, life itself started in water more than 3 billion years ago. More than 400 million years ago, the first living creatures left the water to live on land.

Even though those creatures no longer lived in the water, they still could not live without it. Water has left its mark on all living beings for all time. It takes part in the biochemical processes that occur in living cells. It serves us by dissolving our food and carrying off the waste products from our bodies. Water makes up forty percent of the human body.

How Much of the Earth is Earth

Some time ago our planet was given the name "Earth" and similar names in other languages. Those names were based upon a world view that was prevalent at that time. Today as we move our finger around the globe or our

planes around the world, we can get a more accurate picture of reality. We know that what we call the "Earth" is, for the most part, water. Three fourths of the globe is covered with water. Water is one of the most common substances found on our planet.

No other planet in our solar system has even nearly as much water in liquid form. There are two main reasons for this. The first is because it has "just the right amount" of sunlight. The second is because it has gravitational forces. The sunlight keeps most of the water on the earth in its liquid state. The gravity prevents the water vapor from escaping into outer space.

Six Percent Fresh Water

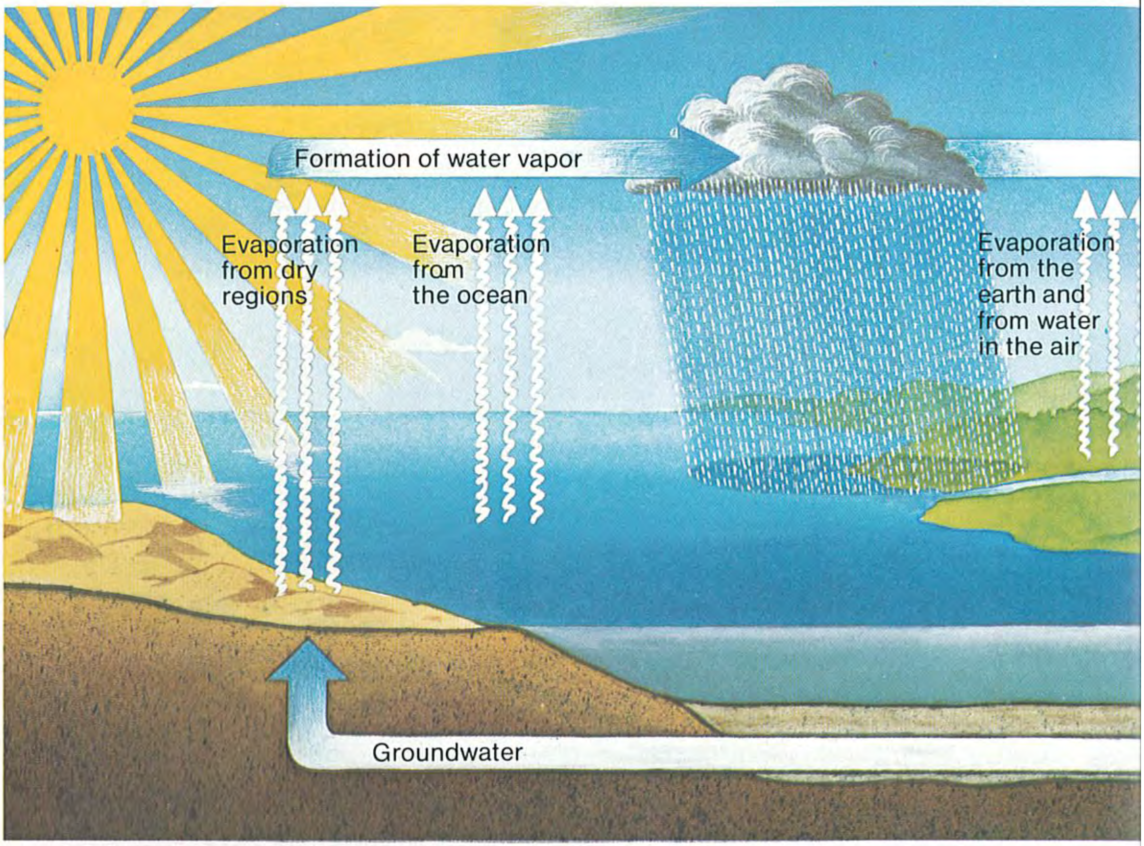
An estimated 94 percent of the water found on the earth is contained in the oceans of the world. The other six percent is fresh water and, of that, one third is located around the polar regions.

Plate 1:1

Water vapor escapes into the atmosphere after it evaporates from oceans, inland waters and plants. The amount that escapes in this way, however, is relatively small. Only one part in 100,000 of the total amount of water on the earth can be found in the earth's atmosphere. What is more, the length of time that the molecules remain there is very short. On the average, about ten days pass from the time they evaporate until they return again to the surface of the earth.

A Never-ending Cycle

How does water get to the land masses? What path does it follow to get there? This seemingly simple question concerning the earth's own water management system was not always so easy to answer as it is now. It was not until the last century that anyone was able to completely account for the total influx of water to a certain region through precipitation alone. Precipitation, runoff and evapora-



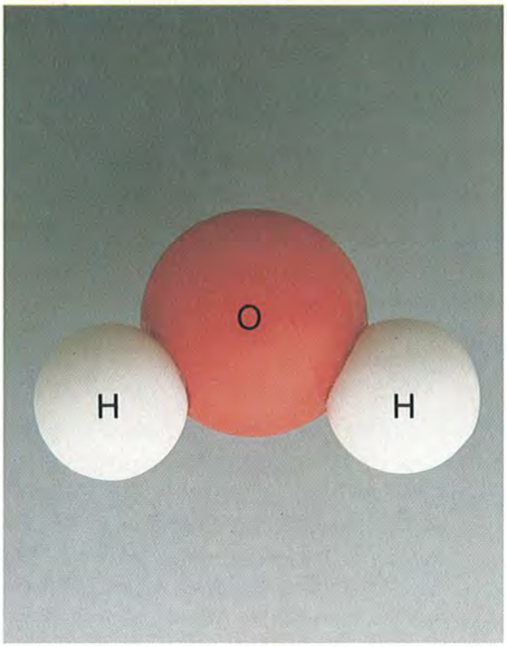


Plate 1:3

Hydrogen (H) *Oxygen (O)*

tion make up the elements of a continuous natural cycle. The formula that summarizes the water cycle mathematically is represented by the equation:

$$P = R + E + C$$

Where:
P = Precipitation
R = Runoff
E = Evaporation
C = Change in water storage (Storage in inland waters, glaciers, groundwater etc.)

An Amazing Substance

H_2O is the formula for the chemical compound we call "water". Two "small" hydrogen atoms and one "big" oxygen atom make up each water molecule.

What is important in this regard is the fact that the oxygen atom has two negative charges and that the hydrogen atoms are both positively charged. Because the centers of the

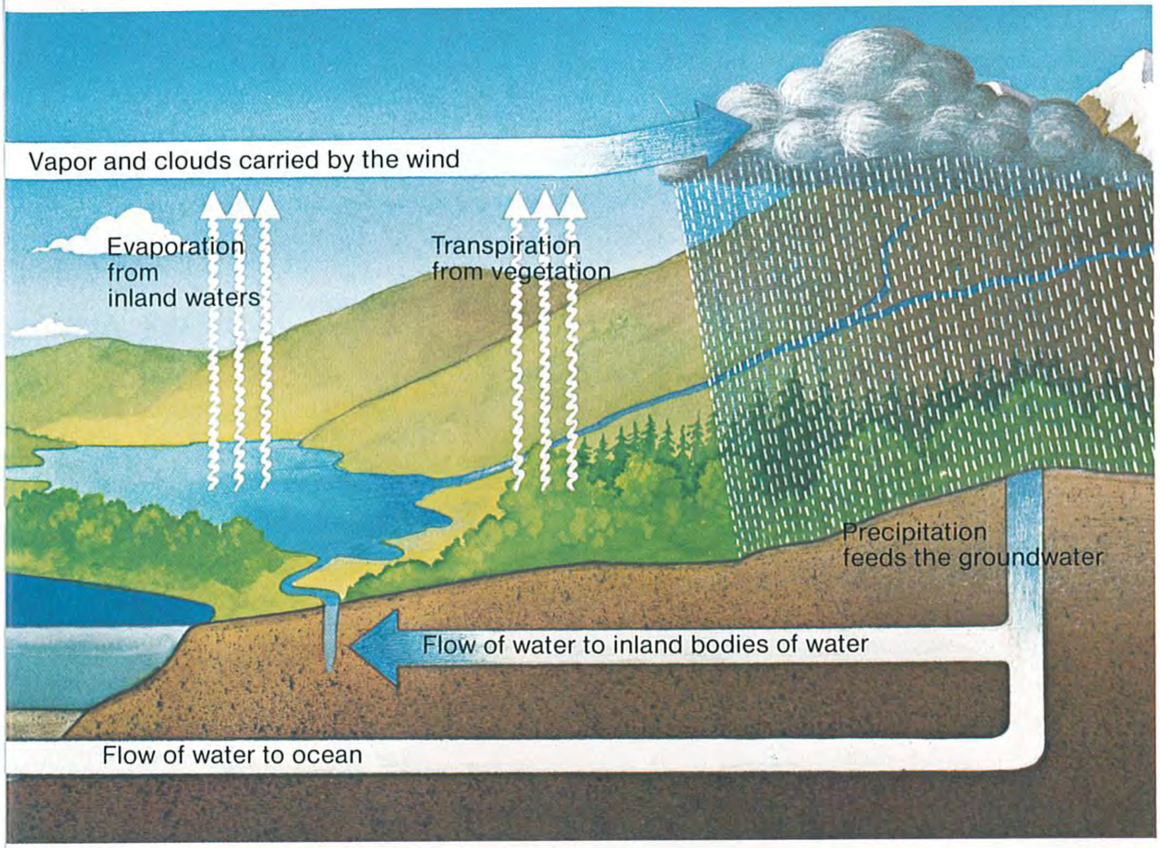
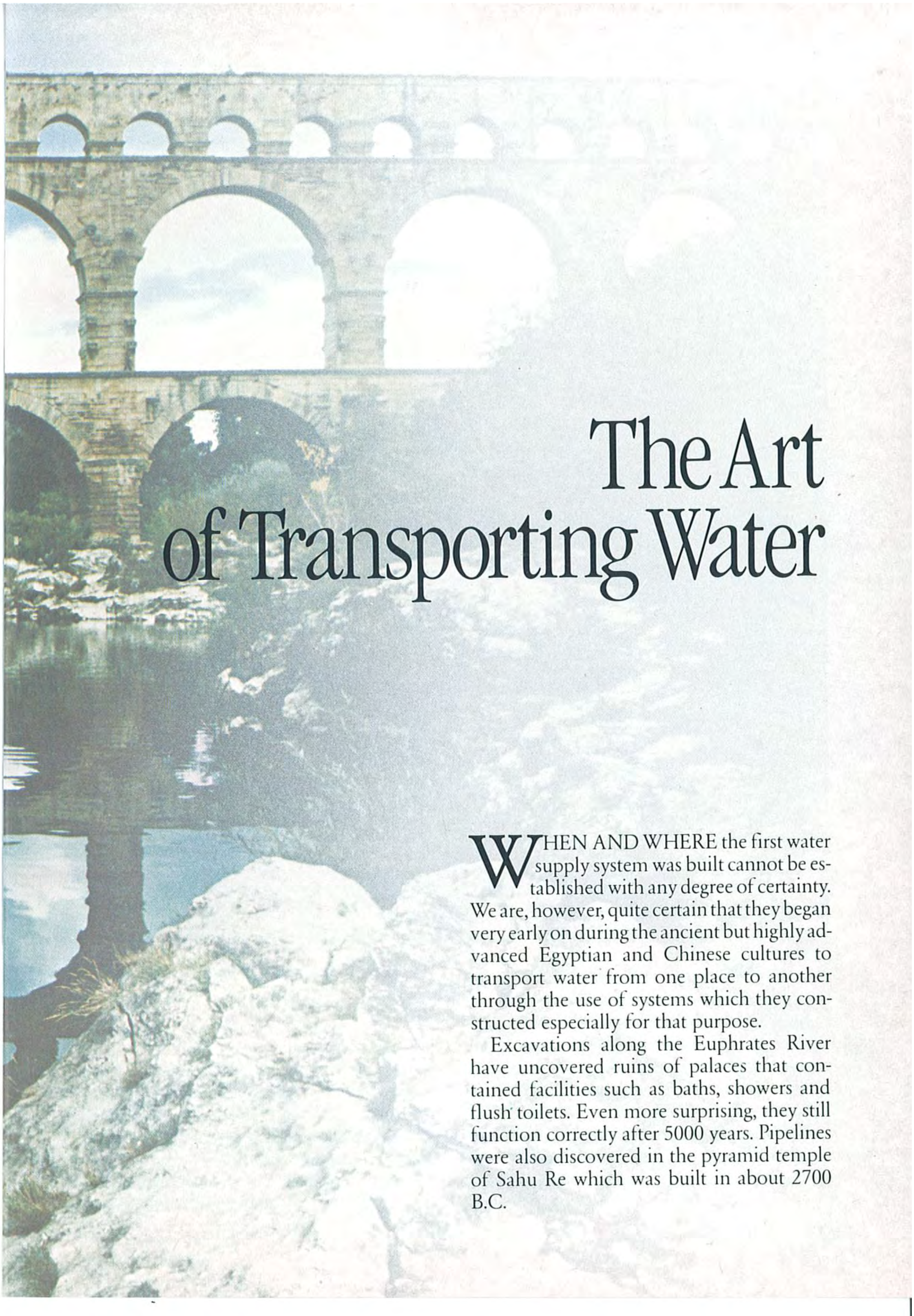


Plate 1:2

electrical charge are not symmetrically arranged in the molecule, a polarized union or a so-called "electrical dipol" is created. That fact has a strong influence on the consistency of the substance we know as water.

"By all rights", the boiling point of water should be −112°F. (−80°C.) rather than 212°F. (100°C.). Another effect of this lack of symmetry is the strongly pronounced ability of water to dissolve other substances. The fact that water attains its greatest density at 39°F. (14°C.), that is, at a temperature above the freezing point, is a characteristic for which we as humans can be quite "thankful" in retrospect. It allows the solid form of the substance to float on top of the liquid form. That is quite different than with most other substances. If this were not the case, the polar seas would freeze from the bottom up. The final result would be that few if any of the life forms we know today would have ever come into existence.



The Art of Transporting Water

WHEN AND WHERE the first water supply system was built cannot be established with any degree of certainty. We are, however, quite certain that they began very early on during the ancient but highly advanced Egyptian and Chinese cultures to transport water from one place to another through the use of systems which they constructed especially for that purpose.

Excavations along the Euphrates River have uncovered ruins of palaces that contained facilities such as baths, showers and flush toilets. Even more surprising, they still function correctly after 5000 years. Pipelines were also discovered in the pyramid temple of Sahu Re which was built in about 2700 B.C.

Clay Pipes Are Not New

The convenience of using a public bath was already available in Asia Minor over 4000 years ago. The water needed for those facilities was supplied by pipes made of fired clay which are very similar to those that are still produced today.

The drainage pipes that were already installed thousands of years ago in India and China were made of the same material.

Clean Water Means Healthy People

The ancient Greeks had already arrived at the insight that clean water serves to keep people healthy and so is an important element in securing the survival of a people or nation. Sport and bathing facilities had public restrooms with constantly running water. In their cities, the Greeks installed water lines made of stone, wood and fired clay.

Supply lines made of bronze or lead also began to be used. A high-pressure supply line

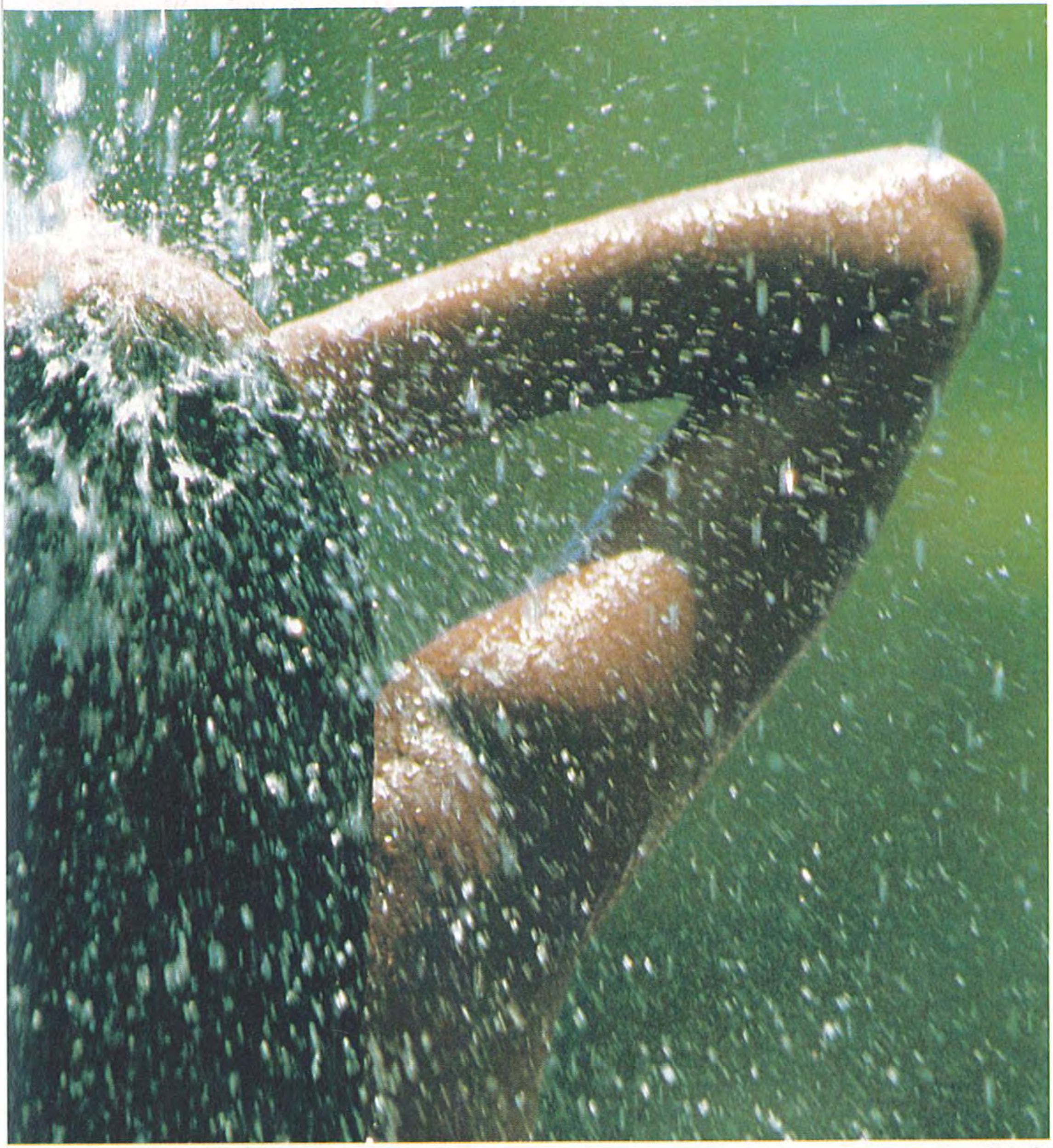


Plate 2:1

made of bronze can be dated back to the 13th century B.C. It was capable of withstanding a pressure of 300 pounds per square inch (20 bar) and was installed in stone tiles drilled for that purpose.

The Deeds of the Pioneers

If there are any people at all who can be considered pioneers in the art of transporting water, the ancient Romans qualify without doubt for the honor. The aquaducts that they constructed, which were truly architectural masterpieces, transported water into the city of Rome. It was a city of more than one million inhabitants who were almost addicted to bathing.

The same was also true of Pompeii as the excavations there have shown. Almost every block of houses was supplied with water by lead pipes. It is surely quite safe to assume that this piping material was detrimental to their health. Some scientists even look upon this as a secondary cause for the downfall of the Roman Empire.

320 Gallons Per Person Per Day

The Roman aquaducts were fed from springs high in the hills and were then used to transport the water across the valleys. The soil filtered the water that came from the rain and the melting snow. Then the natural force of gravity carried the water in the direction of the city.

The eleven aquaducts that were in use during the age of the Caesars (from 14 to 96 A.D.) supplied the city with an average of 320 gallons (800 l) a day for every man, woman and child in the city. This is more than the per capita average in the modern city of Rome. After the popes saw to it that the structures were repaired and rebuilt following centuries of disrepair, averages of up to 440 gallons (1100 l) per person per day were not unknown.

Still in Use Today

Placed one after another, the aquaducts of Rome would stretch out to a distance of over 260 miles (420 km). Some of them carry water not only at one level but at two or three different levels. The structures are still regarded today as belonging to the technical and artistic wonders of the world.

The decline of these structures began in the fourth century A.D. They started to show signs of destruction and decay. A certain amount of restoration was undertaken in the 15th century. Of the aquaducts that remain standing today, there are a few that still carry water to Rome.

GERMAN INNOVATIONS. A new era in piping system technology began in the year 1455. The Dillenburg Castle in the Westerwald installed a water pipe made of cast iron. Almost 200 years later, the water fountains in the gardens at the Castle of Versailles received their supply of water through cast-iron pipes. During the 18th century, people were discovering more and more concerning the possibilities provided by this new technology. Only 100 years later, the use of cast-iron pipes had become the norm throughout most of Europe.

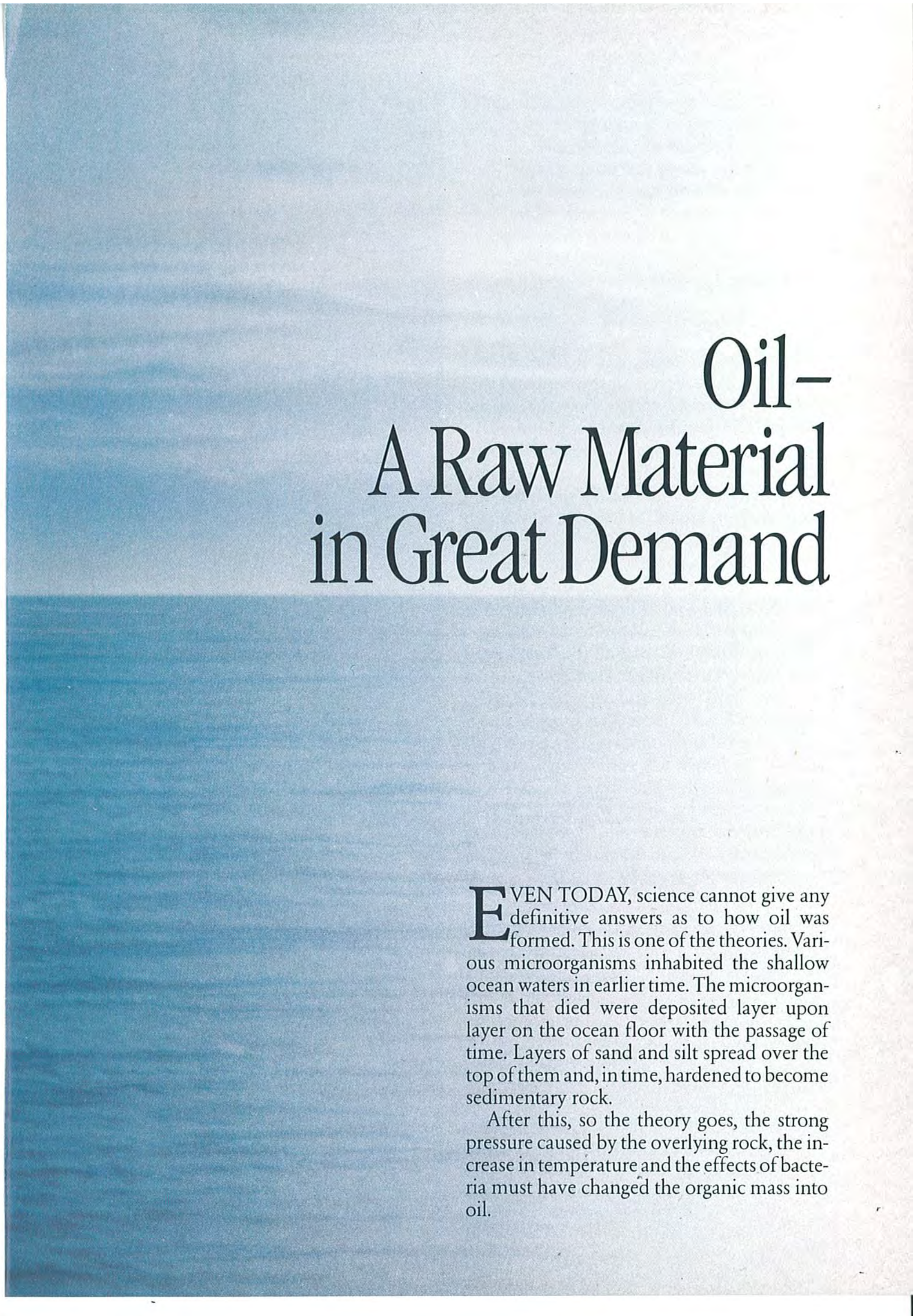
In the forests of Sweden, wood was the first piping material because it was so abundant in nature. The remains of such pipelines have reached the impressive age of almost 1000 years. In the year 1649, a water line almost 2000 feet (600 m) long was installed for the castle at Uppsala. For the first time, wooden pipes proved to be unsuitable. The water pressure was too high. According to old sources, these wooden pipes were replaced by discarded cannons.

Water Out of the Depths

Mankind has not only searched all around the world for water but also into its depths. Already in the year 150 B.C., wells were dug in China to a depth of up to 2000 feet (600 m). The Roman water workers also dug wells in addition to building aquaducts.

The current record for the deepest water well in the world is held by a well in the state of Montana in the U.S.A. It is 7,320 feet (2,231 m) deep. Today, with all the advances in deep-well drilling technology, we are digging deeper and deeper towards the center of the earth. In July of 1979 on the peninsula of Kola, the Russians set the all-time record for the deepest hole ever drilled: 31,909 feet (9,726 m). According to the latest information, they are still drilling.

The ***Archimedian screw*** *has stirred the imagination of technologists for ages. Here is a drawing of a three-tiered apparatus dating from the time of the Renaissance (Agostino Ramelli, 1588).*



Oil– A Raw Material in Great Demand

EVEN TODAY, science cannot give any definitive answers as to how oil was formed. This is one of the theories. Various microorganisms inhabited the shallow ocean waters in earlier time. The microorganisms that died were deposited layer upon layer on the ocean floor with the passage of time. Layers of sand and silt spread over the top of them and, in time, hardened to become sedimentary rock.

After this, so the theory goes, the strong pressure caused by the overlying rock, the increase in temperature and the effects of bacteria must have changed the organic mass into oil.

Most of It Was Lost

Very often the oil-bearing layers were made up of porous materials such as sandstone and limestone. Because of the porosity of these types of stone, the oil that was put under pressure by the rock on top of it could escape toward the upper crust of the earth. Most likely more oil has been lost this way since oil began to form than has ever remained behind in the natural storage places where we find it today.

Millions for Drilling

More than 200 years ago, people already knew how to make use of the crude oil that found its way to the earth's surface. They did so then in eastern Europe. Using a primitive distillation process, they developed a liquid similar to kerosene that was burned in lamps.

The American oil industry was born one hundred years later. The first well was drilled by a man named Drake in the state of Pennsylvania in the year 1859. Since that time, the hunt for "black gold" has been on at an ever-increasing pace and with an ever-increasing use of modern technology.

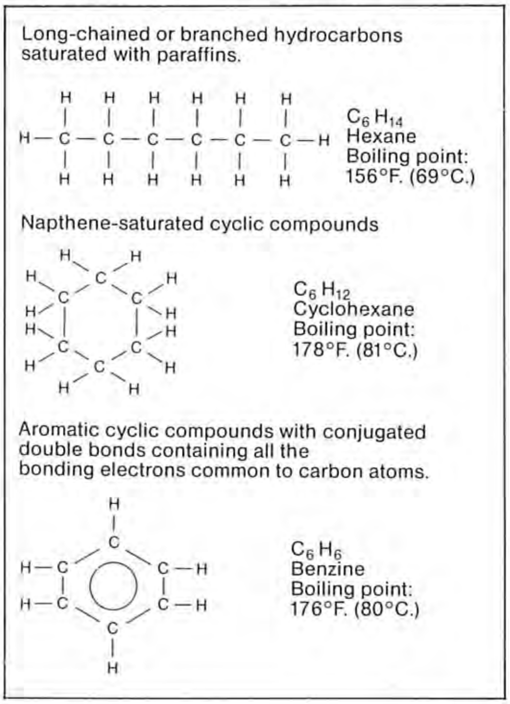
It is probably true that all the "easy" wells have already been drilled. That leaves us with only the "hard" ones and these are the most expensive. It costs about four times as much to drill for oil offshore as it does to drill on land. In the North Sea, for example, the drilling companies have to spend about 5 to 8 million dollars for every well. Even at that price only one out of every 15 attempts ever results in a well that is actually worthwhile pumping for crude oil.

HYDROCARBONS. Crude oil is a mixture of compounds of the elements carbon and hydrogen. Both hydrogen atoms and other carbon atoms can form compounds with carbon atoms. Because of this fact, there are theoretically an unlimited number of possible hydrocarbon compounds.

The characteristic silhouette of an oil refinery. *The high towers are distillation columns in which the crude oil is broken down into various components.*

Plate 3:1

Depending upon how it was formed, crude oil is a mixture of varying amounts of the predominant hydrocarbon groups paraffin, naphthene and aromatics. Figure 3:1 shows an example of each of these groups.


Long-chained or branched hydrocarbons saturated with paraffins.

Napthene-saturated cyclic compounds

Aromatic cyclic compounds with conjugated double bonds containing all the bonding electrons common to carbon atoms.

Figure 3:1

The various components that make up crude oil differ from each other especially by virtue of their different boiling temperatures. Paraffins have up to four carbon atoms and have a boiling point as low as 32°F. (0°C.). The boiling point then rises along with the number of carbon atoms. With 5 carbon atoms, the boiling point rises to 95°F. (35°C.), with 10 carbon atoms it rises to 345°F. (174°C.) and with 30 carbon atoms to 650°F. (344°C.). This characteristic, which can be found in all hydrocarbons, is used to separate the various types of compounds from each other.

Separation in Towers

You have probably noticed the typical, high, metal towers that jut up from the surroundings if you have ever driven past an oil refinery. Inside these towers, the crude oil is broken down into its so-called "fractions" and changed into various petroleum products. This separation process is usually referred to as distillation.

Crude oil is heated to a temperature of 662°F. (350°C.) and transported to the lower portion of the tower (fractionating column). Most of the oil changes into gases during this process. The vapors rise toward the top and at a certain level, depending upon their boiling point, they turn back into liquids. In other words, they condense. The products of this condensation are then collected at each of the various levels. This is how the different hydrocarbons are separated from each other.

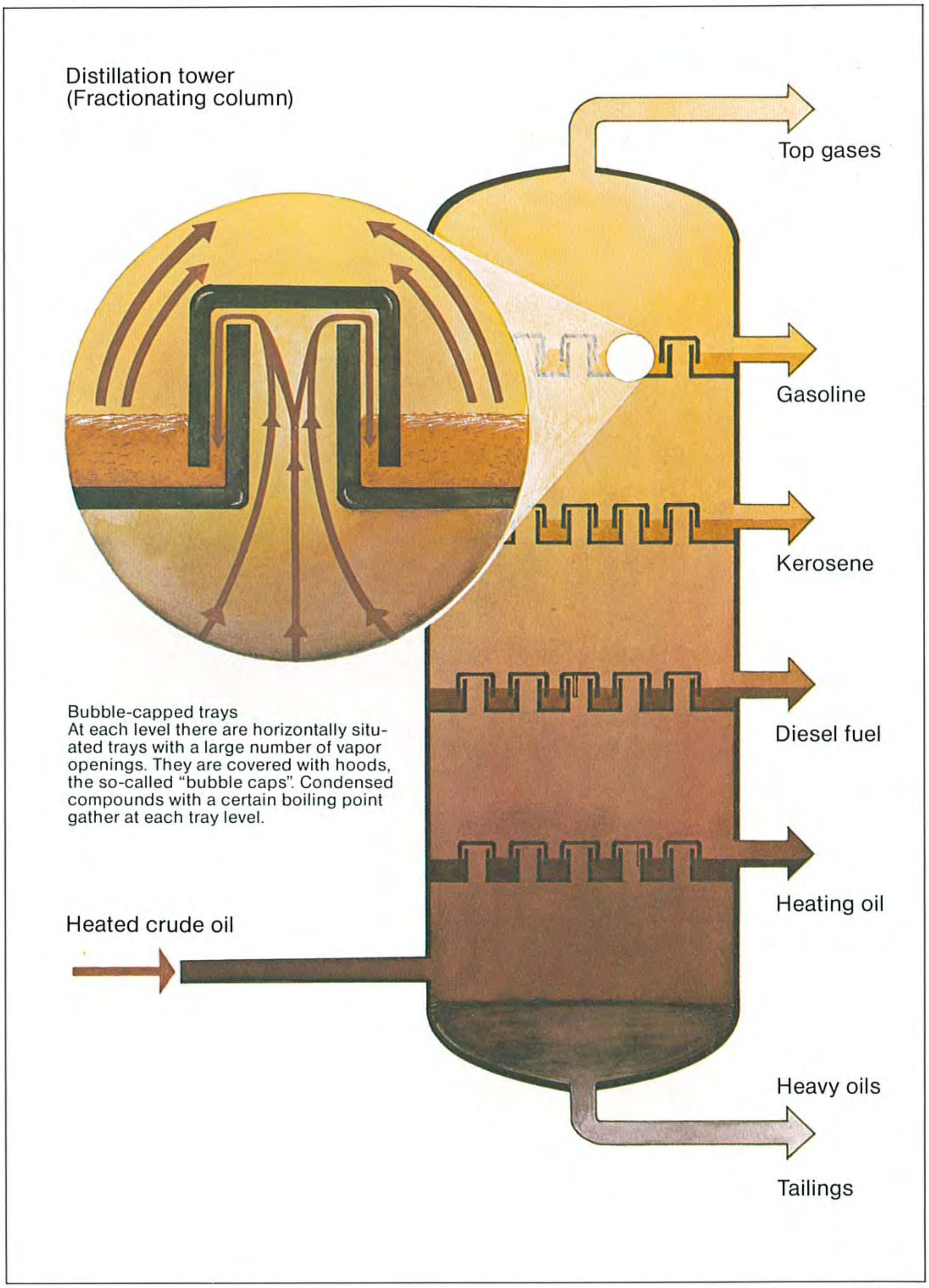
In general, these are the products that are taken from the columns at the various levels beginning at the top: refinery gas (top gas), gasoline, kerosine, diesel oil, light fuel oil, lubricating oil, paraffin, heavy heating oil, asphalt (see Plate 3:2).

The Road to Plastics

The many products that are separated by the distillation process are mainly the raw materials for an immense number of secondary products. Just as examples, we could mention the following: solvents, gaseous and liquid fuels, lubricating oils and greases, detergents, and chemicals for industry and agriculture. But what interests us most is yet another group of products, synthetic plastics.

To produce plastics, a further refinement of the distilled products is necessary. It is possible to split and transform long chain molecules, to combine smaller molecules into molecule chains (polymerization) and to combine different types of molecules into one compound. The various processes are both diverse and complicated.

In time, petrochemists developed the raw materials used for plastics from crude oil but they developed many other products as well. It takes quite a while to get plastics from crude oil and took quite a while historically to develop them as well. Now the future of plastics is being affected by another problem. The reserves of crude oil are on the decline. We have to make sure that we use what remains in a reasonable way. To simply offer these reserves up to the growing energy demands of the world would have dire consequences for the future.



Bubble-capped trays
At each level there are horizontally situated trays with a large number of vapor openings. They are covered with hoods, the so-called "bubble caps". Condensed compounds with a certain boiling point gather at each tray level.

Plate 3:2

Crude oil distillation. *Crude oil vapors are fed into a distillation column where the components condense according to their different boiling points. This is the way that crude oil is broken down (fractionated). The various distillates are then drained off each tray. Distillates with the lowest boiling temperature collect at the top of the tower and vice versa.*

The Age of Plastics

THE STONE AGE, THE BRONZE AGE AND THE IRON AGE are three eras that were named after the most typical raw material of the time. Using the same approach, we can say that today we live in, or are at least at the beginning of, the Plastics Age. Some of the experts in the field believe that we have made only very small inroads into the unimaginably huge world of possibilities offered by synthetically produced raw materials.

Goodyear's Discovery

This is a definition of plastics that is often used today: "Materials that 1) are produced synthetically or through conversion of natural products; 2) are composed completely, or for the most part, of macromolecular organic compounds; 3) are, or were at least at one time, capable of being formed or molded and 4) are usually processed into a hard final product".

If we use this definition as our starting point, we can set the beginning of the Plastics Age in the year 1839, the year in which Charles Goodyear discovered the vulcanization of rubber. Both the soft rubber developed by Goodyear and the hard rubber (ebonite) that has been produced since 1844 were plastics in that sense of the word. Many of the processes and machines that were developed

Plate 4:1

by the rubber industry were later put to use in plastics technology.

A New Kind of Bone and Horn

There are many scientists who want to make a clear distinction between rubber and plastics technologies. At the most, they are only willing to admit to a borderline relationship between the two. For those with this viewpoint, the birth of plastics technology took place in the year 1869. At that time, the American John Hyatt invented a substitute for ivory. This was celluloid, a material that was used at first primarily for producing billiard balls.

In the year 1897, the next type of plastic material was developed. Called "artificial horn" at the time, it was a casein plastic (a casein-formaldelhyde compound). At about the same time, the production of phonograph records made of shellac began. The introduction of Bakelite in 1909 represented another and a very decisive step forward in plastics technology. Patents for Bakelite were awarded quite quickly all around the world and led to the production of a large variety of products. It is a plastic that is still in demand today.

After that, the development continued at an even faster rate. At first, plastics were used as substitutes for rare, natural materials such as ivory, horn, tortoise shell or silk. Then from 1920 on, there was an active search for new products that possessed certain specified characteristics.

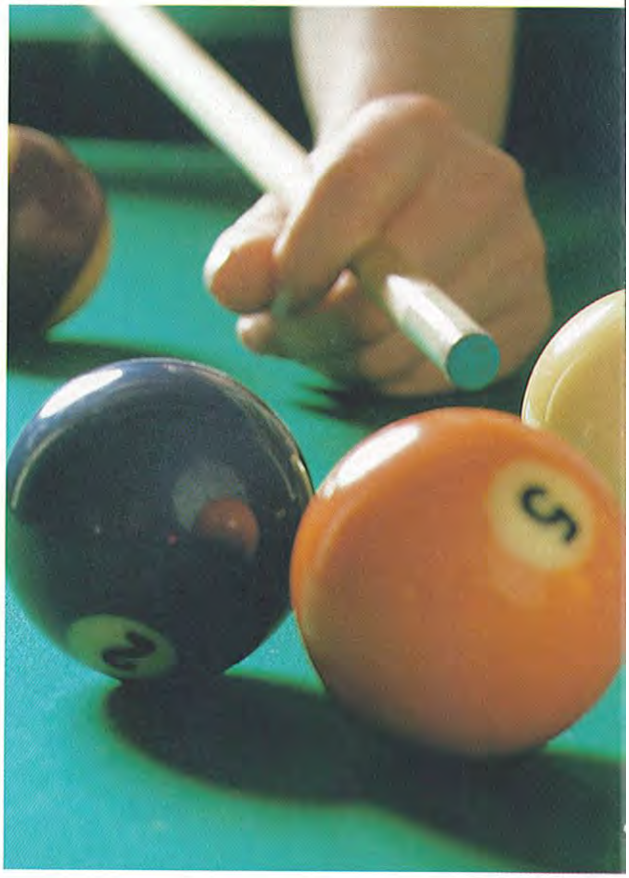
It is easier to get a better idea of the usefulness of plastic after one finds out that the volume of plastic production today is much greater than the volume of steel production.

Thermoplastics and Thermosetting Plastics

A few explanations are in order to make what follows easier to understand.

Plastics are usually divided into two main groups. One of them is known as "thermoplastics" and the other as "thermosetting plastics".

The thermoplastics are characterized by the fact that their molecule chains do not take up a completely static position in relationship to each other. That is, they become liquids when they are heated up to their melting



points and so are "plastic" or moldable. Examples of thermoplastics are polyamides, polyethylenes, polypropylenes, polystyrenes and polyvinyl chlorides.

In the case of the thermosetting plastics, the molecule chains are so incapable of changing their positions in relationship to each other that once they have been given the desired form, they cannot be reformed through heating. Among the thermosetting plastics are the amino plastics, epoxy resins, phenolic resins, unsaturated polyesters and others.

Plastics and Polymers

Up to now we have been using the word "plastic" in the nontechnical way in which it is popularly understood. In the strict sense, however, the word "polymer" instead of "plastic" should be used for substances consisting of long molecule chains (macromolecules) built up through polymerization, polycondensation or polyaddition from small hydrocarbon molecules (monomers).

The gas ethylene (also known as ethene) is, for example, the simplest monomer that can form giant molecules through polymerization.

Ethylene: $CH_2 = CH_2$
Polyethylene: $(-CH_2-CH_2)$

Figure 4:1

In this case, the polymerized molecule is easily one thousand times larger than its monomer.

In the strict sense of the terms, one should only use "plastic" and "moldable material" after the polymeric raw material has been combined with any of the various possible additives to make them technically ready for actual use. That is why the technical literature specializing in plastics often uses the term "polymer" instead of "plastic".

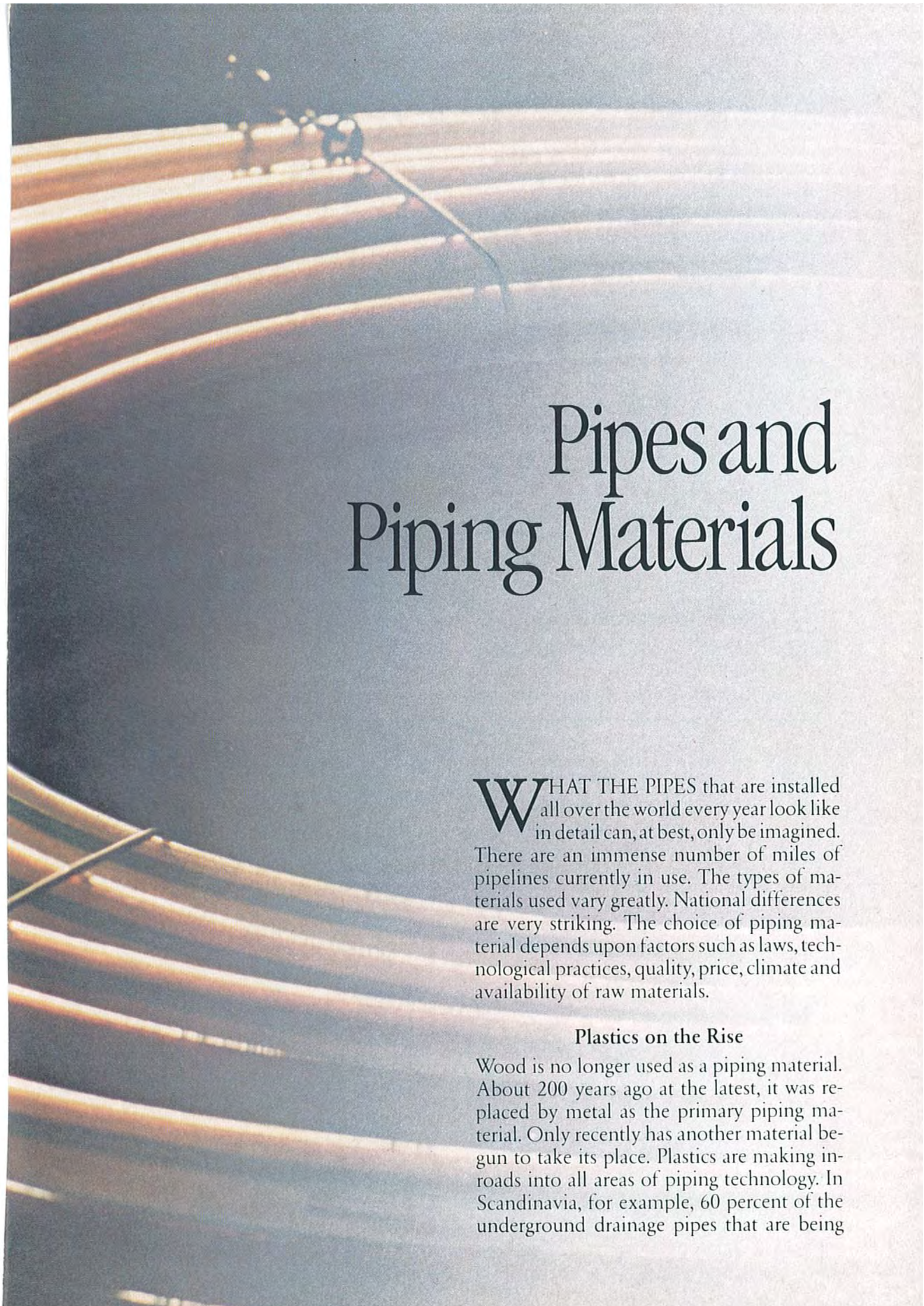
A MARKET THAT NEEDS TO BE UNDERSTOOD. The use of plastics for water systems has become quite acceptable throughout most of Europe. They have been used for many purposes from drainage to water supply to under-floor heating systems.

Nevertheless, there is still no generally accepted testimony concerning the suitability or unsuitability of plastic pipes for transporting water. The main cause for this might be the fact that plastic is a relatively new material insofar as its use for the purposes of climate control and water transport are concerned. There are still no internationally accepted testing methods. Some pipe manufacturers forego conducting any serious long-term tests. It sometimes even happens that test results are referred to in misleading ways in some of the advertising that is done.

We at Wirsbo intend this book to do what it can toward bringing to light some of the facts concerning plastic pipes. The people who are responsible for making decisions regarding the type of pipes to be used should have some sort of dependable resource at hand to guide them.

Plate 4:2

***At one time, billiard balls** were made of ivory, a very costly material. In 1869 an American, John Hyatt, invented a substitute material, celluloid.*



Pipes and Piping Materials

WHAT THE PIPES that are installed all over the world every year look like in detail can, at best, only be imagined. There are an immense number of miles of pipelines currently in use. The types of materials used vary greatly. National differences are very striking. The choice of piping material depends upon factors such as laws, technological practices, quality, price, climate and availability of raw materials.

Plastics on the Rise

Wood is no longer used as a piping material. About 200 years ago at the latest, it was replaced by metal as the primary piping material. Only recently has another material begun to take its place. Plastics are making inroads into all areas of piping technology. In Scandinavia, for example, 60 percent of the underground drainage pipes that are being installed are made of plastic. In this case, they are being used instead of concrete pipes. This development has taken place only over the last 10 to 15 years.

The advancement of plastics into our civilization can best be seen by looking at the worldwide production figures from the last 3 decades as illustrated in Table 5:1.

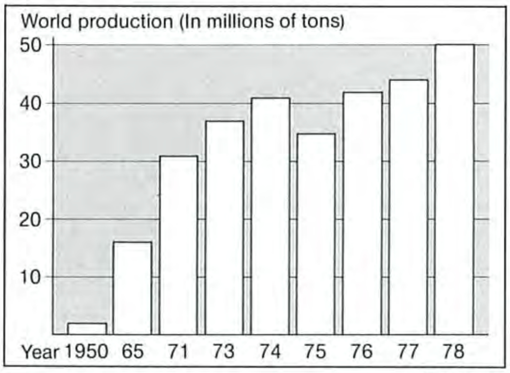


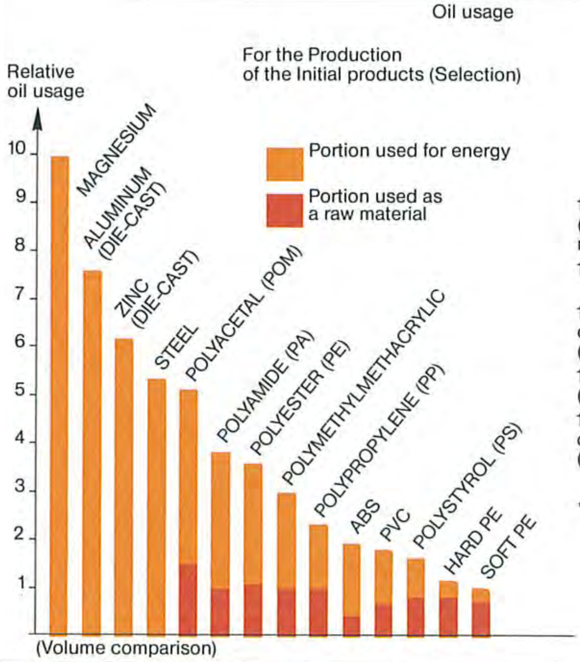
Table 5:1

Energy-efficient Production

New materials will prevail in the long run only if they really demonstrate definite advantages over other materials and not simply because they happen to be the newest fad. Especially in the case of pipelines, there is too much at stake once they have been installed to act on a whim.

Plastics have been gaining in the piping materials market mainly at the expense of concrete and metals. This tendency is noticeable worldwide even though the extent to which it is true varies from country to country. The main reasons for the advance are the technological and economical advantages of plastic tubing. Even a few failures cannot alter that fact. What distinguishes plastic pipes from the others is the relatively "low cost for completely installed systems" despite the fact that they last at least as long as systems made of other materials. With this in mind, it is now simply a matter of how quickly one recognized technology is able to replace another one.

That the production of plastic tubing can be accomplished with relatively little energy expense is no doubt another reason why these new materials are becoming more successful. The following outline should serve to illustrate this fact.



For the Production
of the Final Products (Selection)

1 million sq. yards (m^2) of packing material	POLYPROPYLENE* CELLULOSE	110 155
1 million sacks	POLYETHYLENE* PAPER	470 700
100,000 yards (m) of water pipeline (1 inch (25 mm))	POLYETHYLENE* COPPER STEEL (GALVANIZED)	57 66 232
1 million bottles (1 Quart (1 l)	PVC* GLASS	97 230
100,000 yards (m) of drainage pipes (4 inch (100 mm))	PVC* ASBESTOS CEMENT CLAY TILE IRON	360 400 500 1,970

* includes the oil used as a raw material

(Source: Perstorpshandboken, Maskin AB Karlebo, Sweden).

Amount of oil used in the production of various products.

Table 5:2

An Overview of World Piping Production

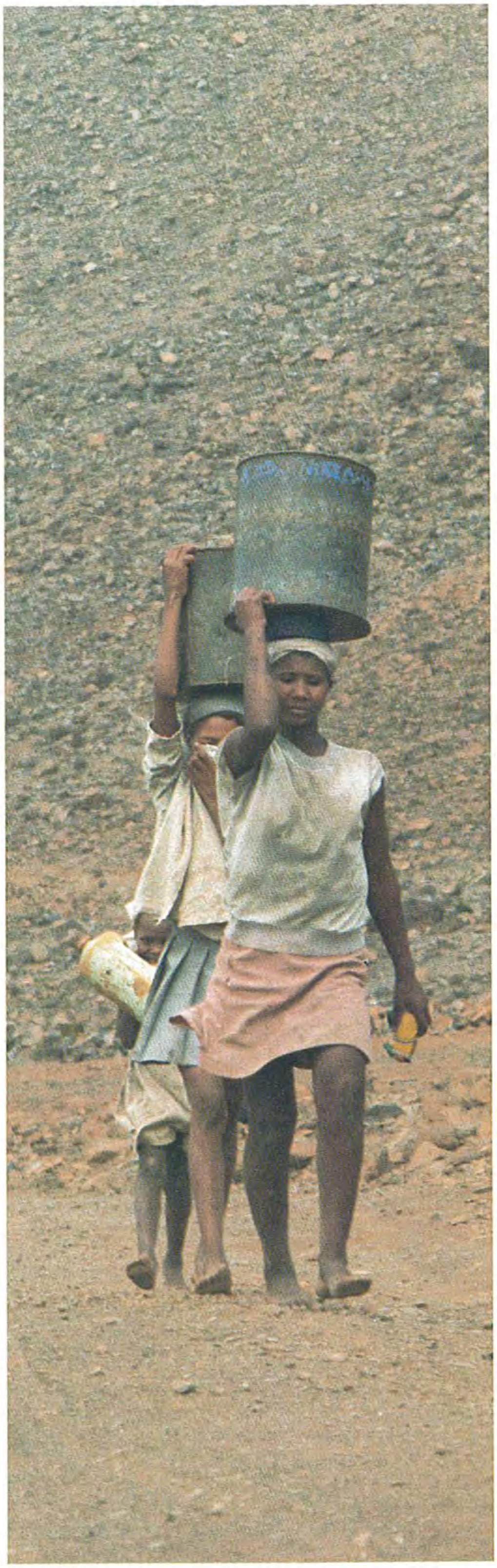
The technology of transporting water through pipelines will always remain up-to-date. What is constantly changing and undergoing new development are the materials used for the pipeline. Such changes are undertaken in an effort to achieve a longer life and easier installation. The most rapid progress, however, is made at times when there are very unusual circumstances to overcome such as high pressure and temperature or when active chemicals are being used.

It is interesting to note that in spite of all the achievements in piping technology, there are still relics of earlier times in use today. Clay pipes are by no means out of the picture. If we look at the world as a whole, the largest amount of all drinking water is still carried in pails and jugs.

The main materials and classes of materials used for pipelines are listed in Table 5:3.

Piping Materials	Uses
Metals	Sewage lines
Copper	in buildings
Steel	underground
Stainless steel	Drainage lines
Cast iron	Hydraulic supply pipes
Minerals	Heating systems,
Clay	in buildings
Stoneware	Drinking and hot water lines
Concrete	
Asbestos cement	Central heating systems
Plastics	Industrial pipelines
PVC	Pipelines (Gas and oil)
PE	
PEX	
PP	
PB	
ABS	
Wood	

Table 5:3



***Buckets and pails** carried on their heads – this is how water is still transported in many parts of the world today.*

Plate 5:1

The West German piping market provides a good example for a comparison of the amounts and the values of the various types of pipes. That breakdown is shown in Table 5:4.

	1980	
Piping material	Amount (t)	Value (1000 DM)
Stoneware	311.442	125.545.–
Reinforced concrete (including smokestacks)	1.244.000	191.996.–
Precision steel pipes, total (seamless and welded)	885.000	1.552.492.–
Copper (nonalloyed)	74.383	351.711.–
Copper (alloyed)	90.228	551.573.–
GF-reinforced PE and epoxy resins	833	14.653.–
PE and other polyolefins	53.156	238.131.–
PVC	229.002	714.171.–
Other plastic materials	9.692	103.414.–

Table 5:4

Usage	PVC-C	PB	PEX	PP	Total
1980					
Surface heating (except floors)	0	30	150	0	180
Floor heating	0	2.085	3.300	5.915	11.300
Radiator heating	115	150	365	50	680
Water supply/drainage	215	150	100	15	480
Other	110	50	320	70	550
Total	440	2.465	4.235	6.050	13.190
1985					
Surface heating (except floors)	0	250	1.020	25	1.295
Floor heating	0	5.550	8.250	10.620	24.420
Radiator heating	310	1.315	1.575	200	3.400
Water supply/drainage	345	1.400	1.225	0	2.970
Other	210	300	1.130	115	1.775
Total	865	8.815	13.200	10.960	33.840
Country					
1980					
Belgium	40	0	25	125	195
France	175	10	790	460	1.435
West Germany	20	1.915	2.265	5.070	9.270
Netherlands	0	20	0	80	100
Italy	20	20	200	20	260
Scandinavia	100	370	720	220	1.410
Switzerland	0	20	105	50	175
Great Britain	85	110	130	25	350
Total	440	2.465	4.235	6.050	13.190
1985					
Belgium	40	25	50	425	540
France	50	950	2.750	1.400	5.150
West Germany	100	5.000	4.600	7.720	17.420
Netherland	25	200	150	125	500
Italy	50	170	1.000	300	1.520
Scandinavia	100	1.250	3.400	570	5.320
Switzerland	0	70	300	200	570
Great Britain	500	1.150	950	220	2.820
Total	865	8.815	13.200	10.960	33.840

Source: Consultex, Switzerland.

Table 5:5

***Usage** (in tons) of plastic pipes for hot water in Western Europe. Some of the advantages that come with using plastic piping materials are a longer life in the case of certain applications, a simplified installation method and a smaller amount of energy used for their manufacture.*

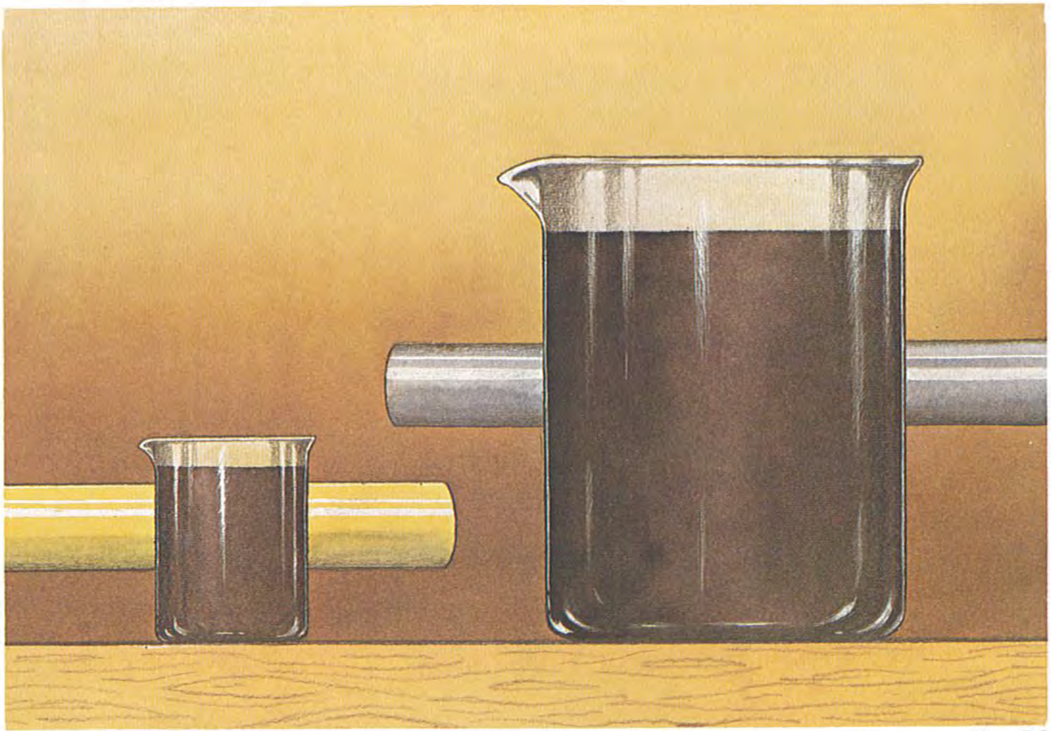
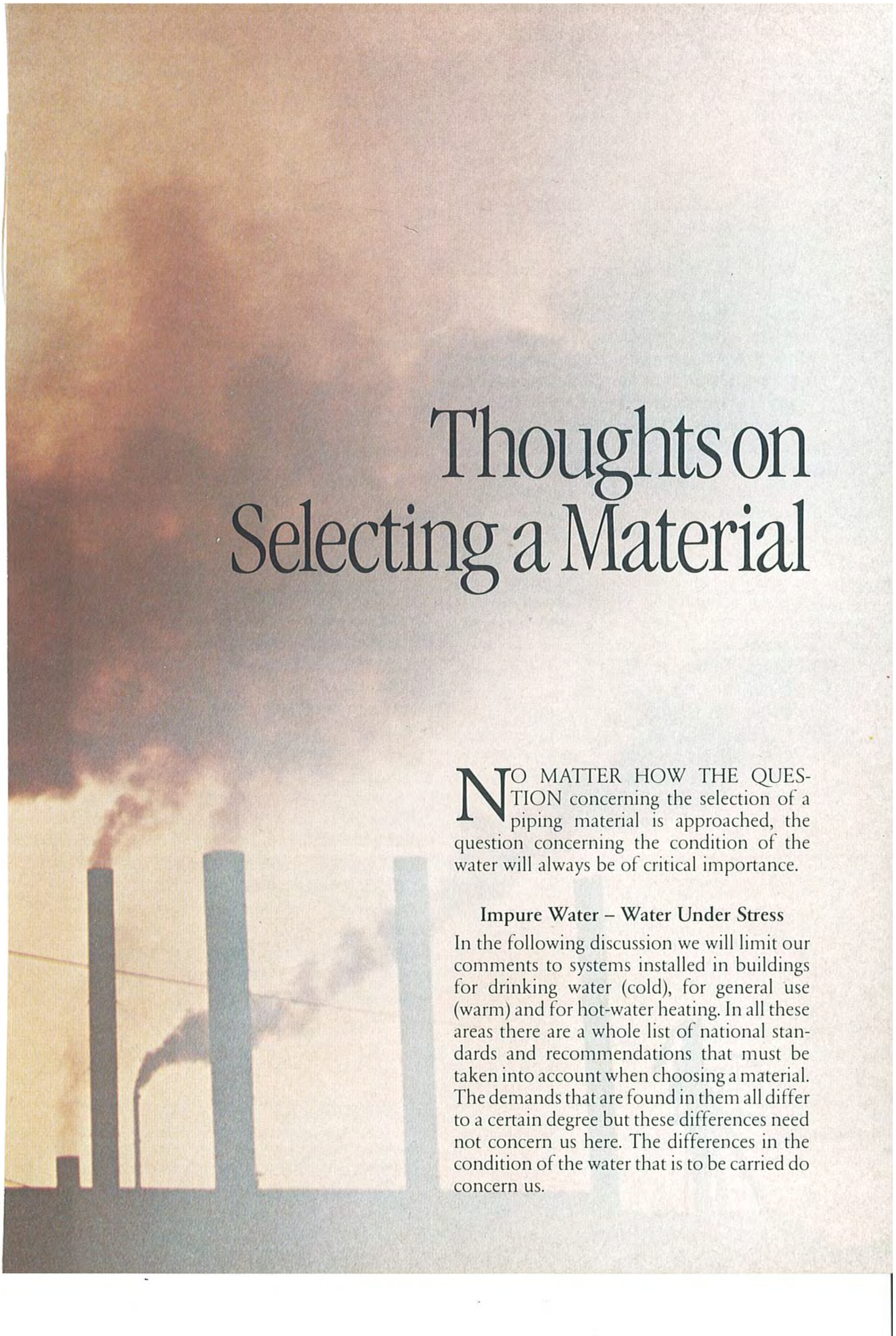


Plate 5:2

***A comparison** of the amount of energy (oil) used for manufacturing pipes made of PVC (left) and pipes made of cast iron (right).*

The sales of plastic pipes have continued to enjoy an immense amount of growth right up to the present day. The statistics shown in Table 5:5 are broken down according to type of material, kind of application and country. In summary, it can be said that plastic is without doubt the piping material of the future. That is why it would be absolutely desirable that everyone who has anything to do with this material gain a thorough and specialized knowledge of it. Such knowledge should include information concerning both its outstanding possibilities and its limits. The people who should gain this knowledge include manufacturers, the responsible officials, architects, consultants, instructors, industrial workers and craftsmen.



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.*

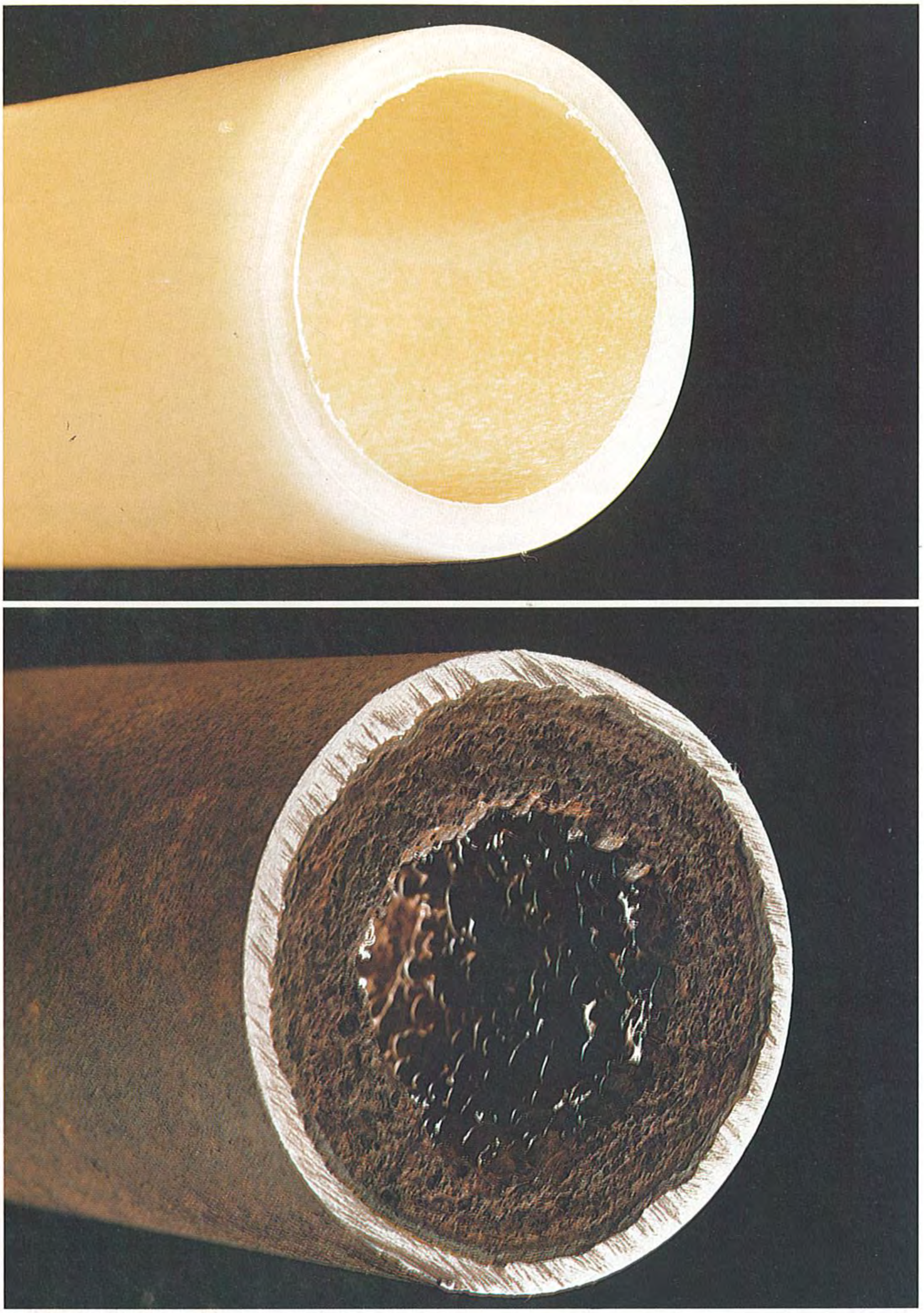


Plate 6:3

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.*

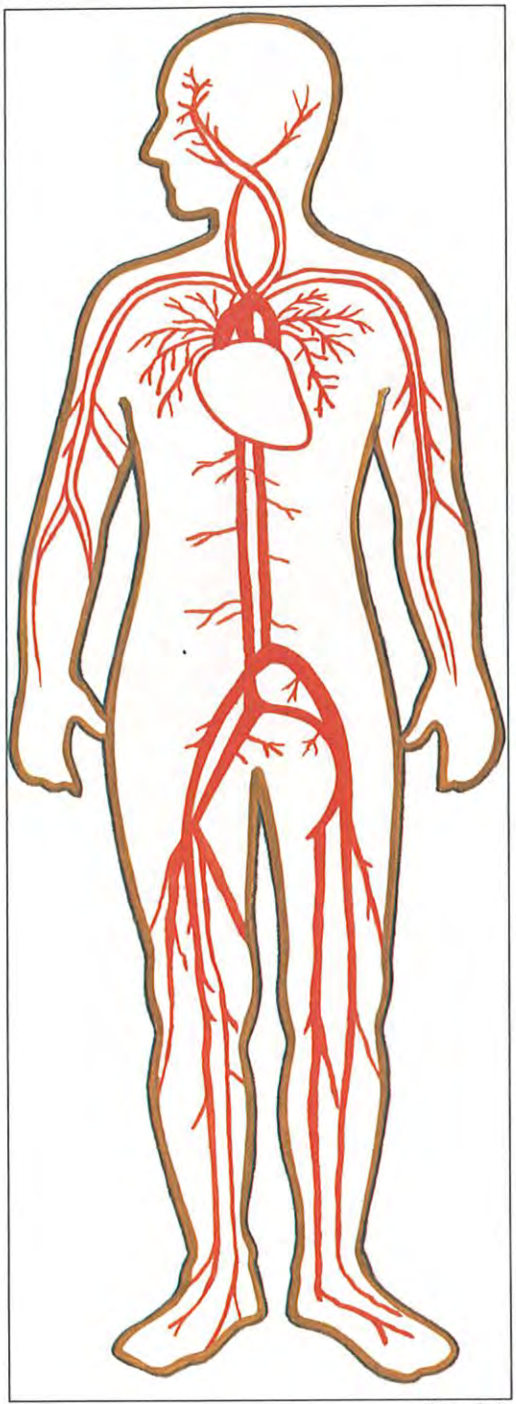


Plate 6:4

If the blood vessels and capillarries 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-

Plate 6:5

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

Plate 6:7

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 $\varepsilon = 10\%$)	23,061 +/−435	30,168 +/−725	26,107 +/−1015	31,038 +/−435
(N/mm^2 where $\varepsilon = 10\%$)	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)

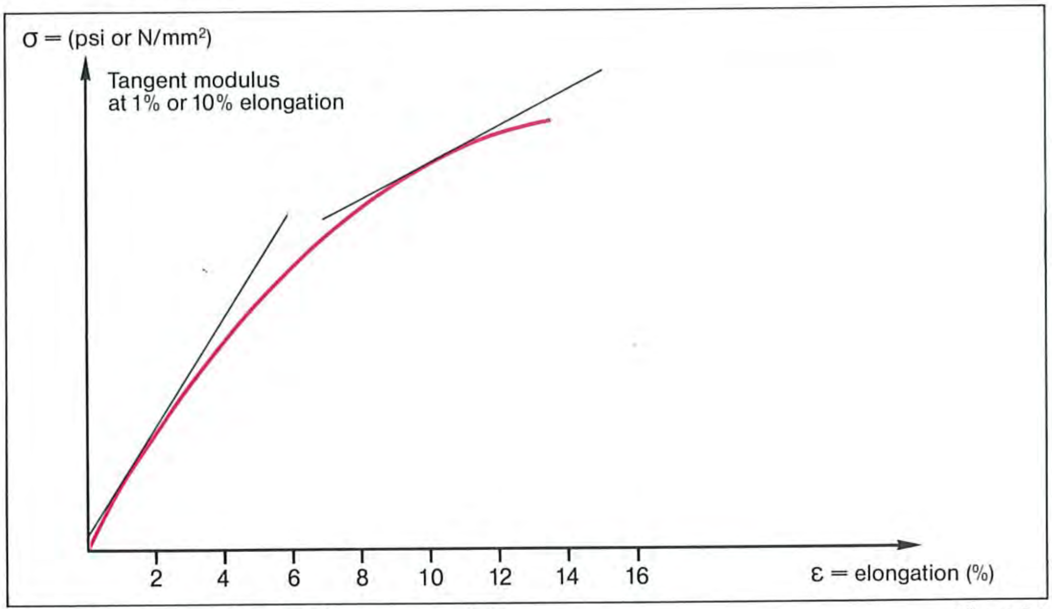
Flexural stiffness (absolute and relative) of various tubing materials.

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	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)

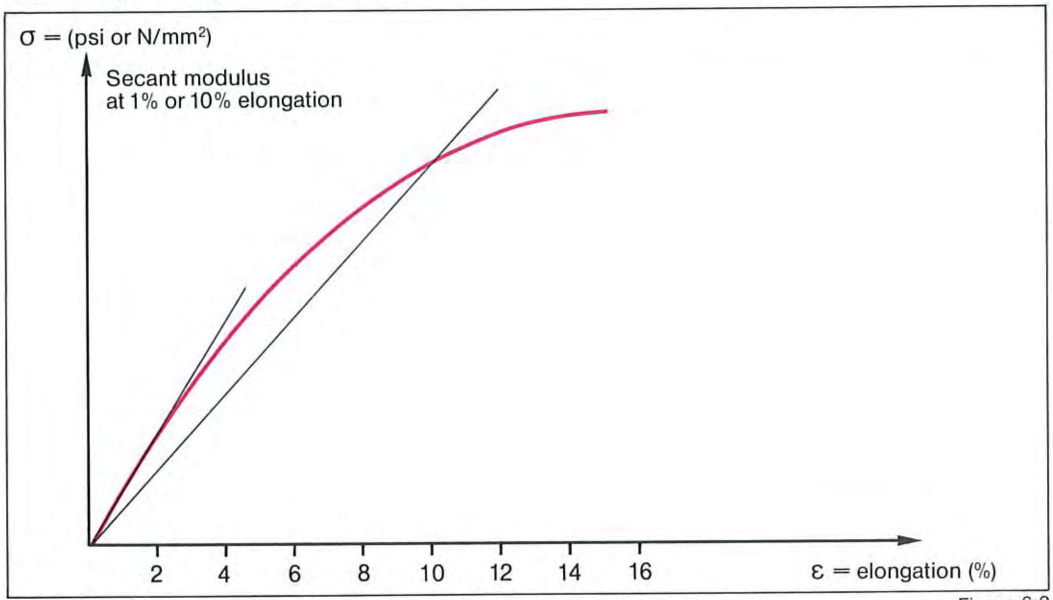
Table 6:2

Elasticity modulus *E (psi or, in parentheses, N/mm^2) of cross-linked polyethylene (Wirsbo-PEX tubing, cf. Chapter 12, page 109).*



Stress-elongation *graph using the tangent modulus.*

Figure 6:1



Stress-elongation *graph using the secant modulus.*

Figure 6:2

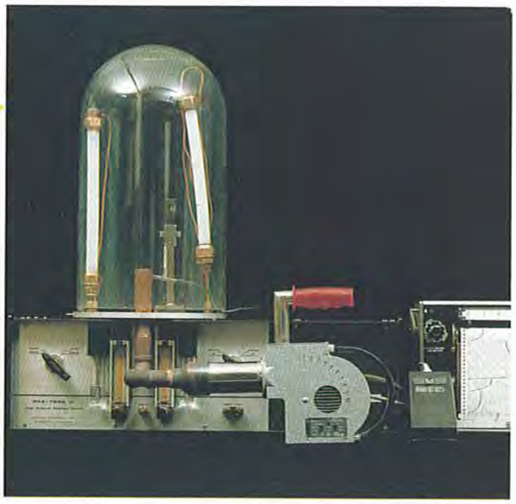


Plate 6:8

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.

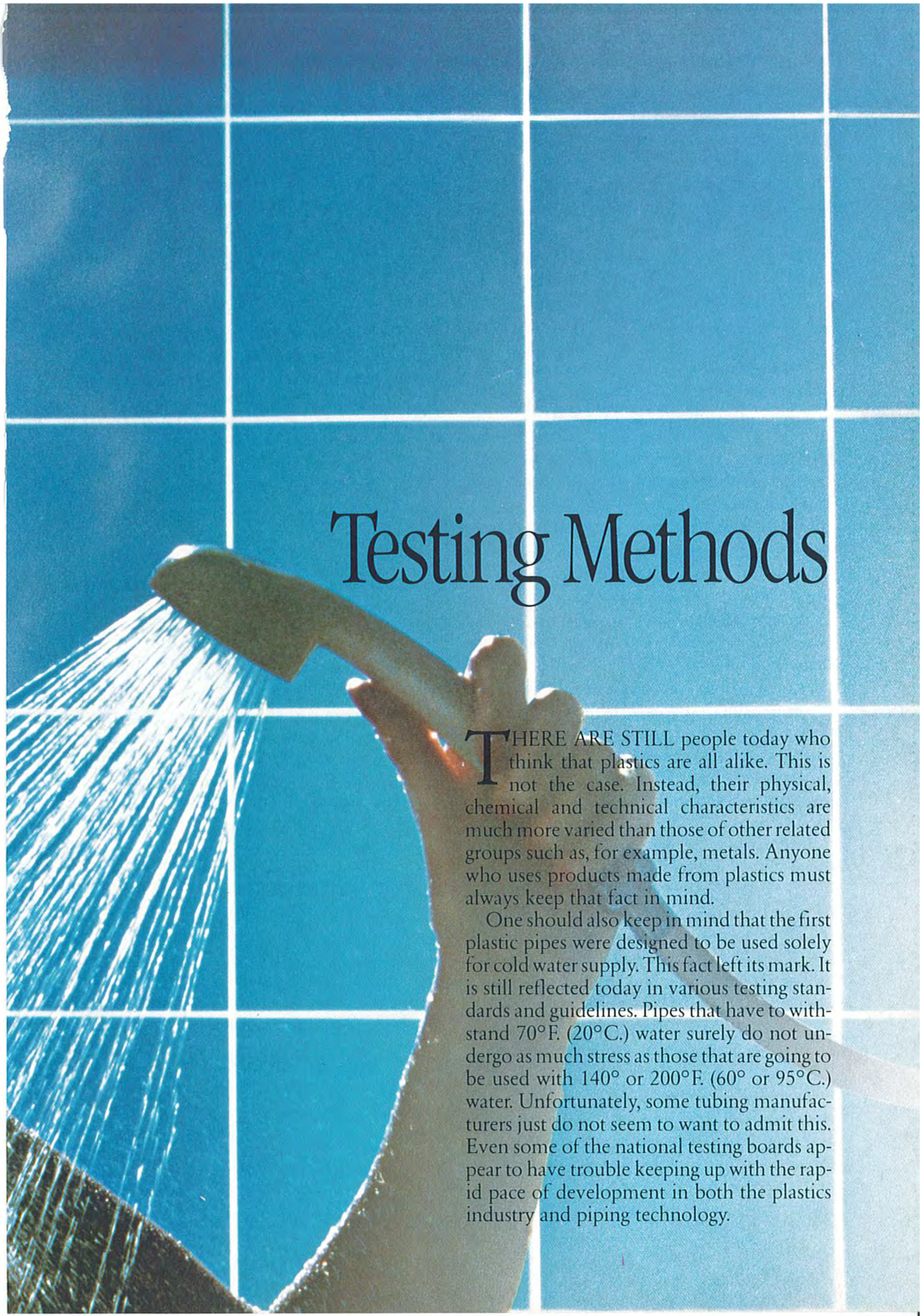
Plastic Tubing Impermeable by Oxygen

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.



Testing Methods

THERE ARE STILL people today who think that plastics are all alike. This is not the case. Instead, their physical, chemical and technical characteristics are much more varied than those of other related groups such as, for example, metals. Anyone who uses products made from plastics must always keep that fact in mind.

One should also keep in mind that the first plastic pipes were designed to be used solely for cold water supply. This fact left its mark. It is still reflected today in various testing standards and guidelines. Pipes that have to withstand 70°F. (20°C.) water surely do not undergo as much stress as those that are going to be used with 140° or 200°F. (60° or 95°C.) water. Unfortunately, some tubing manufacturers just do not seem to want to admit this. Even some of the national testing boards appear to have trouble keeping up with the rapid pace of development in both the plastics industry and piping technology.

Questionable Methods

The use of plastic tubing for cold water pipes is covered almost everywhere today by standards and regulations. This is true in the area of design and manufacture as well as in the area of testing and actual usage in the field. At the present time, all manufacturers and testing laboratories recognize the method of long-term testing at low water temperatures (68° to 140° F. or 20° to 60° C.) and the determination of specific safety factors for each of the various piping materials.

Here are a few examples of some safety factors: polyethylene (PE), a rather rugged and well-tested material: 1.3; polypropylene (PP): 2.0; polyvinyl chloride (PVC): 2.0 to 2.5; polybutylene (PB): 1.8 to 2.0.

Attempts are sometimes made to apply conditions that are present when testing at low temperatures to the situation that is found at 200° F. (95° C.). This is done under the assumption that it is somehow supposed to provide a basis for reliable conclusions. Such attempts are not only a matter of questionable methods. They are also technically indefensible. When put under the stress caused by hot water, there are a multitude of new factors that can have a negative impact upon the durability of plastic pipes. That is why it is necessary to plan long-term tests not only with each of the parameters in mind that can affect the life of a product but also with various combinations of these same parameters.

It would also be technically indefensible to generalize the results of tests done on one kind of tubing and to apply them to all tubing of a similar type. Just in the case of PEX tubing alone, it is possible to distinguish five different manufacturing methods. This fact makes it somewhat less than honest for a manufacturer to put his tubing on the market accompanied by the technical data compiled from tests conducted on another manufacturer's product.

Among the worst examples of this sort of thing are references to test results that are achieved by subjecting samples to temperatures in the range of 275° to 340° F. (135° to 160° C.). The time it takes for the samples to melt or to begin to discolor is then presented as an indication of how long the tubing would last in actual field use at temperatures from 180° to 200° F. (80° to 95° C.). Using this same line of reasoning, steel pipes could be considered better suited for hot water than copper pipes because steel pipes can withstand higher temperatures without melting.

DEMANDS PLACED UPON THE MANUFACTURER. All these facts make it quite clear that the customer has to rely heavily upon the manufacturer and dealer for any guarantee or proof of a product's quality. This is especially true when the product we are dealing with is tubing that is to be used for hot water supply. A break in a cold water pipe that has been laid in the ground is not a huge catastrophe. But the consequences of a leak in a hot water pipe on the upper floors of an apartment building can be quite drastic.

Every manufacturing company that is concerned about its reputation should document the results of tests on its own products in each of the following five areas.

1.DIMENSIONS AND LABELS

Tubing should maintain the specified measurements. The labels serve the purpose of easy identification. They should contain the name of the manufacturer, the size of the tubing, the manufacturing date, the machine number and the machine operator. With this information on the tubing, it will be easier to investigate the causes of any possible trouble that might occur later.

2. LONG-TERM STRENGTH

Long-term tests should, by all means, be conducted by a qualified, independent testing laboratory. If in addition to such testing, the manufacturer also wishes to conduct tests of his own, all the more power to him.

3. HEALTH CLEARANCE

Plastic tubing for use in drinking-water supply lines must provide special official verification of its suitability for that purpose.

4. QUALITY CONTROL

By guaranteeing and monitoring the quality of its own production, a manufacturing company ensures the customer that the quality documented by the various tests is actually maintained in the product. This quality control is especially trustworthy when the manufacturer actually employs an independent testing laboratory to conduct the tests.

5. FIELD TESTING

Manufacturers should also be obligated to prove that the tubing they produce will perform as expected in actual use by conducting tests under field conditions.

In the following discussion we will go into more detail concerning some of the various specifications.

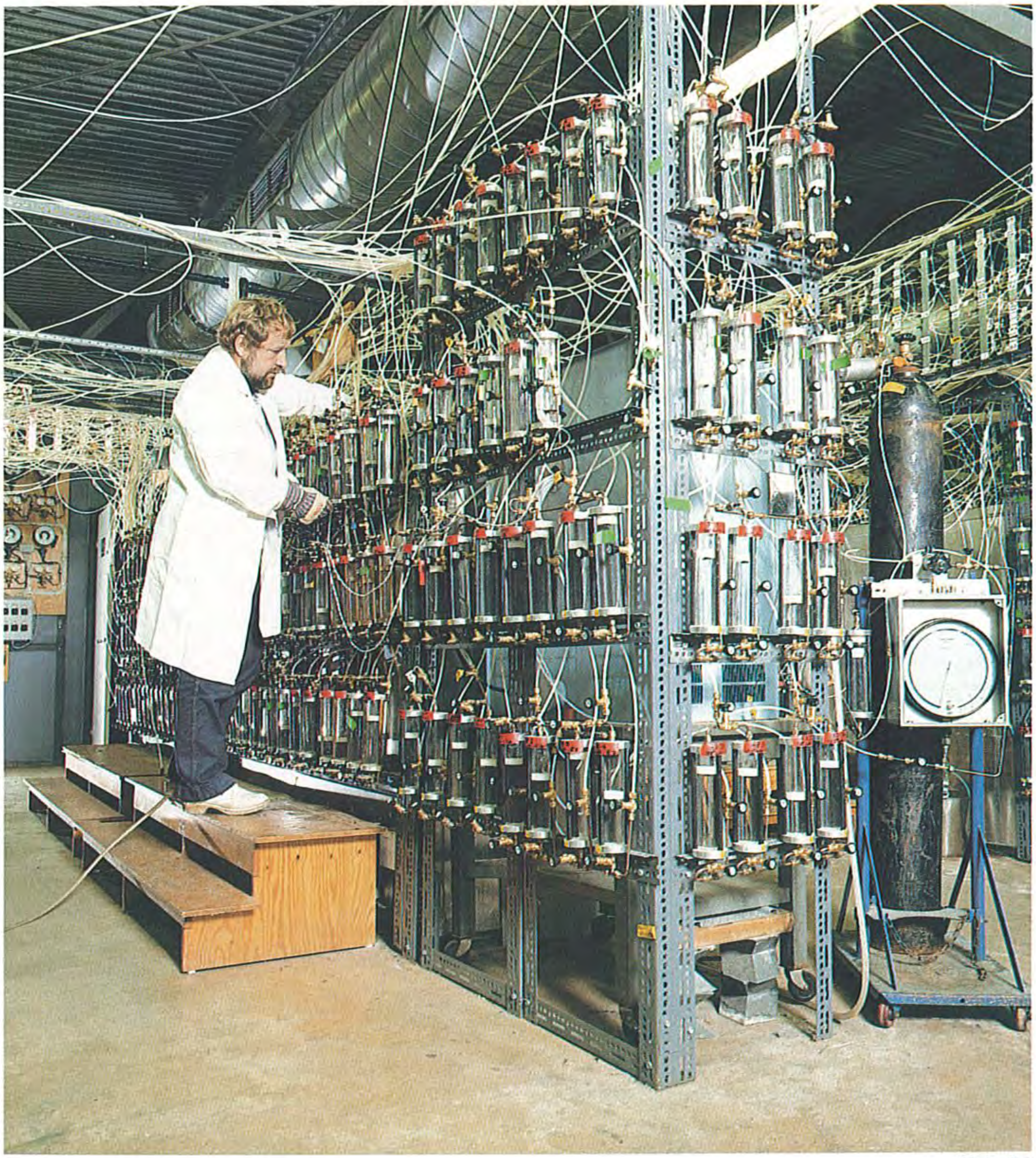


Plate 7:1

Testing equipment *used for internal-pressure, time-to-failure testing of plastic pipes. This is the installation operated by the company, Studsvik Energieteknik AB, an internationally recognized testing facility. During the tests, stress and pressure are applied continuously until the sample breaks.*

LONG-TERM TESTING

"There is still hope." These words are often used to conceal uncertainty concerning the outcome of an event. But when laying plastic pipes, you should not have to settle for anything less than certainty. To put it bluntly, you have every right to ask how long they will last.

For the most part, the answer to this question can be gained from time-to-failure tests. This brings us to the next question. That is, just how are such tests conducted and what kind of data do they produce?

Heat and Pressure

First, the tubing that is to be tested is measured accurately. Then the piece of tubing is sealed at one end, filled with water and attached to a pressure source at the other end. After being prepared in this way, the sample is placed into a warm water bath or into a warm oven.

The Swedish testing laboratory, Studsvik Energiteknik AB, an internationally recognized institute for testing plastic pipes, provides a facility with the testing capacity shown in Table 7:1.

Testing stations: 650
Pipe Sizes: up to 4 inches (118 mm in diameter)
Temperatures: from 75° to 250°F., +/– 1°F.
Pressure: 0 to 450 psi (+/– .2 psi)
(0 to 3 MPa, +/– 10 MPa)
50 pressure levels
Testing medium: water, air, agents that induce stress cracks

Table 7:1

During the test, *stress and pressure are applied continuously until the sample breaks.*

Relationship Between Time and Stress

In order to create a time-to-failure graph that is highly reliable, it is necessary to log a large number of ruptures over a long period of time. To be specific, at least 15 ruptures have to be logged at every testing temperature within a standard interval.

Every rupture point represents a specific relationship between the load time or the length of time the stress is applied and the amount of stress applied. The stress on the tubing wall can be calculated from the simplified formula shown below:

$$\sigma_v = \frac{p \cdot (d_0 - s)}{2\,s}$$

Where:
p = internal testing pressure
d_0 = outside diameter
s = wall thickness

(See page 106, Formula 10.2)

Table 7:2

From the calculated stress values, we arrive at the so-called time-to-failure graph. In general, it looks like the diagrams below (see Figures 7:1 through 7:2:3).

Position of Curve Is Not Certain

When investigating the long-term strength of tubing, the ruptures are spread quite irregularly throughout the coordinate system. This presents a problem. What kind of curve can be used to connect these points? The answer to that question is almost a matter of conscience.

This problem can be solved by using the rules of mathematics or graphs. In principle, these rules are indisputable. Still, we have to pay special attention to how these rules are applied. In this case, that involves making a decision as to where the curve is to be positioned in the coordinate system.

It is not obvious at first where to place the curve. Just how is it to be interpreted as evi-

Figure 7:2:1

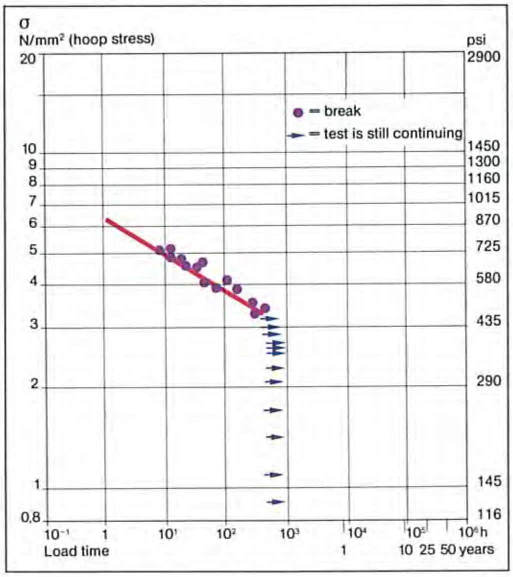
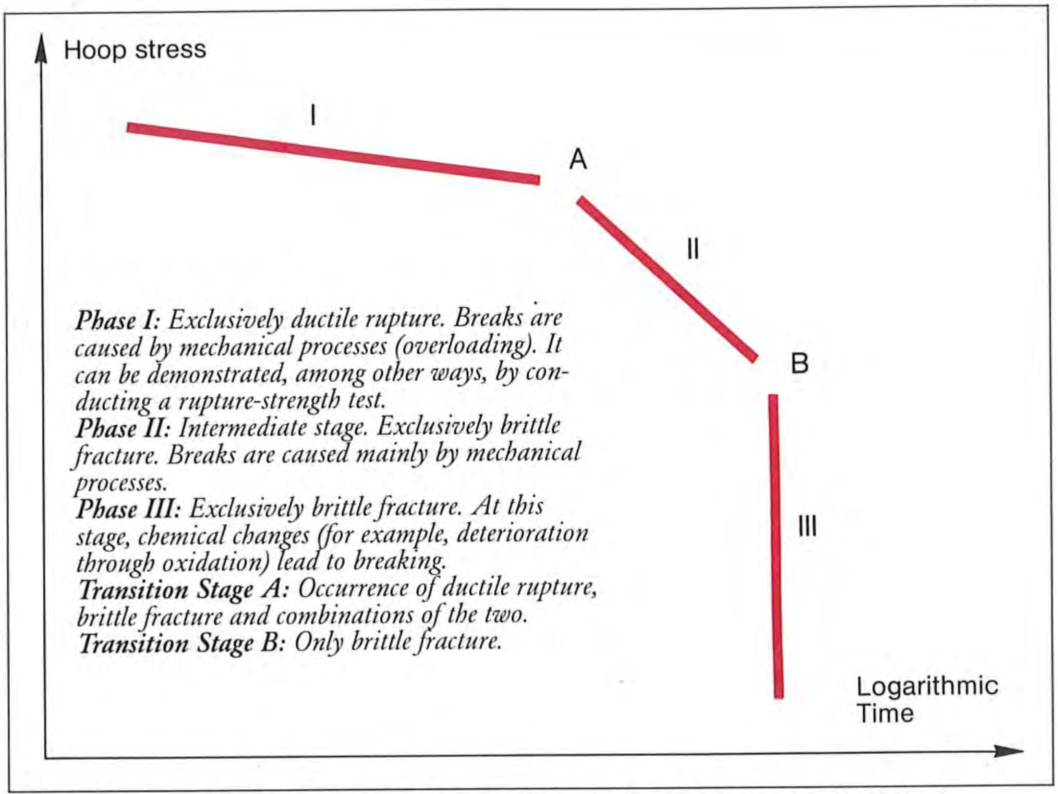


Figure 7:1



Phase I: *Exclusively ductile rupture. Breaks are caused by mechanical processes (overloading). It can be demonstrated, among other ways, by conducting a rupture-strength test.*
Phase II: *Intermediate stage. Exclusively brittle fracture. Breaks are caused mainly by mechanical processes.*
Phase III: *Exclusively brittle fracture. At this stage, chemical changes (for example, deterioration through oxidation) lead to breaking.*
Transition Stage A: *Occurrence of ductile rupture, brittle fracture and combinations of the two.*
Transition Stage B: *Only brittle fracture.*

Time-to-failure graphs based on internal-pressure tests on plastic tubing (generalized view).

Figure 7:2:1. *Test results after about 500 hours. In many cases, the samples have already ruptured (dots). In other cases, the test is still continuing (arrows).*

Figure 7:2:2. *Test results after 8,700 hours (approx. 1 year). The line that had been straight up to now begins to slope downwards.*

Figure 7:2:3. *Test results after 5 years. All the samples have now failed. The curve drops off quite quickly towards the end.*

Figure 7:2:2

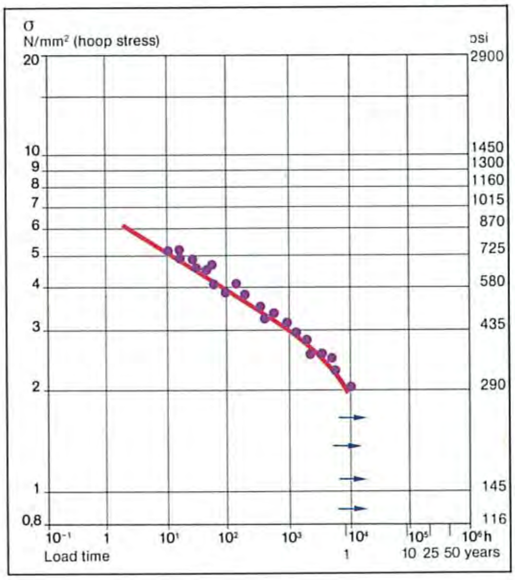
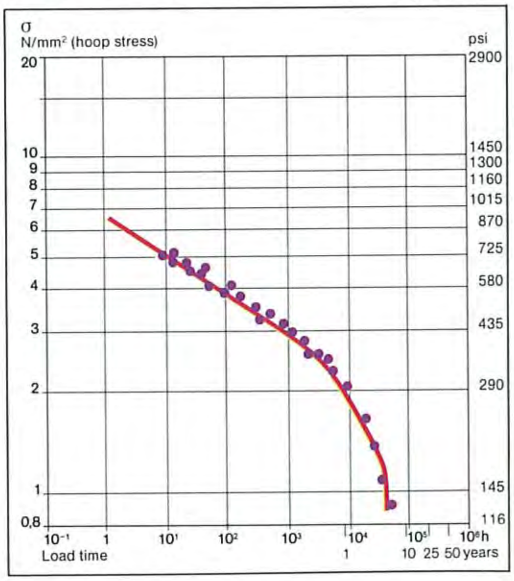


Figure 7:2:3



dence? Are we dealing with average values or does the curve represent minimum values? The probability that the actual tubing will perform up to, if not better than, the standards indicated by the test results is greater when the manufacturer provides a graph showing the minimum values.

Wirsbo always bases its time-to-failure graphs on minimum values. As a result, the statistical reliability lies at about 99 percent.

Even more important than all this are the questions as to whether the manufacturer monitors the performance of the pipes after the testing period is over and how this continued monitoring is done.

How Long Is "Long-term"?

Practically all pipe manufacturers can come up with a time-to-failure graph for their plastic tubing. That is the least that should be demanded of them. On the other hand, it is not a good idea to let oneself be influenced by such graphs until they have been checked out.

Unfortunately, the fact is that some manufacturers are more interested in making a quick profit than in spending money for serious and time-consuming tests.

A question that should be asked is to what degree the curve on the graph was built from actual testing and to what degree it was formed by extrapolation (theoretical projection). In the case of some important plastic materials, long-term-strength tests have lasted up to 100,000 hours (longer than ten years). In the USA, tests usually run for 10,000 (10^4) hours at a specific testing temperature. On the basis of that length of time, extrapolation to 10 years is allowed.

For a long period of time, 10,000 hours was considered the minimum testing time. In the meantime, there have been more and more experts who are of the opinion that at least 30,000 hours (about 3.5 years) should be set aside for such testing. The ISO (International Standards Organization) is even talking about 40,000 hours.

The Determining Factor: Time

All time-to-failure graphs attempt to prove that the tubing being tested will have a useful life of at least 50 years. This is a piece of wishful thinking that is based upon some very pragmatic considerations. The houses that we build are supposed to last 80, 90 or perhaps 100 years. For this reason, it makes sense that we would also want the piping systems that complement our houses to last just as long.

We still have not arrived at an adequate explanation of cracking caused by brittleness. Some investigations have traced its causes back to oxidation from the oxygen normally present in the atmosphere. We at Wirsbo do not share this viewpoint. Time-to-failure tests conducted at 180°F. (80°C.) on normal (non-cross-linked) polyethylene produced enough tubing failures already after 100 hours to cause a downward slope (a so-called knee) in the strength curve. That is too short a time for a chemical breakdown to have taken place. In our opinion (as stated in Figure 7:1), the brittle

Ductile rupture Plate 7:2

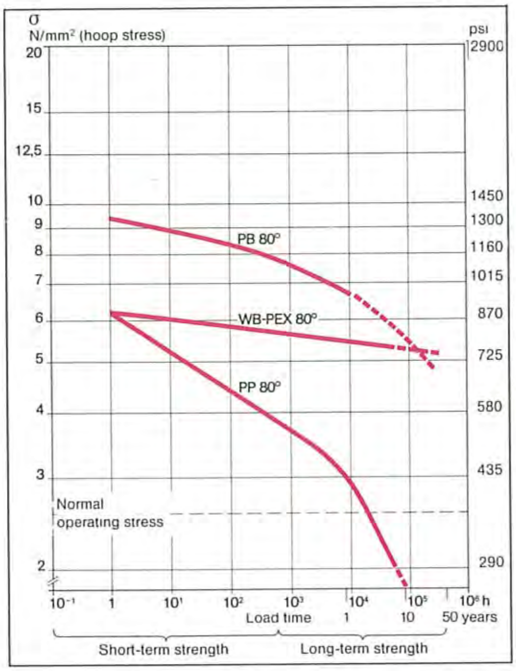
Brittle fracture Plate 7:3

fracture observed in Phase II is caused mainly by mechanical processes. Brittle fracture of the tubing in Phase III, on the other hand, is caused exclusively by oxidation at high temperatures (thermal breakdown).

When the normal operating temperature is expected to be over 100° F. (40° C.), it is absolutely essential that the time-to-failure graphs of the all the types of tubing that are available for use at those temperatures be checked. To what degree does the graph correspond to actual fact? Is the far end of the curve based upon an extrapolation? And if it is, does the curve take into account the downward slope that is normally there when the rupture points are plotted using actual test data? The observation made earlier bears repeating, "The longer the testing time, the more accurate the evidence given by the graph."

It is also very enlightening to compare the downward slope of the time-to-failure curve for the various types of plastic tubing materials. The slope is quite different for each different type. In the case of PVC and PP, the curve shows a sharp downward trend. PEX (Wirsbo-PEX) by contrast, displays a much more gradual downward slope. This means that its strength is affected less by the passage of time. One consequence of this fact is that although the strength exhibited by PP tubing during short-term testing is significantly higher, the opposite is true in the case of long-term testing. It is also true that while there is a wide gap between the strength of PP tubing at low and high temperatures, the difference for Wirsbo-PEX tubing is comparatively small.

Figure 7:3



Time-to-failure graph for straight, scratch-free tubing tested with water.

Look at the long-term strength comparison in Figure 7:3. The dotted lines in the illustration represent extrapolated data. Note that the first downward sloping trend that normally makes up Phase II is missing from the characteristic curve for PEX (Wirsbo-PEX) tubing. After a nine-year testing period at 203° F. (95° C.), we have reached the conclusion that there is no difference between Phase I and II for Wirsbo-PEX tubing. Only when the temperature is raised to very high levels does thermal deterioration begin (Phase III).

Accelerated Testing

One method of producing similar results faster than through long-term testing is by conducting tests at high temperatures. The interpretation of these results should be undertaken with a maximum of care.

Even a temperature that is only 15° to 20° F. (8° to 10° C.) above normal can cause some basic molecular changes to take place. The result is that we have an almost completely different material to test. Even the performance of the stabilizers that prevent deterioration can change radically at higher temperatures.

If accelerated testing is to lead to reliable conclusions, a long list of factors must be taken into account. These factors must be considered both in the context of normal and above- normal temperatures. Wirsbo has conducted exhaustive tests to arrive at just these relationships and comparisions.

Straight Tubing Does Not Provide All the Answers

What we have heard up to now concerning long-term testing is valid for straight tubing only. While the results of such tests are quite valuable, they do not provide us with everything we have to know to draw conclusions concerning how long the tubing might last in the field. Installation and use put a great amount of stress upon it. It is bent. It gets scratched. Agents that cause stress cracks and other chemicals that may be present in water affect the tubing. These are only a few of the many examples we could mention.

Bent Pipes

The elasticity coefficient (E-modulus) of plastic tubing is, among other things, a measurement of its flexibility. It is generally known that, on the one hand, plastic tubing is more or less easy to bend but that, on the other, it is quite sensitive to the internal stress that is created by being bent. The stiffer the material that is used in the tubing, the less suitable the tubing is for bending.

For this reason, it is appropriate to request the manufacturer to provide the results of long-term (at least 3000 hours), internal-pressure, time-to-failure tests. These tests should be performed at the highest operating temperature on tubing with bends that are equivalent to the smallest bends allowed for the tubing being tested.

FORMATION OF STRESS CRACKS. We use the term "stress cracking" to refer to the brittle fracture of materials that normally tend toward creep rupture. Stress cracks can be caused by mechanical forces (either outside or inherent) when there is some sort of other agressive influence present even though the stress might be below that which would normally cause cracking.

A classical example of stress-crack behavior is a polycarbon rod that remains normal while it is being stretched until it comes into contact with a drop of methyl chloride. At the exact moment of contact, it suddenly disintegrates into bits.

Similarly, stress-crack formation in tubing is often the result of a combination of internal stress and the presence of impurities in the water. The presence of internal stress can be detected by immersing a piece of tubing into a methyl chloride bath. Another method is to cut up a piece of tubing and heat it up. Any change of shape that then takes place is an indication of the presence of internal stress.

Is the knowledge of a tubing's stress-cracking behavior important? It could be a matter of life and death! A pipe that is under internal stress is a sensitive pipe. This situation is then made worse by the stress that it has to undergo when it is being installed, such as being bent. The test results that are obtained during time-to-failure testing of straight tubing is no longer valid under these circumstances.

It is just not acceptable to depend on guesses when dealing with properties that are decisive for a pipe's longevity, such as its stress-crack behavior. That is why it is necessary to require two different types of information from the manufacturer when tubing is going to be bent. The first type is data on time-to-failure tests at the maximum operating temperatures. The second is data from testing conducted with agents that tend to form stress cracks (detergents).

Wirsbo has had both of these types of tests done for them on their PEX type tubing by an official testing institute. The testing conditions included a temperature of 203°F. (95°C.), and were conducted in pure water

Plate 7:4

Plate 7:5

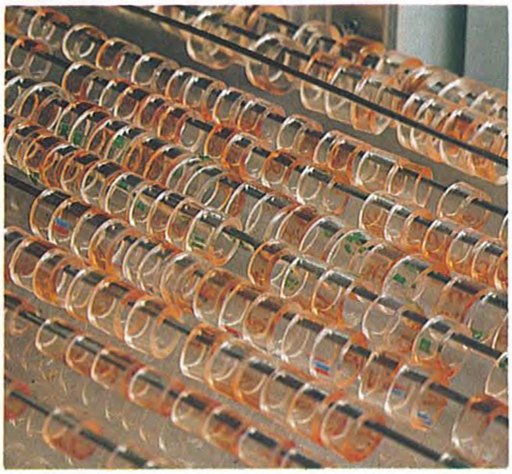
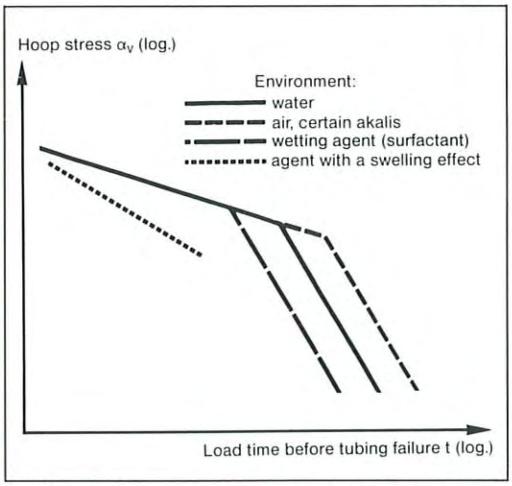


Plate 7:6

Figure 7:4



Influence of certain environments *on the time-to-failure behavior of polyolefins at normal temperatures.*

Plate 7:4. *Pipes and pipe connectors during the temperature-cycle test using the specifications of the DVGW (The German Gas and Water Specialists Association)*

Plate 7:5. *Dr. P. Stagge of the MPA Darmstadt seals a joint for the official pipe connector test.*

Plate 7:6. *Checking for thermostability (resistance to aging) during production.*

and in a 2 percent solution of a stress-crack inducing agent. After a two and one-half year study, they were not able to observe any stress-crack formation nor notice any sharp downward slope in the time-to-failure curve.

As a rule, the liquids carried by pipes have a different effect on the long-term strength of the tubing material. For a generalized illustration of this, see the diagram in Figure 7:4.

Scratches Are Unavoidable

It is just not possible to avoid scratches when installing pipes. This fact should not be ignored. Instead, it should be taken into account when tests are conducted and data should be gathered concerning how scratches affect the life span of the tubing being tested.

At the present time, there are no international standards for testing the strength of scratched tubing. That is unfortunate. That is why Wirsbo is temporarily using the pressure test that is officially employed during production monitoring. The testing is done at a temperature of 202°F. (95°C.) at a hoop stress of 667 psi (4.6 N/mm^2) which corresponds to an internal pressure of about 160 psi (11 bar/mm^2) in a typical tubing used for intermediate pressures. The duration of the test is at least 170 hours.

Plate 7:7

A scratch in tubing made of polyolefin reduces its durability.

Wirsbo creates the scratches on the PEX tubing used in the tests with a blade that produces a cut 1 µm (.00004 in.) in edge diameter. The depths of the cuts that are made both on the inside and the outside of the tubing are between 1 and 30 percent of the thickness of the tubing walls.

The results show that the tubing from Wirsbo that is manufactured according to the Engel process came through the 170-hour test without damage after being subjected to scratches as deep as 20% of the tubing wall. Even when Wirsbo continued the tests for up to 20,000 hours, no breaks occurred.

By comparison, it should be noted that there is tubing whose durability is already impaired by scratches that are only one percent deep.

The reason for the insensitivity of Wirsbo-PEX tubing to scratches and for its favorable stress-crack behavior is to be found in, among other things, its cross-linked molecular structure. The forces that are released by the tearing of the molecule chains, no matter how the tearing takes place, are held in by the surrounding molecules in the overall network. In this way, all concentrations even themselves out. For more information concerning cross-linking, see page 75ff.

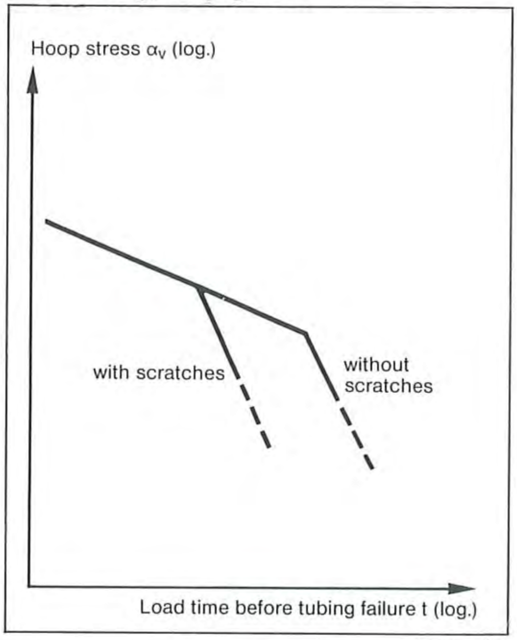
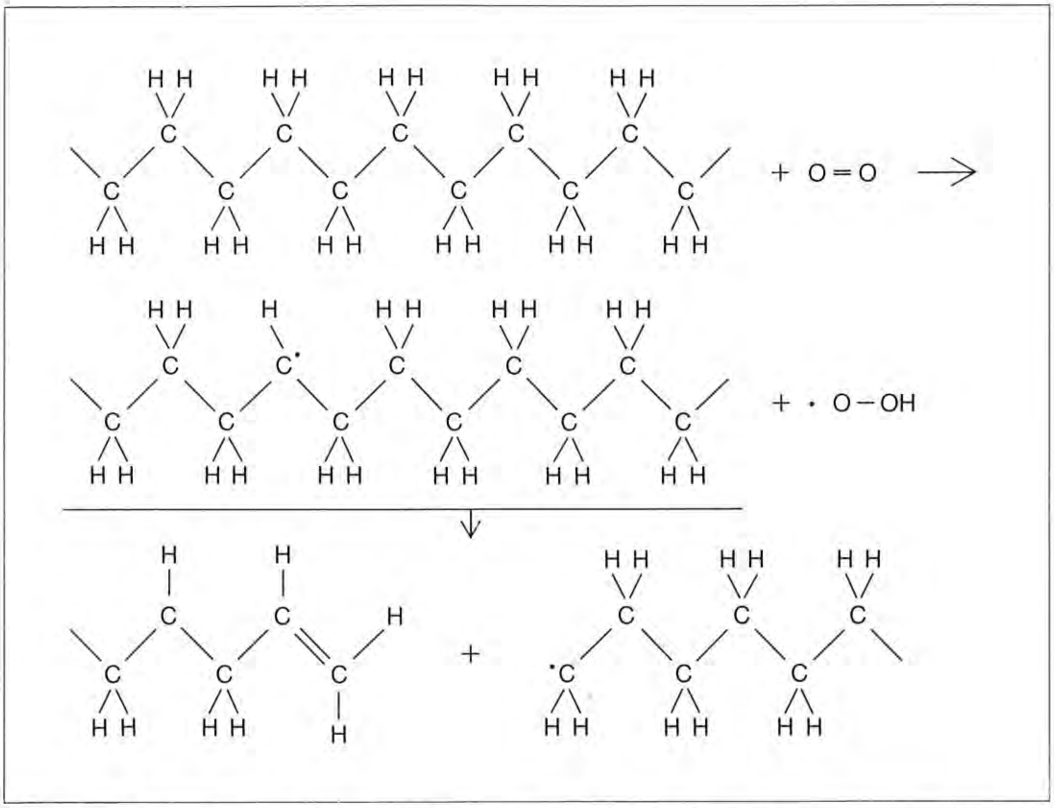


Figure 7:5

***Influence of scratches** on the long-term strength of plastic tubing.*



Thermal oxidation of polyethylene (a simplified presentation of the chemical reaction). Figure 7:6

The Worst Enemy of Plastics

Without oxygen there would be no life. That is for sure! But something that is at the very foundation of life can, in some cases, be quite detrimental. Because of its oxidizing effect, oxygen is also a great destroyer.

It is also a destroyer of plastics. Especially under the influence of heat, oxygen works itself into the material and breaks the molecular chains down into ever smaller pieces. When this happens, we can see the effects of oxidation. It causes breaks in the molecular structure of plastics. Sunlight has a similar effect on them. Whether this deterioration is caused by oxygen, by ultraviolet light or by both, it takes place at varying rates of speed depending upon the type of plastic that is involved. The most decisive factor in the speed of deterioration is the composition of the chain molecule. The more complex its structure, that is, the more secondary groupings it has, the more likely it is to show a tendency toward deterioration.

Branches are the weak points of molecular chains. That is where deterioration starts and where the breakup begins. The molecular structures of polyethylene and polypropylene illustrate the difference between simple and complex molecules.

The type of polyethylene raw material used by Wirsbo for their process, shows an average of about 10,000 carbon atoms between every branch in the molecular chain. The situation is quite different in the case of polypropylene. In it, there is a branch for every second atom. As a result, PP is more endangered by the effects of oxidation than PE and so has to be subjected to a greater degree of stabilization. The same is true of polybutylene (PB).

"Radical Eaters"

It is not possible to completely prevent deterioration. It is possible to slow it down to such a degree that the plastic tubing achieves an acceptably long life span. In order to do this, it is necessary to institute the controlled use of a stabilizer.

For polymerized piping materials, phenol compounds (cyclic or annular compounds) are often used as stabilizers (antioxidants). One of their characteristics is that they react more quickly to the destructive effects of oxygen than the polymers, that is, they oxidize more quickly.

The pieces of molecules that break off as a result of a polymer's reaction to oxygen are called "radicals". The main accomplishment of a stabilizer consists in the way it attaches itself to radicals. When polymers are unprotected, the radicals that are freed take part in splitting the molecular chains. It is just this chain reaction that is eliminated by an antioxidant.

Searching and Researching

Anyone who manufactures plastic products has to demand a lot from an ideal stabilizer. For example, it may not be poisonous. In order for it to work correctly, it must be spread finely throughout the material. It must display a certain degree of mobility but still be immobile enough so it does not wash out or escape through the walls of the tubing. These items are only mentioned to give you an idea of the many factors that have to be taken into account when trying to protect plastic tubing from the effects of oxidation and aging.

Wirsbo has been dealing with these problems for more than ten years now. The tests that are currently being conducted for them at BASF are just part of a search for the optimum stabilizer. The long-term strength tests are still continuing there after a period of ten and one-half years (as of early 1984) at a temperature of 203°F. (95°C.). This is a world record time for testing at such a high temperature. It has already been shown that the stabilizer that was chosen is doing the job it was intended to do.

There Are No Pat Answers

It is really tempting to suppose that one could conduct quick tests at high temperatures on stabilized plastics and then simply apply the conclusions reached in these tests to the behavior of these same plastics at lower temperatures. It is tempting but is really just a little too easy. It is a pipe dream that only exists in the minds of some technicians. But the polymers themselves cannot be fooled as easily. They cannot be fooled quite simply because the structure and behavior of their molecules at 300°F. (150°C.) is completely different from their structure and behavior at 140°F. (60°C.).

This difference is reflected in different rates of deterioration at different temperatures. As a result, the ability of the stabilizing agent to work in the way that was planned is adversely affected.

So we are left with long-term testing at different temperatures if we want to gather reliable data concerning the thermal stability of a product. It would be advisable for the customer to ask the manufacturer for that type of data.

Here are two examples of the careless use of test results. In one case, a manufacturer had arrived at a life expectancy rating of 204 years for a particular type of tubing by conducting short-term tests at high temperatures and then using theoretical extrapolation to arrive at a long-term conclusion. In actual usage in the field, the tubing began to "deteriorate" after only 90 days. In response to such methods, we would just like to repeat the observation that impressive facts and graphs should only be given credence after one knows how and by whom they were gathered and created.

The other example deals with the sensitivity of certain polymer materials to metal ions (for example, brittleness caused by copper). The tendency toward this type of deterioration is greater depending upon how complicated the molecular chains are. The polypropylenes and polybutylenes are especially prone to this so-called "catalytic deterioration". To combat this reaction we have to resort to the use of special stabilizers called "metal deactivators". Still, all of them have a decided disadvantage. They are poisonous and so cannot be used in drinking-water supply lines. Some manufacturers avoid this problem by using pipe fittings made of stainless steel instead of copper when conducting long-term tests. In this way, they are able to achieve results that are quite a bit rosier than they would otherwise be.

Discharging the Stabilizing Agent

During the usual long-term, internal-pressure tests, the water is kept in the test sample during the whole testing process. That leads to the liquid's being quickly saturated with the antioxidants that, under normal circumstances, are quite difficult to dissolve in water. Any further elimination of these materials comes to a halt. The situation is completely different when the tubing is actually being used under normal conditions. Water is constantly streaming through the tubing. When it does, it causes a continuous discharge of the antioxidizing agent, especially when the agent has not adhered sufficiently to the tubing material.

Wirsbo is investigating this behavior by boiling the samples repeatedly in distilled water. Then the material's resistance to oxidation is tested both before and after being boiled. Keep in mind that Wirsbo expects its tubing to last for 50 years. If this is the case, then the bulk if the antioxidants must still be present after being boiled for months.

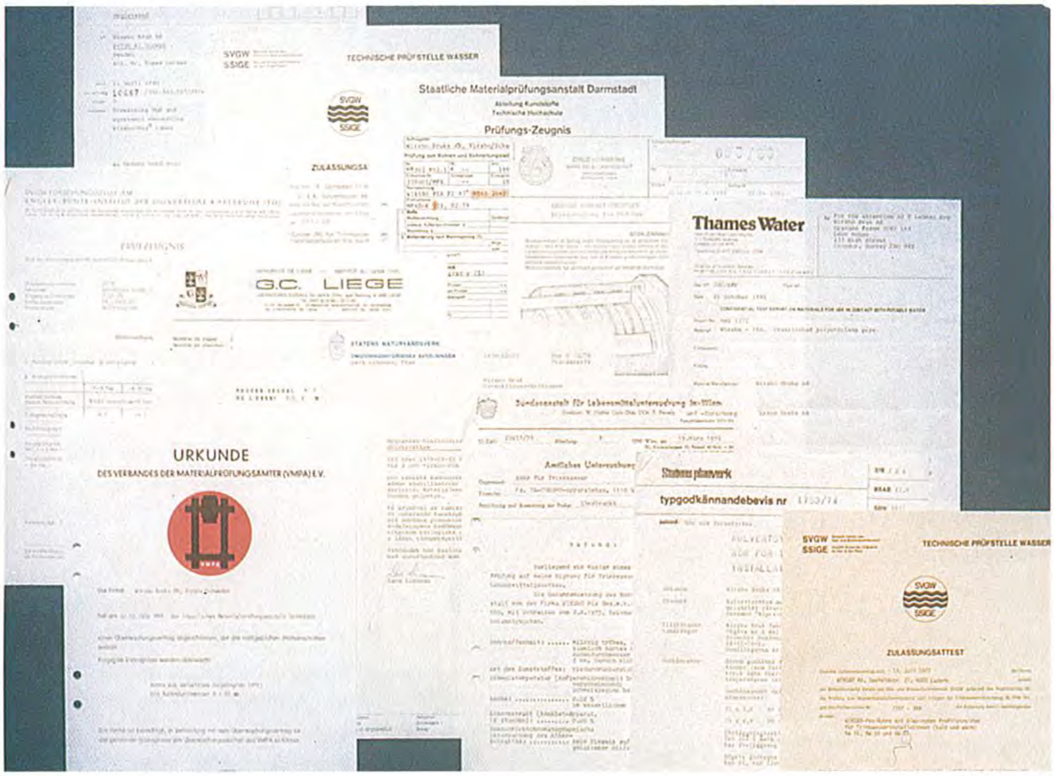
HEALTH CONCERNS

The effect of metal water-supply pipes on human health has never been the subject of much debate. That might just be the case because they have been in use for such a long time. An exception to this has been restrictions on the use of copper pipes in certain countries in order to preserve water quality.

In the case of plastic pipes, the situation has been quite different. Right from the start, people have been skeptical concerning whether humans could tolerate them. They should be. For example, there have to be limits to the amount of lead that a PVC pipe may give off. The stabilization system of Wirsbo-PEX tubing has been proven not to be toxic. That is, the test results have shown that it is no more toxic than, for example, sugar.

Discharge of Harmful Materials

Plastic tubing is investigated for purposes other than toxic material content. It is also tested to discover the extent to which it af-



SVGW SSIGE

TECHNISCHE PRÜFSTELLE WASSER

Staatliche Materialprüfungsanstalt Darmstadt

Prüfungs-Zeugnis

Thames Water

G.C. LIEGE

URKUNDE

DES VERBANDES DER MATERIALPRÜFUNGSÄMTER (VMPA) E.V.

Statens planverk

typgodkännandebevis nr

ZULASSUNGSATTEST

Plate 7:10

***Documents,** certificates and testing contracts – all evidence for the quality of Wirsbo-PEX tubing (representative sampling).*

fects the taste, odor, color or clarity of the water that passes through it. One of the testing and resarch institutes that conducts just that kind of test for manufacturers around the world is KIWA in Holland. Among the various tests that this institute conducts on plastics is one that entails leaching them in distilled water. After a period of 72 hours the water is chemically analyzed to determine values for taste, odor, discoloration and clouding. Other European institutes also conduct similar tests. The National Sanitation Foundation (NSF), Standard Number 14, covers the U.S.A.

Ask For Documentation

Health standards (food and drug laws and so on) can vary significantly from country to country. Because they can, there is some importance advice that the customer would do well to follow. Always ask the manufacturer or dealer for an official certificate that is valid in the country where the tubing is to be installed attesting to the safety of the material. Documented data is much less likely to be questionable.

REALISTIC TESTING

No test gives as much insight into the actual behavior of plastic tubing as one conducted under conditions similar to those actually found in the field. Such tests just do not permit any compromises.

Wirsbo began its first broad-based testing program back in the years 1972 and 1973. The Swedish Building Research Institute (SIB) and all of the official testing boards in Scandinavia took part in it. It was during those tests that the certification of the various types of Wirsbo-PEX tubing for drinking water, hot water and heating systems was granted. By the year 1982, we were able to get similar certification in ten different countries.

75,000 Temperature Cycles

The following items were of special importance during the extensive testing program:
Different installation conditions: tight, loose, in conduit and in cement.
Rough handling: scratches, kinks and bends.
Pipe connectors: various brands and types of fittings.
Temperature cycles: admission of cold (50° F., 10° C.) and hot (203° F., 95° C.) water (at about 145 psi or 10 bar/cm^2) in three-minute cycles. The pipes underwent a total of 75,000 temperature cycles during the 15-month period.

Four Pipe Connectors Out of Twenty

"The joints are the weakest links in the whole system," is what one often hears. Just what kind of evidence did the practical tests performed by Wirsbo bring in support of this belief?

- Of the 20 types of connectors tried out on the tubing, only four of them could measure up to the demands placed upon them. In later tests, a few other pipe connectors proved to be usable. When installed properly, there were no problems presented by any of them.
- There have been close to six million pipe connectors installed on Wirsbo-PEX tubing in past years. There have been few if any complaints throughout this whole period. Those few cases all involved faulty installation (nuts not tightened enough, parts left out and so on).

Experience tells us that some people in the industry tend to doubt the truth of these statements. Our response to this takes the form of a question. Where can you find a testing program that is as encompassing as that of Wirsbo?

Speed of Water Flow Not a Factor

Copper tubing is normally permitted for hot water supply when the water flow is ten feet per second or less. When the water flows faster than that, there is danger of pitting caused by corrosive erosion.

The Swedish Building Research Institute tested Wirsbo-PEX tubing (with and without bends) over a one-year period with water running at a speeed of 92 feet (28 m) per second at a temperature of more than 195° F. (90° C.). These tests showed that the tubing developed no problems whatsoever from such treatment.

No Noise From Water Hammering

Closing a valve very rapidly causes a pressure

Plate 7:12

***Connectors approved** for use with Wirsbo-PEX tubing (a selection).*

surge in a water supply system. Pipelines and other equipment have to take this problem into account. The city waterworks of Adelaide, Australia has investigated the behavior of Wirsbo-PEX tubing in that regard. Tubing that was intended for use at up to 145 psi (10 bars) of pressure was submitted to 833,000 surges at 220 psi (15 bars). The tubing withstood even this test without any problems. The current and projected standards specify 10,000 to 40,000 surges as an adequate test.

Pressure surges do not only put extra stress upon pipes. Their presence can also be noticed through the annoying noise that they cause – when the pipes are made of metal, that is. Plastic pipes do not have that problem because the tubing material itself dampens the sound.

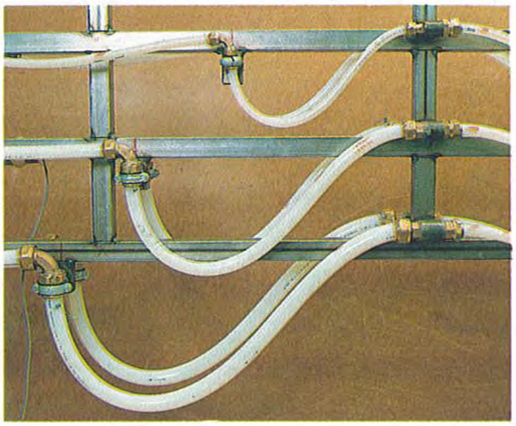
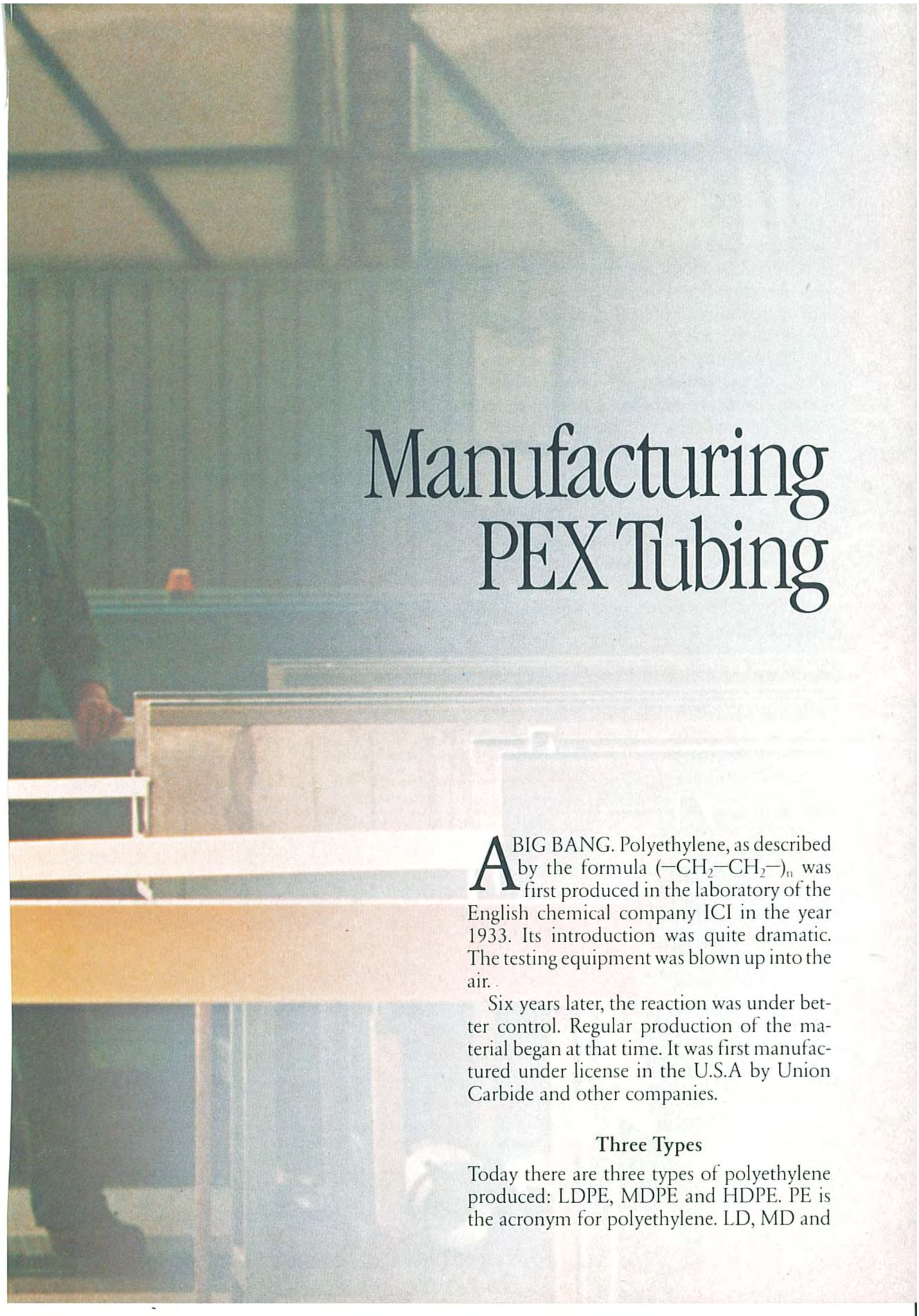


Plate 7:13

***Fatigue testing** of pipe connectors through 75,000 temperature cycles. This test shows which connectors can withstand such treatment.*



Manufacturing PEX Tubing

A BIG BANG. Polyethylene, as described by the formula $(-CH_2-CH_2-)_n$ was first produced in the laboratory of the English chemical company ICI in the year 1933. Its introduction was quite dramatic. The testing equipment was blown up into the air.

Six years later, the reaction was under better control. Regular production of the material began at that time. It was first manufactured under license in the U.S.A by Union Carbide and other companies.

Three Types

Today there are three types of polyethylene produced: LDPE, MDPE and HDPE. PE is the acronym for polyethylene. LD, MD and

HD stand for low density, medium density and high density. The division of the three types is made according to these ranges:

LDPE: 56.8–57.8 lb/ft^3 (0.910–0.925 Mg/m^3)
MDPE: 57.9–58.6 lb/ft^3 (0.926–0.940 Mg/m^3)
HDPE: 58.7–60.0 lb/ft^3 (0.941–0.965 Mg/m^3)

Wirsbo-PEX tubing is produced from an HD polymer with an extra-high molecular weight and a density of about 59.3 lb/ft^3 (0.95 Mg/m^3). This factor is decisive in determining the properties of the final product because the crystallinity of the polymer is directly related to its density.

"Crystallinity" refers to the regular arrangement of molecules in the overall structure caused by strong adhesive forces in the material. The opposite of that, the irregular arrangement of the molecules, is referred to as a material's amorphous state.

Both types of structures can be seen in the schematic illustration shown in Plate 8:2.

The greater the density, the higher the degree of crystallinity and, as a result, the greater the strength of the plastic. The extent of crystallinity in the polymer that Wirsbo uses for its PEX tubing is 90 percent.

The X Stands for Cross-linked

The X in the acronym PEX refers to cross-linking. This term is used to describe the chemical linking of the PE molecules into a three-dimensional network.

The technique that Wirsbo uses to achieve the cross-linking in its tubing material is based upon a process developed by the German inventor, Thomas Engel. The cross-linking that is attained using that method is the basis for the outstanding characteristics of Wirsbo-PEX tubing.

Monitoring the Raw Material

Before the manufacturing process begins, the macromolecular raw materials and the additives, such as stabilizers, cross-linking agents (peroxide) and so on, are subjected to thorough monitoring procedures. Ratings such as the melting index, homogeneity and density are determined in Wirsbo's own laboratory.

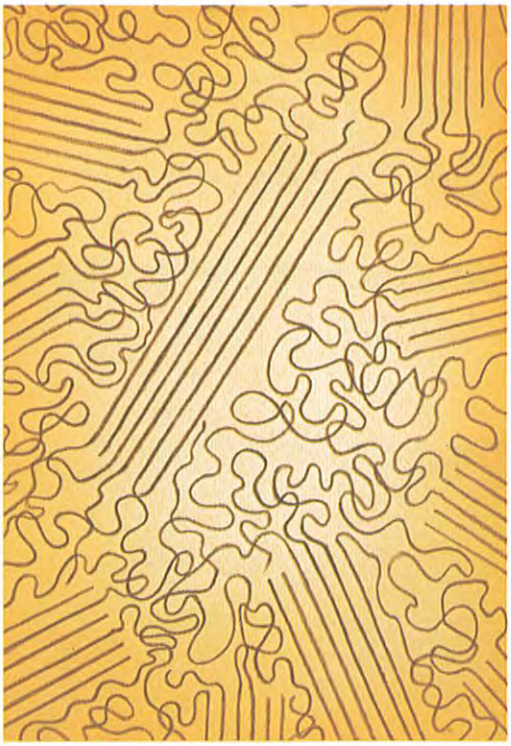
A portion of the raw material that is found to be satisfactory is then put into the laboratory mixer. From there it is taken to the testing

Plate 8:1

***The raw materials** used to make Wirsbo-PEX tubing.*

***The structural arrangement** of the polyethylene (HDPE) chain molecule. The crystalline (regular) and amorphus (irregular) areas are very clearly defined.*

Plate 8:2



track or "pilot plant" as it is sometimes called. Regular production begins only after it has been determined from an actual finished piece of tubing that the composition of the material, as well as the technique used to produce it, is correct.

440 Pounds for 5,000 Feet

The raw polyethylene that Wirsbo procures in powder form is strained to get just the size of grain desired. Then it is weighed electronically and combined with the additives in a mixer using an elaborate technique.

The mixture is transferred to a 440-pound (200 kg) container. After being marked according to the type of tubing that will be produced from it, it is set aside in a holding room for a few days.

Finally the mass is fed from the containers into the extruders. 440 pounds (200 kg) of the powder is enough to produce about 5000 feet (1500 m) of 3/4-inch (20 mm) Wirsbo-PEX tubing with 3/32 inch (2 mm) thick walls.

Cross-linking in its Amorphous State

The tubing is given its shape by an extruder that, in general terms, takes up the raw material in powder form at one end and, by applying heat and a great degree of pressure, forces the tubing out through a ring-shaped opening at the other.

Cross-linking also takes place while the tubing is being formed. At this time, it might be well to mention an important difference between Wirsbo-PEX tubing and other tubing made of cross-linked polymers. The cross-linking takes place while the material is in an amorphous state, that is, at a temperature above that at which the crystals melt. As a result, there are no crystalline areas present that could have a negative effect upon the cross-linking process. The linking can take place evenly and without hindrance.

Searching for Defects Electrically

As the amorphous material emerges from the molding machine, it is almost transparent. While still in that state, it is subjected to monitoring equipment that employs an electrical field to continuously analyze the finished

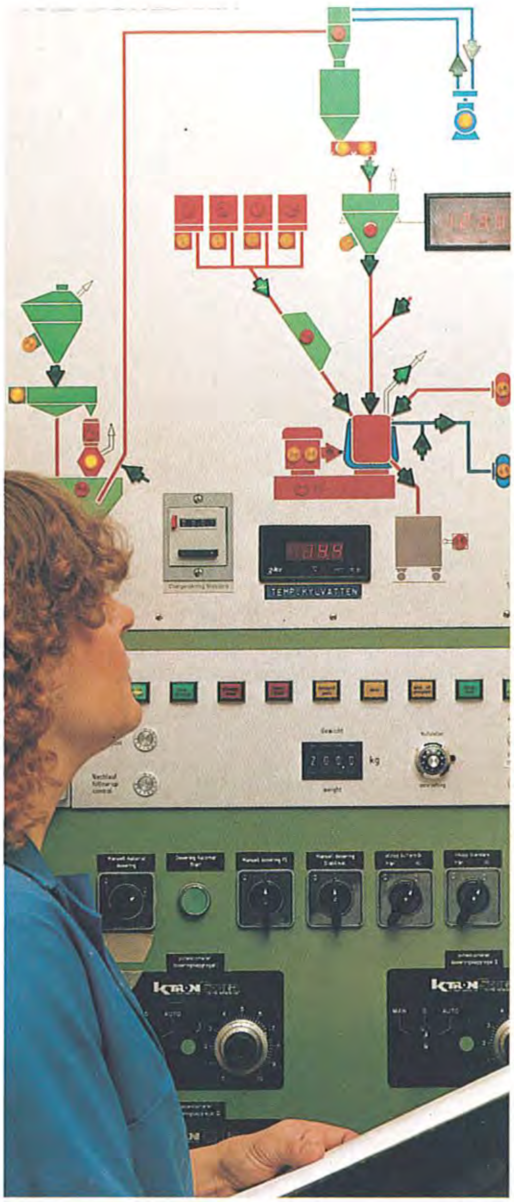


Plate 8:5

Plate 8:5. *The control unit of the automatic raw-material dispensing unit used for Wirsbo-PEX tubing.*

Plate 8:6. *The raw-material containers are exchanged during the ongoing production process.*

Plate 8:7. *Analysis of the temperature-dependent behavior of plastics (melting point and so on). Method: Differential Thermal Analysis (DTA).*

tubing. It uses a field intensity of 12,000 Volts for every 1/16th inch (7,500 volts for every millimeter) of wall thickness. Every disturbance in the electrical field that might be caused by a deviation in wall thickness or by the incorporation of air or dirt immediately sets off an alarm. Besides monitoring for thickness and homogeneity, any gaseous remains in the material are removed at this time.

Calibrating equipment and a cold water bath follow right after the monitoring equipment. It is at this spot that the tubing material crystallizes and takes on its characteristic, milky white color. Right after that, the tubing is printed with detailed information, cut for length and wrapped into a coil ready for shipping.

Entries are made in a daily plant journal for every coil showing the date, time of day, the responsible operator, and other similar types of information. Other items are also entered into this journal, such as the type of material being used at any given time and any changes in extruder dies.

Not One Coil is Overlooked by Wirsbo

The Wirsbo laboratory collects a sample from each coil and then puts them through an almost painfully exacting battery of production tests and checks. Wirsbo has set up standard tolerances for inside and outside diameters and for wall thicknesses that are lower than the tolerances normally allowed for plastic tubing. If there is a variation of .0008 inches (0.02 mm) outside of the set tolerances for any of the three measurements mentioned, the whole coil is considered to have failed the test. It is sawed to pieces.

This "finickiness" has a solid practical purpose. If the person installing Wirsbo piping is to work as fast as Wirsbo always insists he can, the pipe fittings must sit exactly right the first time.

Cross-linking: Not Too Much, Not Too Little

The properties of tubing made of cross-linked polyethylene are determined mainly by the degree of cross-linking they undergo, that is, by the proportion of molecule chains that are


Plate 8:8

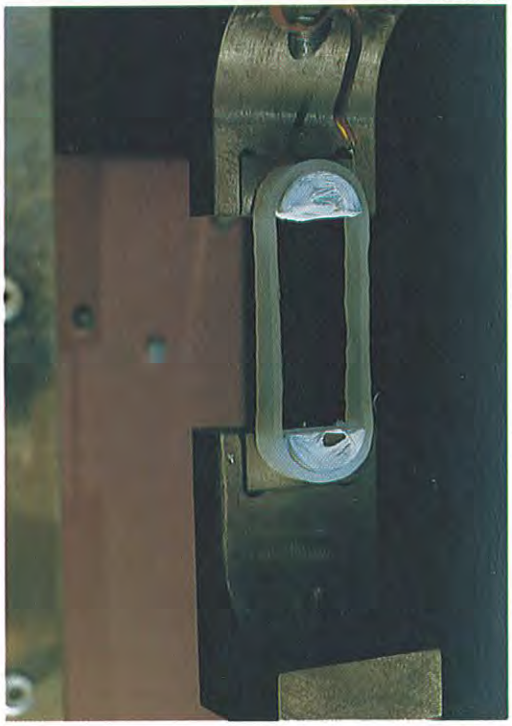


Plate 8:9

Plate 8:8. *Production monitoring in the Wirsbo factory. Every value is recorded in a journal and archived.*

Plate 8:9. *Determining the degree of cross-linking in tubing materials using the quick method: testing for tensile strength after heating to a temperature of 310° F. (155° C.). (Plant photo: Studsvik Energiteknik AB).*

linked to each other. This proportion has to be well balanced. If it is too small, the material will be more like noncross-linked PE with its limited durability at high temperatures. If it is too large, the material will quickly become brittle.

The degree of cross-linking in Wirsbo-PEX tubing should lie between 70 and 90 percent. The Wirsbo laboratory checks this out using two different methods. The first employs a fast but very reliable mechanical method (our own patent) and the second uses chemical analysis based upon ASTM and DIN standards. The second method is also used for calibrating the mechanical test.

Pressure Test

Once a week, Wirsbo takes five samples from each production line for a pressure test. The samples are placed in 203°F. (95°C.) water, filled with water and kept under excess pressure for 170 hours.

For example, a pipe with a nominal pressure rating of 87 psi (6 bar) is tested by Wirsbo at an internal pressure of 145 to 174 psi (10 to 12 bar). The result is a hoop stress on the tubing wall of 667 psi (4.6 N/mm^2). This is a value very close to the actual strength of the material. There is a good reason why Wirsbo works with such high values in these tests. Wirsbo wants to apply the same stress in the short-term tests as used in the compilation of the time-to-failure graphs. This approach provides an additional guarantee of quality. Wirsbo also conducts similar tests which last for 1000 hours although less frequently.

In accordance with valid standards, one-hour pressure tests and even burst-pressure tests are also performed. It is Wirsbo's view that these short-term tests are of no significance and should be omitted if certain relevant raw-material tests are performed.

Dimensional Change Test

The samples are taken from each production line three times a week. They are measured in the most precise way possible. Then they are heated in a 248°F. (120°C.) oven for one hour. Finally they are measured again after they have been taken out and cooled off.

This test gives Wirsbo an insight into the

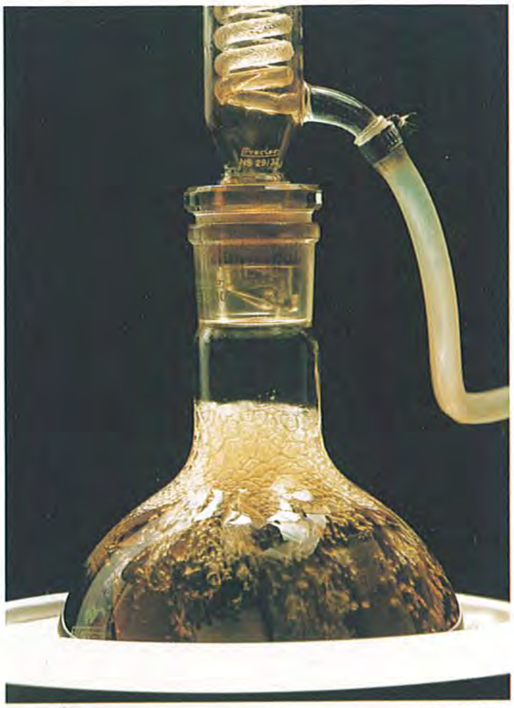


Plate 8:12

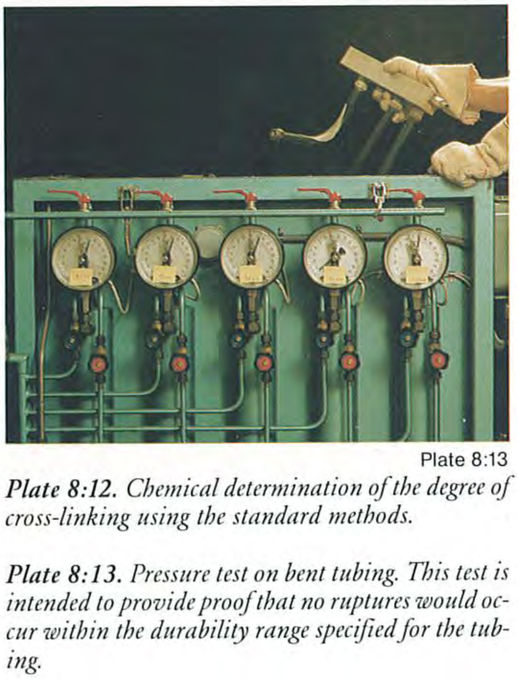


Plate 8:13

Plate 8:12. *Chemical determination of the degree of cross-linking using the standard methods.*

Plate 8:13. *Pressure test on bent tubing. This test is intended to provide proof that no ruptures would occur within the durability range specified for the tubing.*

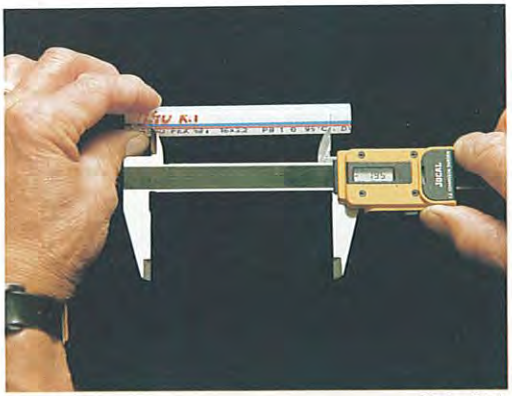


Plate 8:14

Plate 8:15

Plate 8:14. Elongation test. The change in length of the sample is measured after it has been heated in an oven.

Plate 8:15. Official quality monitoring. Dr. Stagge of the MPA Darmstadt entering the results gained from a random sampling into a log book.

amount of internal stress in the material used for its tubing. Some testing standards allow 3 percent and others 5 percent as the upper limit of acceptable change in a tubing's length. Wirsbo has set its upper limit at 3 percent.

In the case of some materials, a higher percentage of change in its shape indicates a greater tendency towards breaking and rupturing.

The Watchful Eye

The production monitoring that is done in the Wirsbo plants should:

1. prevent the sale of defective tubing and
2. ensure that all tubing sold will meet the requirements of the official certification especially since it was based upon the results of tests conducted by Wirsbo.

In order for the internal production line monitoring to become as trustworthy as possible, it has been placed under the supervision of neutral testing boards. Two to three times a year, representatives from such boards in the United States, West Germany, Holland, Norway, France and Sweden visit the Wirsbo plants. What is even more, they appear unannounced. They inspect the specifications, journals and testing equipment and they take samples with them back to their laboratories for testing.

Quality has been an integral part of the Wirsbo tradition ever since the company was founded in the seventeenth century. It was in this spirit that such an extensive system of quality assurance was developed. The demands that Wirsbo places upon itself are high. Wirsbo strives to be the best. Anything less than that is not enough.

MORE ON CROSS-LINKING. Over the past years, the plastics industry has developed various cross-linking methods for PE molding or extrusion either alone or in combination with other plastic materials. Just because a plastic is given the generic name "PEX" does not mean that it contains the same material as all the rest that are known by the same name. Every manufacturer produces a version of PEX tubing that distinguishes itself from that produced by other manufacturers. These differences can be caused by the characteristics of the raw material, by the method used to produce the final product and by the degree of quality demanded.

In addition to the Engel process used by Wirsbo, there are other cross-linking methods in use.

Radiation Cross-linking

When normal PE tubing is bombarded by electrons, the energy produced by the rays sets the cross-linking action into motion. This process occurs at room temperature. The linking that takes place is concentrated on the areas in the material that are still amorphous at the time of the bombardment. Doing so does not appreciably reduce the degree of crystallinity achieved.

This relatively new method is best suited for small-sized tubing. It has, however, some drawbacks. One danger is that of holes forming in the tubing wall as the result of a possible electric breakthough during the bombardment. There is also a tendency toward uneven cross-linking or toward excessive cross-linking with brittleness as a possible result.

Silane Cross-linking

This process, which was developed by the Dow Chemical Company, is based upon saturating the PE macromolecule with silicon. Subjecting it to water vapor in the presence of a catalyzer activates the cross-linking process. The linking takes place through so-called siloxane bridges (—Si—O—Si—). These bridges are, however, weaker than normal C—C bonds.

Sioplas Method

This process takes place in two steps.

In the first step, the polymer is mixed with an organic silicon derivative. Under the influence of a peroxide and an antioxidant, it saturates the PE chain.

In the second step, the pretreated polymer and a catalyst is mixed with a PE base material. After this is done, the tubing is produced. The cross-linking takes place relatively slowly through the addition of water vapor and heat. It is determined by how well the water penetrates the tubing wall.

Monosil Method

This cross-linking technique, which was developed by the Maillefer and BICC companies, is similar to the Sioplas Method insofar as its chemical reaction is concerned. The difference is that only one step is required. It is used primarily for the manufacturing of cables and for tubing to be used in the middle temperature ranges.

Pont-à-Mousson Method

Under the PAM method, the tubing is shaped at the temperature at which peroxide reacts. This means that the cross-linking takes place in a fused-salt bath at a temperatue of 480° to 540° F. (250° to 280° C.).

When using this method, it does become a problem to preserve the shape and the surface characteristics of the tubing during the cross-linking stage because of the high temperatures used. Compared with the Engel process, it also requires a larger amount of peroxide.

AZO Method

The Swedish company, Uponor AB, uses AZO compounds (molecules with the grouping —N=N—) in its method for cross-linking PE. The tubing is formed at a temperature lower than that at which AZO unions occur. Then the temperature of the salt bath is raised up to that required for the reaction to take place. It is substantially higher than the temperature required for a peroxide reaction.

The PE that is being used in this case is one with a high density and a high molecular weight. The cross-linking takes place in a fused-salt bath in a way similar to the PAM method.

Other Peroxide Methods

Several recently developed methods all use peroxide for cross-linking. Peroxide is either mixed with the raw materials before extrusion or added by diffusion techniques during or after the extrusion process. In either case, the shape of the tubing must be carefully controlled during the cross-linking period when the temperature is increased. Because these methods are quite new, they are still undergoing further development.

UHF Cross-linking

Professor Menges of the Technological University at Aachen recently developed a new method for cross-linking polyethylene.

This method is based upon the fact that polarized substances absorb energy from a UHF (Ultra High Frequency) field. In this way, the peroxide disintegrates into radicals that can bring about cross-linking and it does so at a temperature that is lower than that normally required. The PE chain itself is not polarized and so does not absorb any energy.

A Comparison of Properties and Behavior

Material 1: *Cross-linked polyethylene (PEX) produced by the Engel method as further developed by Wirsbo.*
Material 2: *Polyethylene cross-linked by radiation.*
Material 3: *Polyethylene cross-linked by chemical methods other than the Engel method.*
Material 4: *Other polyolefin materials, such as PB, PP, PPC (PE).*

Property	Materials			
	1	2	3	4
Thermal stability at 203° F. (95° C.)	1	2	2–3	2–4
Time-to-failure up to 203° F. (95° C.)	1	2	2–3	2–4
Stress-crack resistance	1	2–4	1–2	2–4
Flexibility	1	2	2–3	2–4
Impact strength	1	1	1	3–5
Thermal conductivity	2	2	2	3–4
Elongation	4	4	4	3–4
Measurements, tolerances	1	2–4	2–4	2–4
Surface characteristics	1	2	2–5	2
Mechanical properties at room temperature:				
Short-term strength	2–3	2–3	2–3	1–2
Tensile strength	1	2–4	2–3	1–2
Material residue, toxicity	1	2	2–3	2–4
Induction period at 392° F. (200° C.)	3	2–3	1	2–3
Creep behavior	1	1	1	1–3

1 very good
2 good
3 satisfactory
4 questionable
5 bad

Table 8:1

The ratings refer to the property itself and/or to the backup data available for the particular property.

It is also possible to add other polarized substances (carbon black) and to use otherwise "normal" peroxide that will form radicals through thermal decomposition. The mass, along with all its additives, is then extruded at as low a temperature as possible. After that, it is cross-linked in a UHF stage.

One advantage of this method is the even distribution of the energy throughout the material which results in an homogenous cross-linking effect.

The problems with this method are the search for suitable, nonpolarized additives for the tubing and the effect that remaining radicals might have.

This method is not yet ready for use in mass production.

The Temperature Makes the Difference

The properties of the PEX materials depend upon the temperature at which the cross-linking process takes place. It is especially important to make a distinction between tubing that has been subjected to cross-linking at a temperature above the crystal melting temperature and one that has undergone the process below that temperature.

At temperatures above the crystal melting point (while the material is in an amorphous state), cross-linking occurs naturally without any chemical or mechanical disturbance. When cross-linking takes place below that temperature, it must occur among molecules in the amorphous area between crystallites and so the results are not as good. For example, the tubing that is developed in this way undergoes a change in some of its properties after hot bending. Being subjected temporarily to high temperatures has a great negative effect upon its strength due to the changes in the crystalline structure that it causes.

Tubing that undergoes cross-linking at temperatures below the crystalline melting point (for example, when using the silane or radiation cross-linking methods) normally loses from 10 to 15 percent of its strength when heated up to temperatures over that point. Tubing that is cross-linked using the Engel method does not share this loss of strength under similar treatment.

Creep

In the case of polymers as well as many other materials, the reponse to a constant load over an extended period of time is an elongation or deformation of a part or all of the material. This reaction, which increases over a period of time, is known as "creep". The deformation that occurs in such situations can be divided into an initial deformation and a creep deformation. The ratio of the initial deformation to the creep deformation is dependent upon the amount of the load or stress, the temperature of the material and the actual material being tested. (See Figure 8:1.)

Elongation (Deformation) is a Function of Time and Load (expressed as stress).

When comparing different materials it is important to:

1. Distinguish between the initial deformation and the creep deformation. (See figure 8:2.)
2. Make the comparisons between materials regarding creep relative to their strength (or elasticity modulus, stress rating, etc.). For example, the amount of creep for PVC at 2000 psi (25 N/mm^2) could be compared to the amount of creep for a specific PE at 400 psi (5 N/mm^2).
3. Conduct the comparison at temperatures commensurate with the materials being tested. For example, if the materials are to be used for hot water pipes, 180°F. (80°C.) would be an appropriate temperature.

The generalized curves shown in Figure 8:1 would be valid for three different temperatures (for example 70°, 140° and 230°F. or 20°, 60° and 110°C.) at the same stress as well as for three different stresses at the same temperature as is actually shown.

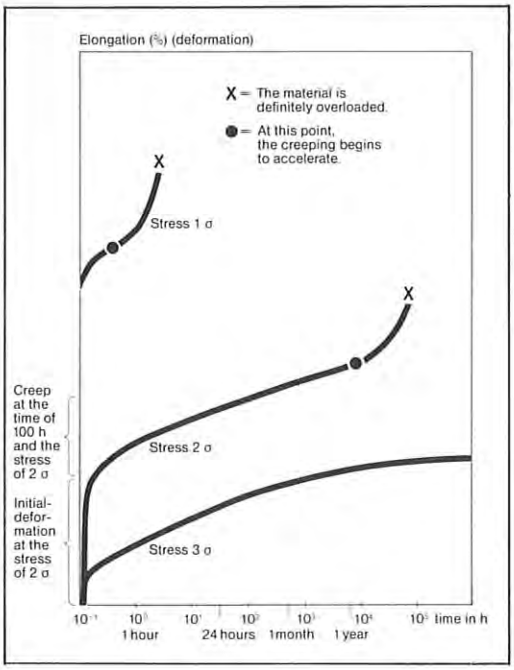


Figure 8:1

At this point, the creeping begins to accelerate. The material is definitely overloaded.

Creep Curves Elongation (Deformation) is shown here as a function of time. Generalized creep curves at three different stresses (at a specific amount, at two times that amount and at three times that amount).

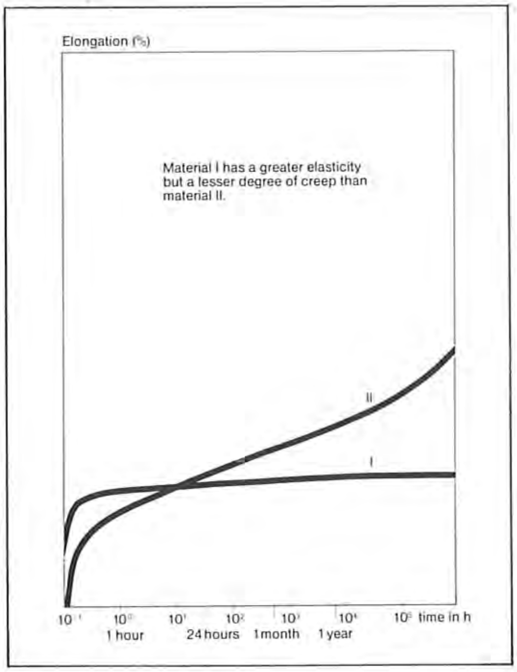


Figure 8:2

Material I has a greater elasticity but a lesser degree of creep than material II.

Creep curves. This graph illustrates the difference between two materials. Material I undergoes a large initial deformation but a small creep. The opposite is true of material II. While its initial deformation is smaller, the degree of creep is larger.

Tips on Tubing Selection

SOME OF THE RULES FOR EVALUATING the qualities of the various brands of plastic tubing have been gathered in this chapter.

Every serious dealer has to be in a position to provide documented data concerning each of these criteria.

1. Which type of plastic is used to manufacture the tubing?

The manufacturer should make it clear both in announcements and in other information supplied by the company as well as on the tubing label itself just what raw material was used in the tubing.

The flexible plastic tubing that appears on the market for heating, drinking water and hot water are, for the most part, produced from the raw materials shown in Table 9:1.

2. What commercial brand of the raw material is actually used to manufacture the tubing?

The tubing manufacturer should be asked to provide information as to which commercial variety of the raw material has been used in his tubing.

Examples of commercial brands are:

- BASF Lupolen 5261 Z Q 100 for PEX tubing manufactured according to the Engel method (Wirsbo-PEX tubing)
- Hoechst Hostalen PPH 2222 for polypropylene tubing
- Shell PB 4121 for polybutylene tubing

3. Is the tubing adequately labeled?

It must be possible to indentify a high-quality tubing by means of a label that will not easily rub off. Various items must be included on that label.

1. The name of the manufacturer or the brand name of the tubing
2. The tubing's measurements (wall thickness, outside diameter)
3. Permissible operating temperature
4. Permissible pressure at the permissible operating temperature
5. Stamp of approval from the relevant monitoring agency
6. Kind of raw material (name or code)
7. Number of the production machine (in case the manufacturer uses several machines)
8. Year of manufacture

4. Is there a contractual agreement between the manufacturer and an official quality-assurance and monitoring board?

Every serious manufacturer should be able to provide proof that the product he manufactures is monitored by a recognized and respected testing institute for the maintenance of certain quality standards. For a list of some of these official quality-assurance and monitoring boards see Chapter 11. (Page 99).

5. Is there official authorization for the proposed usage?

The manufacturer has the burden of providing the proof of such authorization in cases where it is necessary. That is true especially when the tubing is to be used for hot-water and drinking-water systems.

6. Does the tubing have a negative impact on health when it is used for hot-water or drinking-water systems?

Manufacturers who offer tubing for use in such situations must have a certificate from an official board attesting to the fact that the products are unobjectionable from a health standpoint (hygenic and toxicological certification).

7. The tubing must meet the relevant standards and guidelines – but is that enough?

The tubing has to fulfill the reguirements of the standards and quality guidelines that are

Uses and Suitability of Some Selected Piping Materials

Materiale	Abbreviation	Heating	Drinking Water	Hot water
Low-density polyethylene	LDPE	(x)	x	–
High-density polyethylene	HDPE	–	x	–
Cross-linked polyethylene*	PEX, (XPE, XLPE)	x	x	x
Polypropylene**	PP	x	x	–
Polypropylene** (Copolymerized)	PP-C	x	x	–
Polybutylene-1	PB-1	x	x	(x)

* Cross-linked polyethylene is not a specific piping material but rather a whole group of materials that cover a broad spectrum of differences in quality.

** Numerous kinds of polypropylene and polybutylene are offered, each with varying degrees of quality.

Table 9:1

Interpretation of the table:
x = common usage
(x) = usage not as common
– = not used

laid down for the specific purposes for which it will be used. The qualification should also be made here that these regulations only represent the minimum requirements. Just the mere fact that they are met still does not represent any guarantee of quality. Normally the requirements of the testing boards go significantly beyond the standards.

8. Is the time-to-failure strength documented?

The manufacturer should be able to provide evidence of the official testing of the hydrostatic time-to-failure behavior of the tubing.

The long-term testing should not be done on sample tubing provided by the raw-material supplier or on specially produced samples from the processor. Rather, it should be conducted on tubing from the manufacturer's regular production line.

The time-to-failure results should be provided for:

a) The highest operating temperature
b) Temperatures beyond those permissible for normal operation
c) Bent tubing
d) Tubing with predetermined breaking points (scratches)
e) Tubing that comes into contact with stress-crack inducing agents
f) PEX tubing made of PE that has been cross-linked in varying degrees. In each case, they should be tested as described in a) through e).

9. How resistant is the tubing to aging?

a) The resistance of a tubing to aging, that is, its resistance to degradation from thermo-oxidation, should be documented. This should be done both for tubing that is not under stress and for tubing that is put under stress by boiling. The boiling water used in the tests should be exchanged periodically (as proof that the stabilizer system does not wash out of the tubing material).
b) It should be possible to demonstrate that investigations of the aging and time-to-failure behavior of the tubing have been combined.

10. Has any official testing been done at installation sites?

One should also ask for results of tests conducted on tubing actually installed in the field. Some examples are:

a) Temperature-interval (fatigue) tests on:
    1. Pipe connectors (of different construction and brands)
    2. Pipes enclosed in concrete slabs
    3. Bent tubing
b) Other tests on pipe connectors:
    1. Tensile strength
    2. Rupture strength
    3. Impulse pressure
c) References

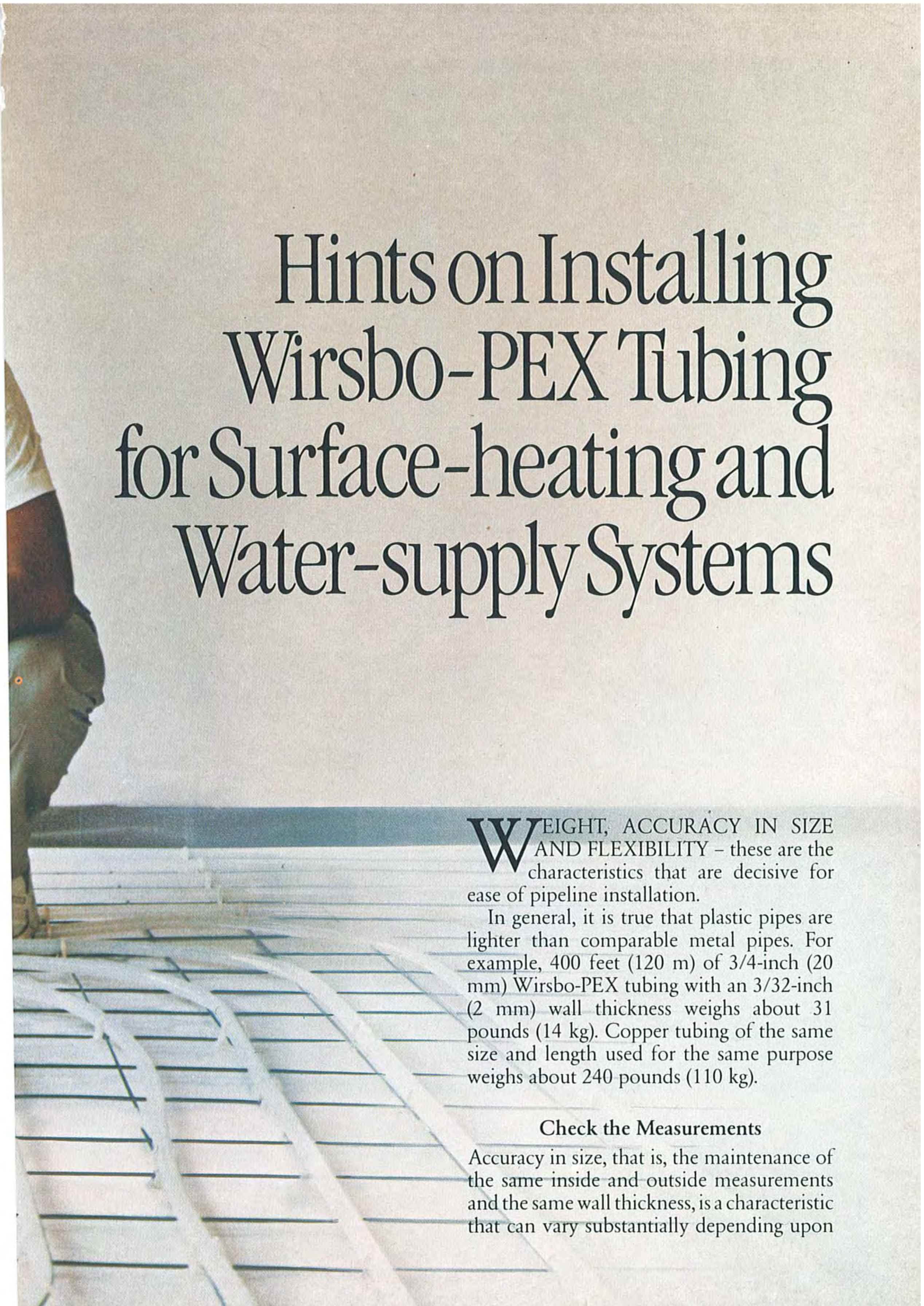
11. Are there any installation instructions and if so, what do they say?

In case the manufacturer provides any guidelines and instructions for installation, they should give information concerning the following items:

a) The permissible temperatures and the nominal pressure limit
b) Flexibility (limits)
c) Cold-breaking behavior (if apropos)
d) Resistance to ultraviolet rays
e) Fusibility
f) Flexibility when warm
g) Pipe-connector system
h) Elongation factor

12. What kind of data has been gathered concerning the tubing material.

a) Mechanical data
    1. Density
    2. Tensile strength
    3. E-modulus
    4. Elongation at breaking
    5. Impact strength
    6. Water absorption
    7. Coefficient of friction
    8. Surface tension
    9. Oxygen permeability
b) Thermal data
    1. Temperature limits
    2. Linear thermal-expansion coefficient
    3. Fusing temperature
    4. Specific heat
    5. Heat conductivity



Hints on Installing Wirsbo-PEX Tubing for Surface-heating and Water-supply Systems

WEIGHT, ACCURACY IN SIZE AND FLEXIBILITY – these are the characteristics that are decisive for ease of pipeline installation.

In general, it is true that plastic pipes are lighter than comparable metal pipes. For example, 400 feet (120 m) of 3/4-inch (20 mm) Wirsbo-PEX tubing with an 3/32-inch (2 mm) wall thickness weighs about 31 pounds (14 kg). Copper tubing of the same size and length used for the same purpose weighs about 240 pounds (110 kg).

Check the Measurements

Accuracy in size, that is, the maintenance of the same inside and outside measurements and the same wall thickness, is a characteristic that can vary substantially depending upon

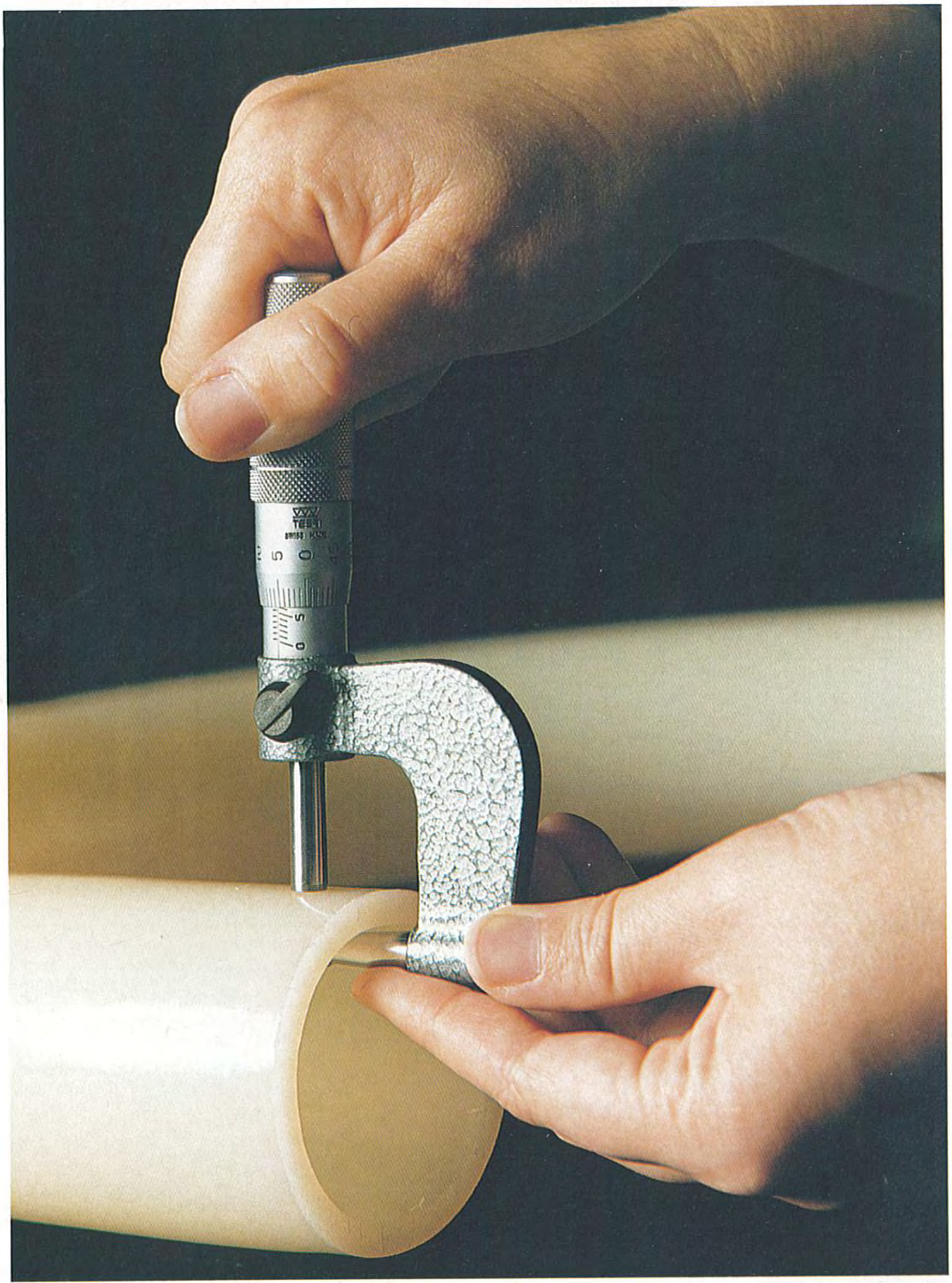


Plate 10:1

the type and brand of tubing. That is why it is necessary to make an urgent recommendation. Before using any type or brand of tubing that you have not used before, be sure to get a list of the manufacturer's specifications along with several samples that can be used for testing. Whether or not the connectors fit well on the tubing gives a quite reliable indication of how easy it is to install.

The Forgiving Pipe

The ease with which plastic tubing can be laid out and shaped according to the existing requirements is probably the greatest advantage of plastic pipes over those made of metal. Still, it is true that there can be substantial differences among the individual types of plastic tubing. An important indication of just how great these differences are can be gained by simply trying to bend a few of the pipes.

In the case of Wirsbo-PEX tubing, there is no need to fear brittleness even in the case of extreme cold down to a temperature of −148°F. (−100°C.). 3/4-inch (20 mm) tubing with a 3/32-inch (2 mm) wall thickness can be bent cold without difficulty up to 180°degrees with a minimum bending radius of 6 inches (150 mm (center to center). Hot bending is possible with a minimum of up to half that radius.

In the case of a mistake when bending, such as for example, causing a kink, Wirsbo-PEX tubing behaves very "forgivingly". By carefully heating the tubing with a hot-air gun up to a temperature of about 275°F. (135°C.) and then cooling it down again, the tubing recovers its original shape and strength. As the plastics experts sometimes put it, the tubing material has a thermal memory.

Plate 10:2

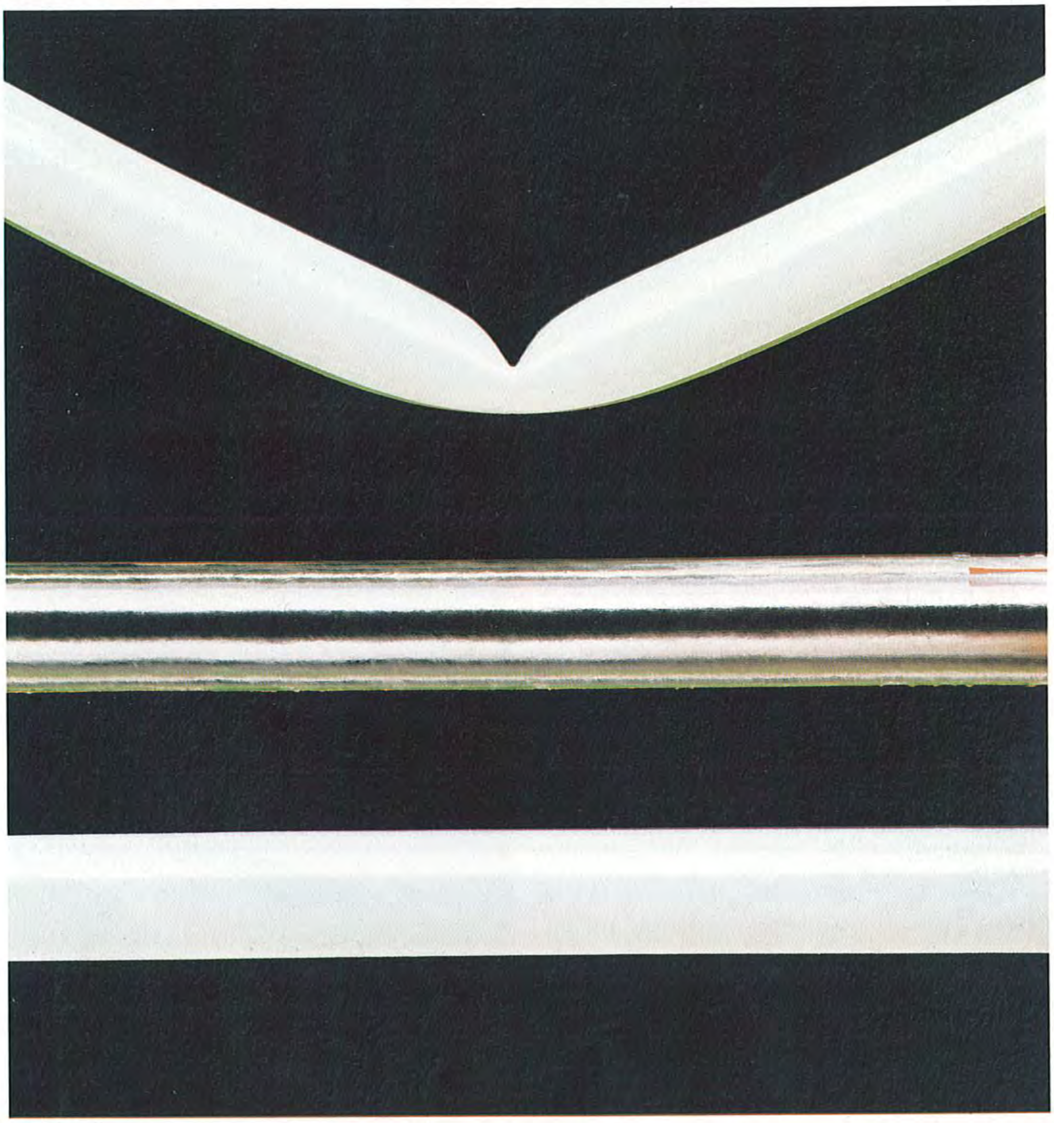


Plate 10:3

ONLY A FEW SIMPLE TOOLS. The person who installs Wirsbo-PEX tubing does not have to bring along a huge box full of tools. What is more, every coil of tubing is accompanied by brief installation instructions.

Only one simple tool is needed for cutting the tubing. It should be noted that in order to ensure optimum sealing with connectors, the cuts should be made at a 90 degree angle.

To prevent dirt from getting into the tubing, open ends should be covered with caps. A supply is packed along with the tubing.

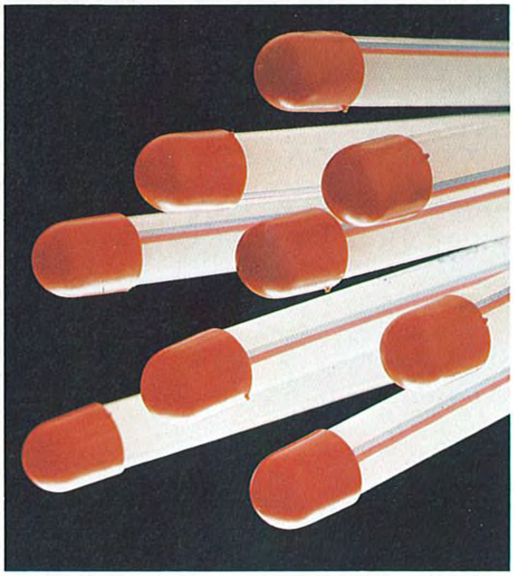


Plate 10:4

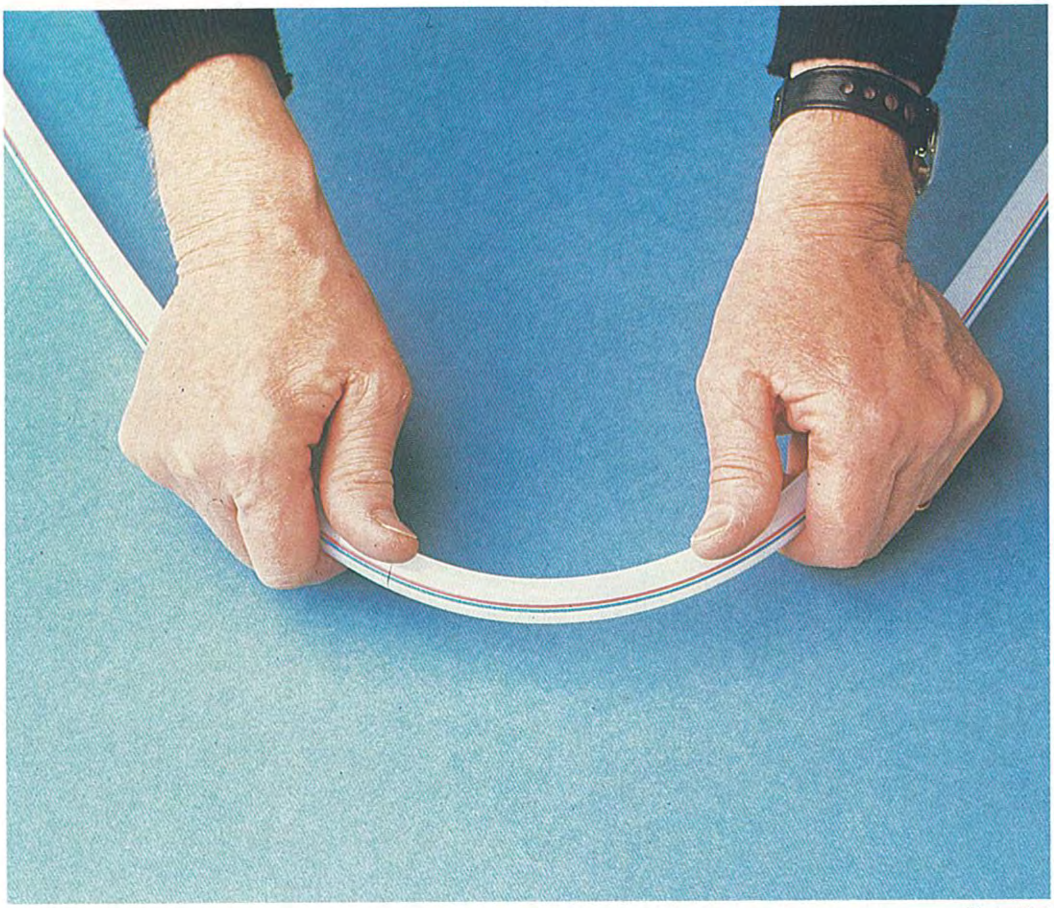


Plate 10:5

Wirsbo-PEX tubing can be bent cold or hot as desired. When the tubing being used has a small diameter, it is possible to bend it by hand.

There are devices (cold-bending tools) available for use for cold bending at 90-degree angles when a small bending radius is required (for 3/8- to 3/4-inch (10 to 20 mm) tubing.

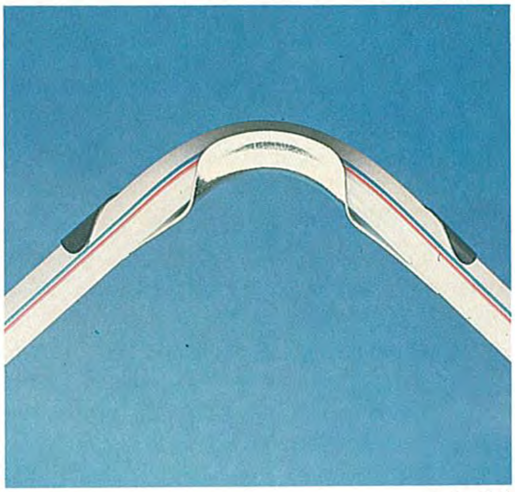


Plate 10:6

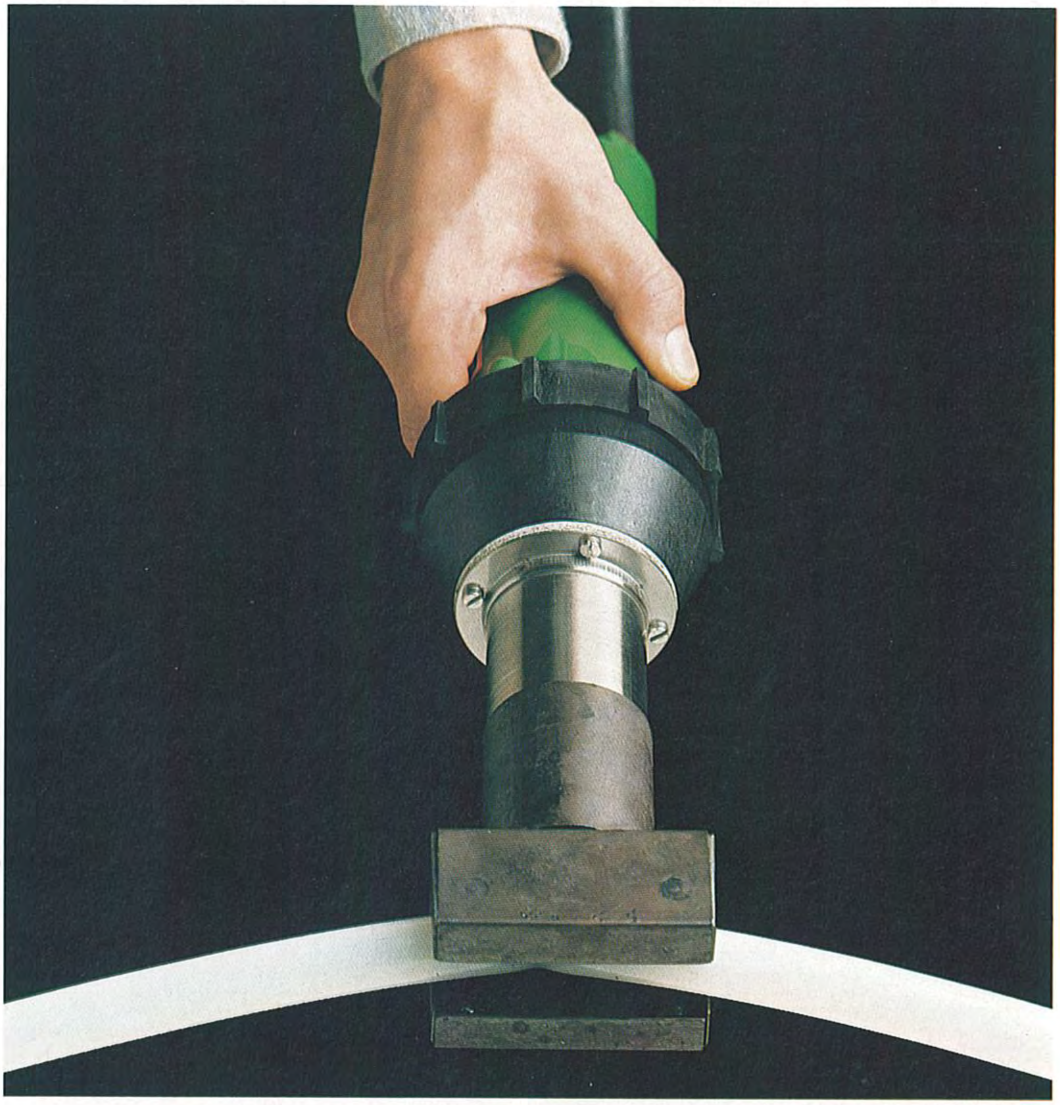


Plate 10:7

When not bending, the tubing may not be brought into contact with an open flame. For this reason, a hot-air gun with a socalled "heating jacket" shoud be used.

This is the method to be used for hot bending. Heat the area to be bent up to about 275° F. (145° C.). (The tubing becomes transparent at that temperature.) Then place the tubing over a simple bending jig or form and create the bend. After that let the tubing cool in water or in the air.

Table 10:1 shows the smallest allowable bending radius for each of the individual tubing sizes and bending methods.

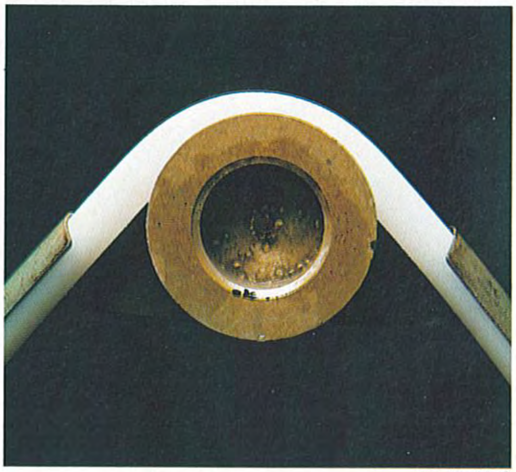


Plate 10:8

Smallest Bending Radius inches and (mm)							
Tubing Size		Hot Bending		Cold Bending			
				Bending Tool			
				with		without	
in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
0.39	(10)	0.79	(20)	1.18	(30)	1.77	(~45)
0.47	(12)	0.98	(25)	1.18	(30)	2.36	(60)
0.59	(15)	1.34	(34)	1.77	(45)	2.95	(75)
0.63	(16)	1.41	(36)	2.56	(65)	3.07	(78)
0.71	(18)	1.58	(40)	2.76	(70)	3.54	(90)
0.79	(20)	1.77	(45)	3.94	(100)	3.94	(100)
0.87	(22)	1.89	(48)		—	4.33	(110)
0.98	(25)	2.01	(51)		—	4.92	(125)
1.10	(28)	2.44	(62)		—	5.51	(140)

Table 10:1

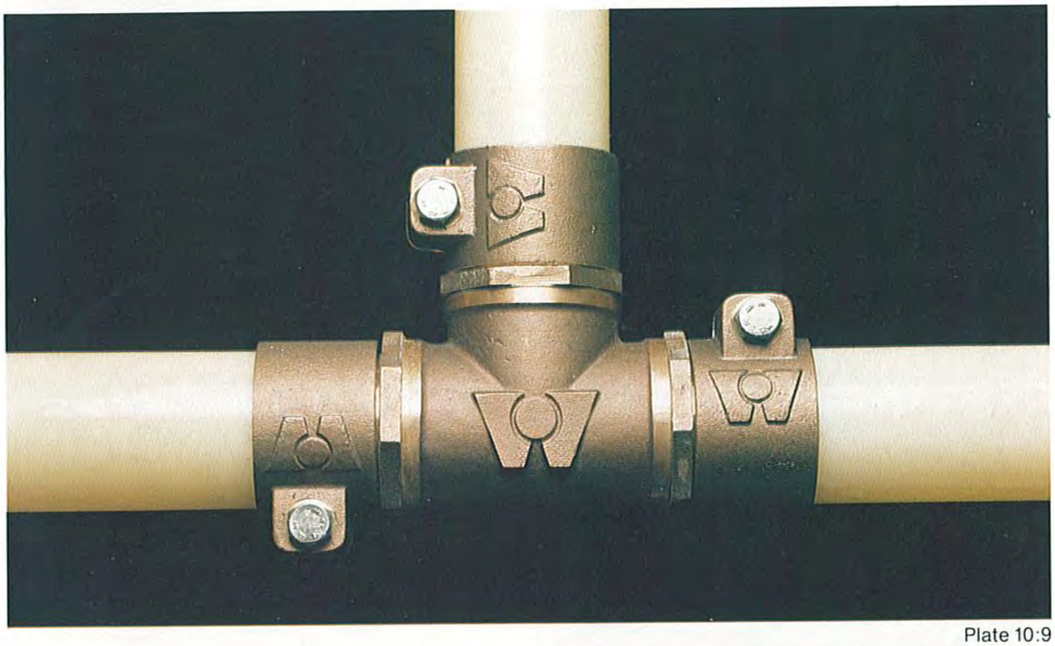


Plate 10:9

When bending tubing with larger diameters than those shown in the table, please ask Wirsbo or your dealer for advice.

Pipe Connectors

Wirsbo-PEX tubing should be connected with compression connectors. There are various versions of that type of connector on the market. Your Wirsbo dealer can make recommendations to help you in making a choice among them.

An insert sleeve should always be used when making a connection. When joining the tubing to valves, one-sided, threaded connectors are permitted. Connections made with them are less bulky. In any case, all the instructions given by the fitting manufacturer should be followed.

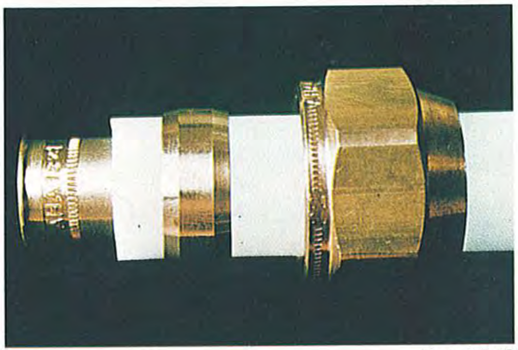


Plate 10:10

Plate 10:11

MUCH LOWER INSTALLATION COSTS are what you get by using Wirsbo-PEX tubing for drinking-water and warm-water systems. You can now make use of the hollow spaces in buildings. If you are looking for places to lay pipelines, take into account the already existing hollow spaces such as shafts, hollow ceilings, walls with furring strips, channels etc. Such hollow spaces allow for both hidden installation and later access to the system.

Plate 10:12

Plate 10:13

Installing Tubing in Conduit

A variant of laying tubing in existing hollow spaces that shares in many of its advantages is the insertion of the tubing into conduit. The conduit to be used for this purpose should be made of thermostabilized PE. Installation in both concrete and cement-block walls are possible uses for this technique. The most important advantages of the conduit technique are the already mentioned possibility of later access and the almost complete exclusion of danger due to water damage.

Conduit can be used from the lowest installation temperature to the highest service temperature without difficulty. In some cases, the hot-water and cold-water pipes can share a common conduit. As long as it is not a circulating system, there will not be any noticeable rise in the temperature of the cold water. The dead-air space in a conduit that is tightly closed at each end has outstanding insulating properties. Additional thermal insulation is only seldom necessary.

With its ideal degree of stiffness and flexibility, Wirsbo-PEX tubing is very good for insertion into conduit. Bends in the conduit are not a problem for this type of installation.

The installation of a junction box at the end of the conduit is advisable.

As a substitute for or extension of a conduit, it is also possible to lay the tubing on or between furring strips.

Wherever there are built-in appliances (such as in kitchens), the bases are available for laying pipes.

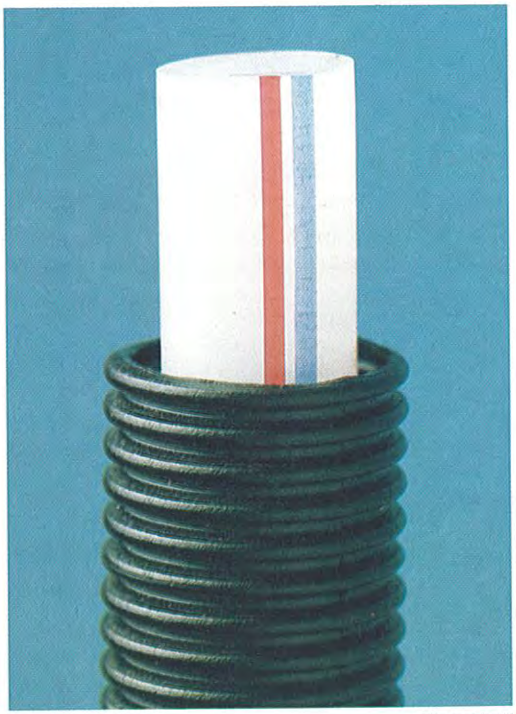


Plate 10:14

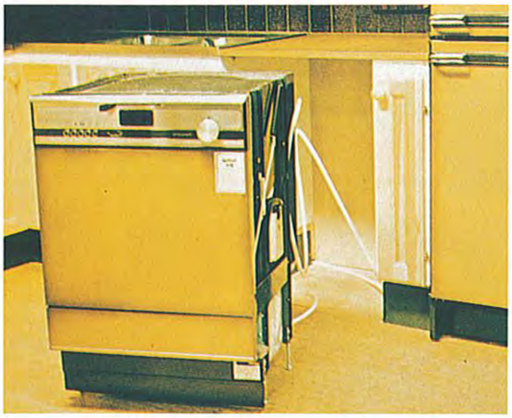


Plate 10:15

When used with an automatic dishwasher, the tubing can be coiled into a loop just before it is connected to the machine. It can then be pulled out for maintenance without disconnecting the tubing.

In floors with a thick, multi-layered construction, the tubing can be installed in a routered groove in one of the layers.

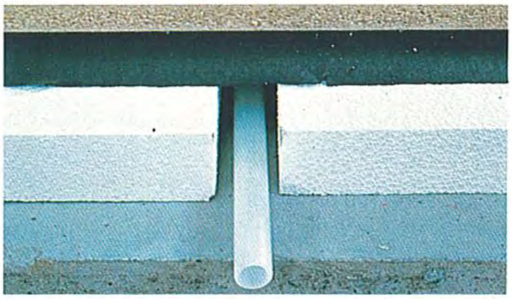


Plate 10:16

In concrete ceilings and in masonary or concrete walls, it is often possible to plan channels or grooves for laying tubing.

When it is available, the hollow area or crawl space underneath the ground floor of a building is suitable for installing pipes. The tubing is laid upon a bed made of foil and insulation and is covered with a second layer of insulation.

Plate 10:17

Wirsbo-PEX tubing is ideal for installation in concrete. It is corrosion and abrasion resistant even at high flow rates and does not tend

Plate 10:18

toward formation of cracks at bends or curved areas. The degree of expansion is held within limits so that even when installed under thin layers of cement, cracks do not tend to form.

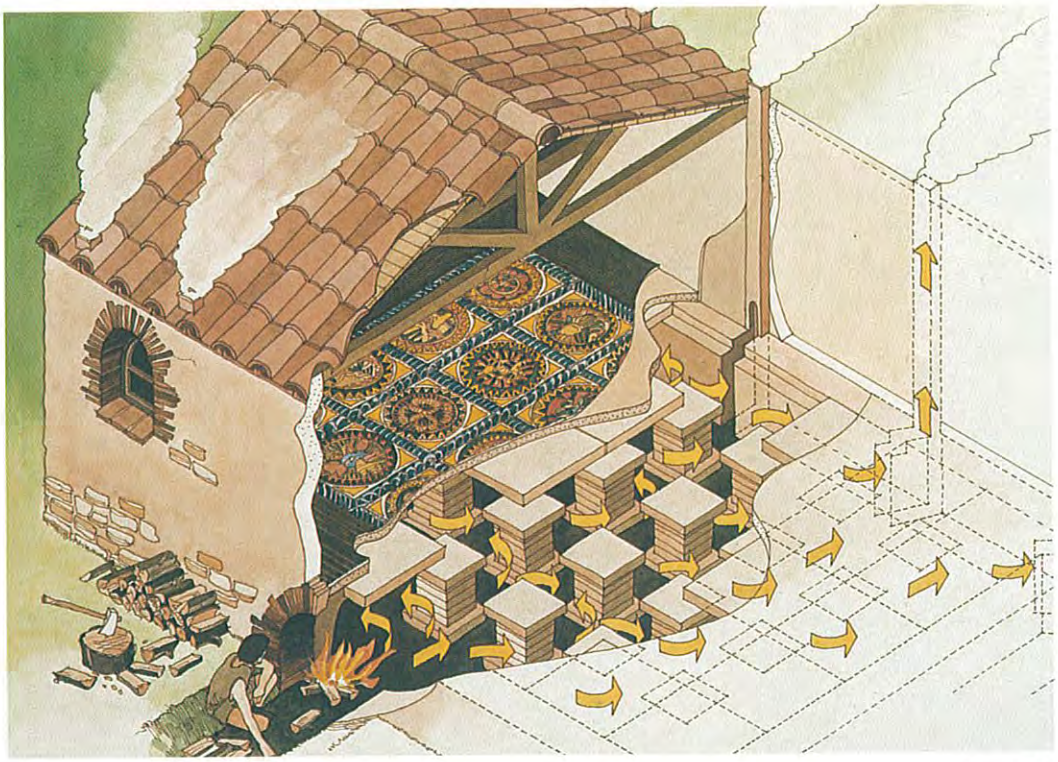


Plate 10:19

WARM FLOORS are not new. Underfloor heating was not invented by modern man. Rather, it was already in existence thousands of years ago. At that time the heat was carried by warm air. Basically, that is all that has changed since then. Today, as you know, one uses water for this purpose since it is technically more effective.

This does not mean that the use of water is entirely without problems. Steel pipes can be attacked by rust. Copper pipes tend toward the formation of fatigue cracks because of their movement during expansion and contraction. Another danger is dependent upon the number of possible leakage points. It is greater when there are a very large number of connectors in the system.

A piping system consisting of plastic tubing as supplied by Wirsbo-PEX tubing provides ideal solutions for all these problems.

The Ideal Curve Is Almost Achieved

There are good reasons why surface heating and especially hot-water under-floor heating are becoming more popular. The cost of heating is continually rising. This fact is forcing a growing number of people to resort to various methods of insulation. That, in turn, makes it more likely that some form of low-temperature heating method, such as hot-water under-floor heating, will be seriously considered. The trend away from oil makes the use of substitute forms of energy even more inviting. Some of these techniques, such as solar energy or geothermal energy reach their greatest effectiveness exactly in the area of low-temperature heat. For that reason, they are especially attractive for use in surface heating.

The use of under-floor heating also addresses the desire for a greater degree of living comfort. The diagram shown in Plate 10:20 i s based upon the results of a study undertaken to discover the ideal temperature distribution throughout the area of a room. The comparison shows that the distribution curve for floor heating comes the closest of all to the ideal heat-distribution curve.

Millions of Feet Per Year

Every year there are millions of feet of Wirsbo-PEX tubing installed for hot and cold wa-

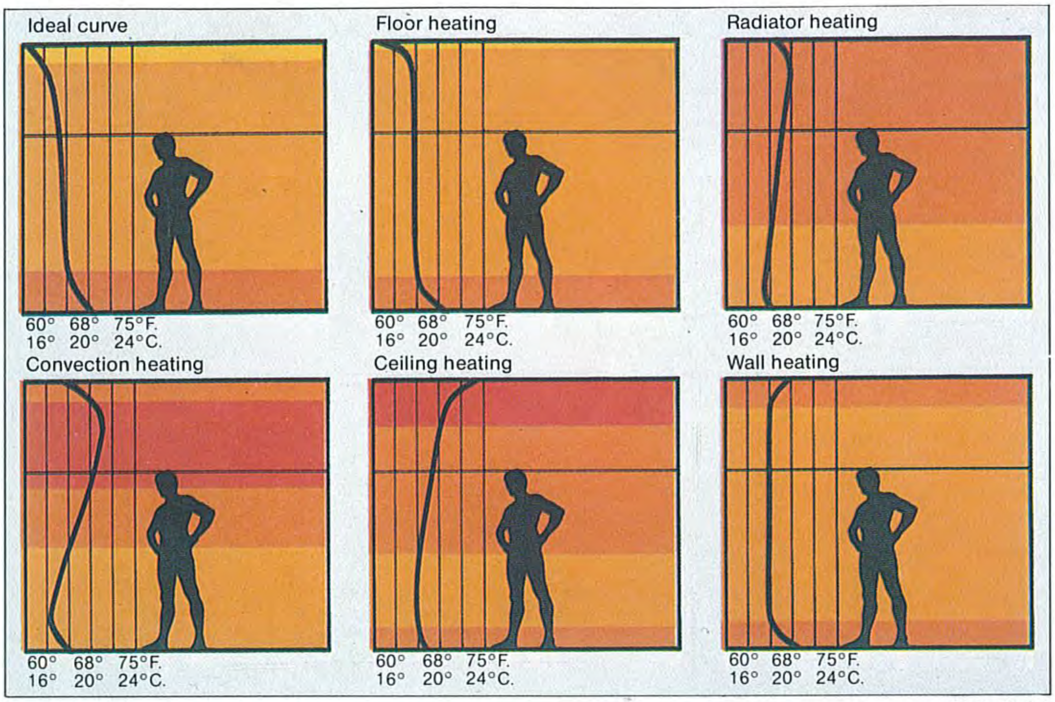


Plate 10:20

ter supply lines and for under-floor heating. In West Germany, Switzerland, Italy, Austria, Holland, Belgium, Spain, Sweden, Norway and Denmark among other countries, an ever-increasing number of people are making the decision to use Wirsbo-PEX tubing for heating systems.

The reasons for this are to be found in a whole list of advantages. Wirsbo-PEX tubing really is corrosion resistant, free of health threatening additives, soft and flexible. Scratches, bends and chemicals that are sometimes found in places where it is used do not affect its durability. The various forces released by thermal expansion are buffered by the tubing material itself. (The tubing and the surrounding concrete are not damaged.) Finally, because of the overall length in which it is produced, installation is possible with a minimum number of joints.

Wirsbo-PEX tubing is the heavyweight among the leading European water-supply and surface-heating systems. Your Wirsbo representatives are more than happy to put their system descriptions, installation instructions and cost estimates at your disposal.

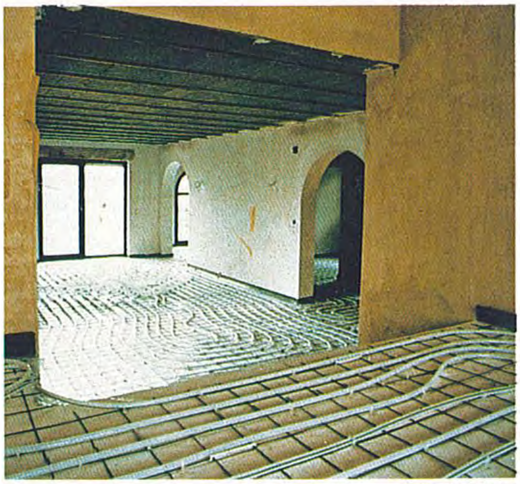


Plate 10:21

Plate 10:22

Symbol	Quantity	Unit
l	Length (Pipe length)	ft
d	Diameter (general)	in
d_o	Outside diameter	in
d_i	Inside diameter	in
r	Tubing radius	in
r_a	Average tubing radius	in
s	Wall thickness (of tubing)	in
δ	Thickness, layer thickness	in
A	Surface, cross section	ft^2
V	Volume	ft^3
h	Height	ft
Δh	Difference in height	ft
v	Velocity	ft/sec
g	Gravitational acceleration (local) (≈ 32.17)	ft/sec
R	Ratio of diameter to wall thickness (D/s) (Standard Dimension Ratio, SDR)	Dimensionless
m	Mass (weight)	lb_m
m_T	Tubing weight	lb_m
m_M	Weight of medium in tubing	lb_m
ρ	Density	lb_m/ft^3
ρ_T	Density of tubing material	lb_m/ft^3
ρ_M	Density of medium	lb_m/ft^3
ρ_W	Density of water	lb_m/ft^3
F	Force	
lb_F		
p	Pressure	psi (lb_F/in^2)
Δp	Difference in pressure	psi (lb_F/in^2)
σ	Normal stress (tension) Also: Wall stress, hoop stress	psi (lb/in)
$\dot{V}$	Throughput volume	gpm (gallons/min.)
υ	Kinematic viscosity	ft^2/sec
υ_w	Kinematic viscosity of water	ft^2/sec
Re	Reynolds number	Dimensionless
c	Pipe friction index*	Dimensionless
T	Temperature (thermodynamic)	R (= °F + 460)
t	Temperature	°F
a	Linear-expansion coefficient	ft/ft · R
Q	Amount of heat	Btu/hr
Q_l	Heat loss	Btu/hr
λ	Thermal conductivity	Btu/hr · ft · °F
α	Thermal-transfer coefficient	Btu/hr · ft^2 · °F
k	Thermal-penetration coefficient	Btu/hr · ft^2 · °F
Λ	Thermal-conductance coefficient	Btu/hr · ft^2 · °F
R_t	Thermal-penetration resistance	ft^2 · hr · °F/Btu
π	3.1416	
ln	Natural logarithm	

* In technical literature λ is often used.

FORMULAS USED FOR PIPELINE CALCULATIONS

1. Piping weight based upon a length of 1 foot
$m_T = \pi/144 \cdot (d_o - s) \cdot s \cdot l \cdot \rho_T$ (lb_m) $l = 1$ ft

2. Piping capacity based upon a length of 1 foot
$V = \pi/576 \cdot d_i^2 \cdot l$ (ft^3) $l = 1$ ft

3. Weight of the medium in the pipe based on a length of 1 foot
$m_M = \pi/576 \cdot d_i^2 \cdot \rho_M \cdot l$ (lb_m) $l = 1$ ft

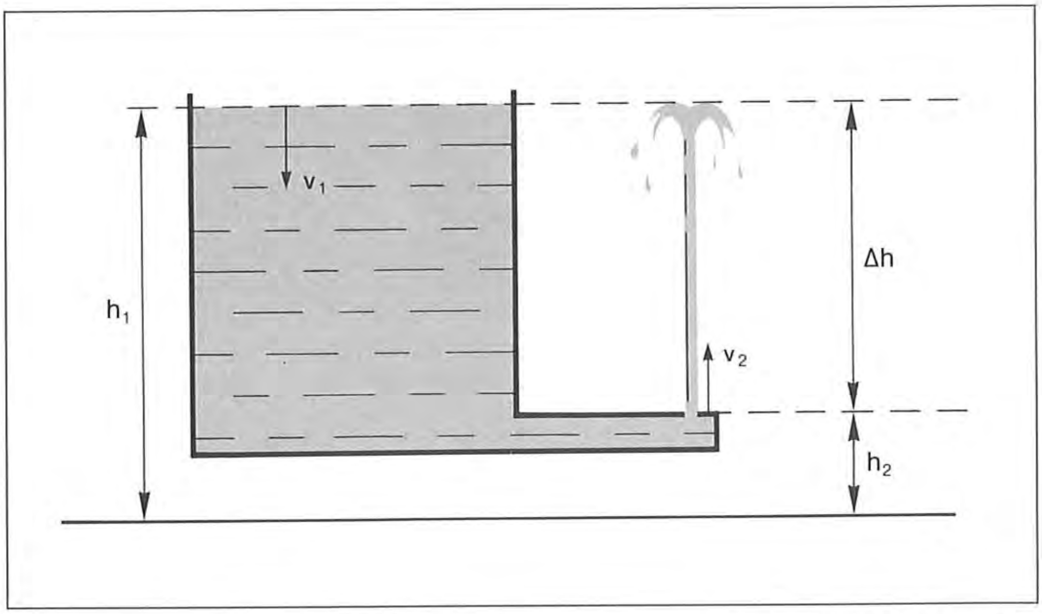
4. Density of water as a function of temperature (empirical, numerical-value equation that is valid for the range of 50 to 200°F)
$\rho_W \approx 62.2685 + .0077761 \cdot t - .0001252 \cdot t^2 + .000000157 \cdot t^3$ (lb_m/ft^3)

5. Kinematic viscosity of water as a function of temperature (empirical, numerical-value equation that is valid for the range of 50 to 200°F)
$\upsilon_W \approx 10^{-6}$ $(28.001587 - .371028 \cdot t + .0020269 \cdot t^2 - .00000384 \cdot t^3$ (ft^2/sec)

6. Pressure drop per foot of pipe
$\Delta p = c \cdot \rho \cdot v^2 \cdot l/24 \cdot d_i^2 \cdot g$ (psi)

6.1 c is the pipe friction index. The following equation is sufficiently precise for flowing water in any of the various Wirsbo-PEX tubings (Nikuradse's formula)
$c = .0032 + .221 \cdot Re^{-.237}$ (good for $10^4 < Re < 10^8$)

7. This isolates and illustrates the water head $v^2/2$ g from the Bernoullian equation

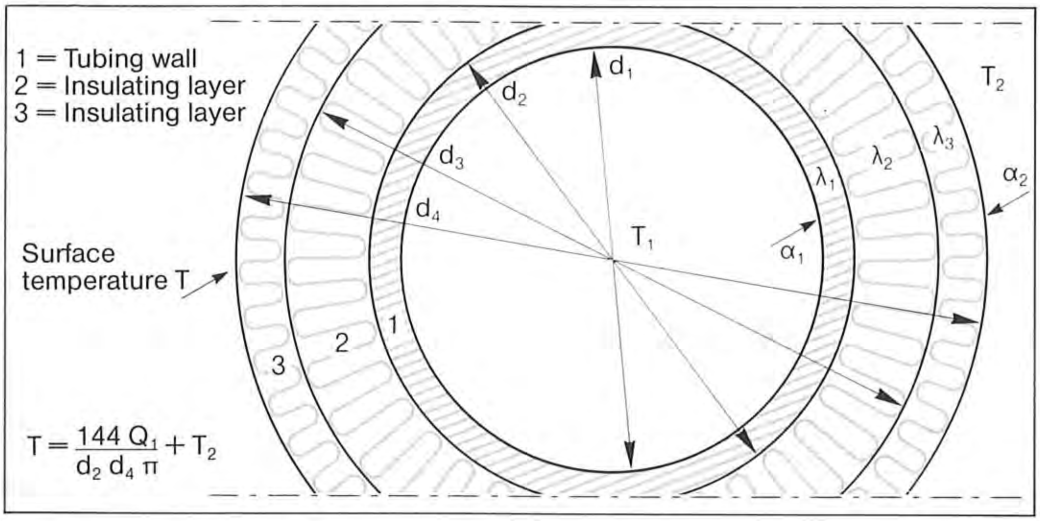


Ignoring the effect of fluid friction and assuming a large volume of liquid (with a velocity v_1 approaching zero), the exit velocity v_2 is arrived at from the following two equations:

7.1 $\Delta h = h_1 - h_2 = v_2^2/2 \cdot g$ (static head) (ft)

7.2 $v_2 = \sqrt{2 \cdot g \cdot \Delta h}$ (exit velocity) (ft/sec)

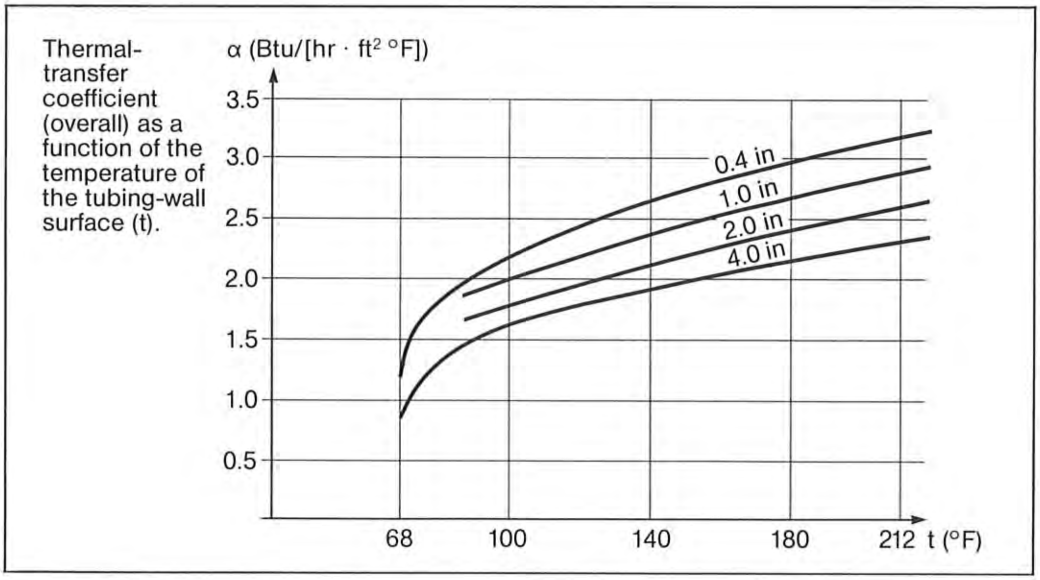
8. Heat loss in pipelines based upon a length of 1 foot as illustrated on an exposed cross-section of tubing that contains two layers of insulation.



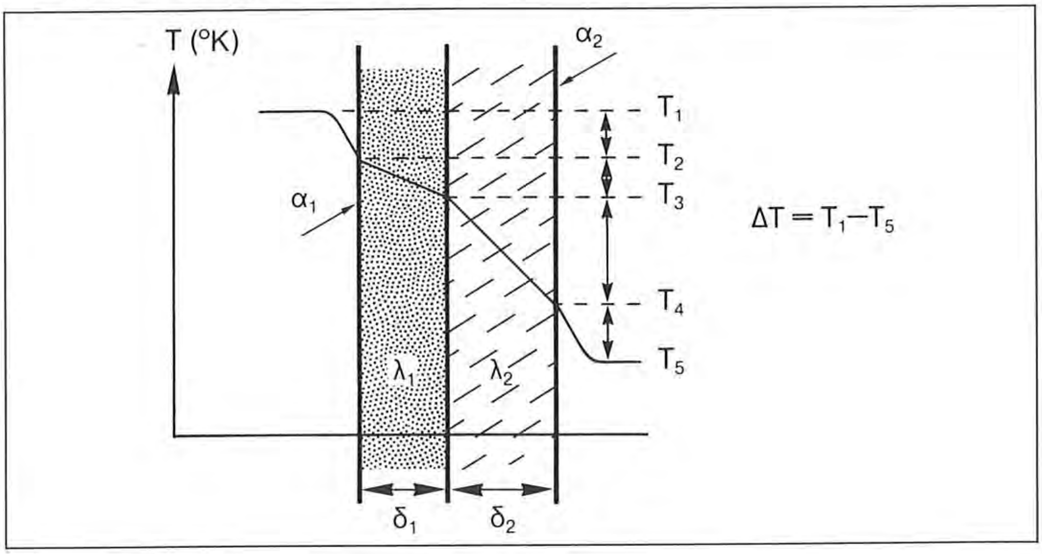
$$Q_L = \frac{\pi \cdot l \cdot (T_1 - T_2)}{12/(\alpha_1 \cdot d_1) + 12/(\alpha_2 \cdot d_4) + \ln(d_2/d_1) \cdot 1/(2 \cdot \lambda_1) + \ln(d_3/d_2) \cdot 1/(2 \cdot \lambda_2) \ldots \ldots + \ln(d_4/d_3) \cdot 1/(2 \cdot \lambda_3)} \quad \text{(Btu/hr)} \quad l = 1\text{ ft}$$

In cases where the liquid to be carried in the pipeline is warm, the term that contains the thermal-transfer coefficient α_1 is low enough to ignore when compared to the other terms of the equation. If the tubing has no insulating layers, then $d_2 = d_3 = d_4$. The natural logarithm of the fractions d_3/d_2 or d_4/d_3 (which at that point would each take on the value of 1) would be zero. The corresponding terms of the equation would be dropped.

8.1 The thermal transfer coefficient takes into account the transfer of heat due to convection and due to radiation. The following graph shows, with adequate precision, the thermal-transfer coefficients of insulated and noninsulated tubing under free-flow conditions with a surrounding air temperature of 68°F.



9. Heat loss through uniform layers (walls) based upon a 1 square foot surface.

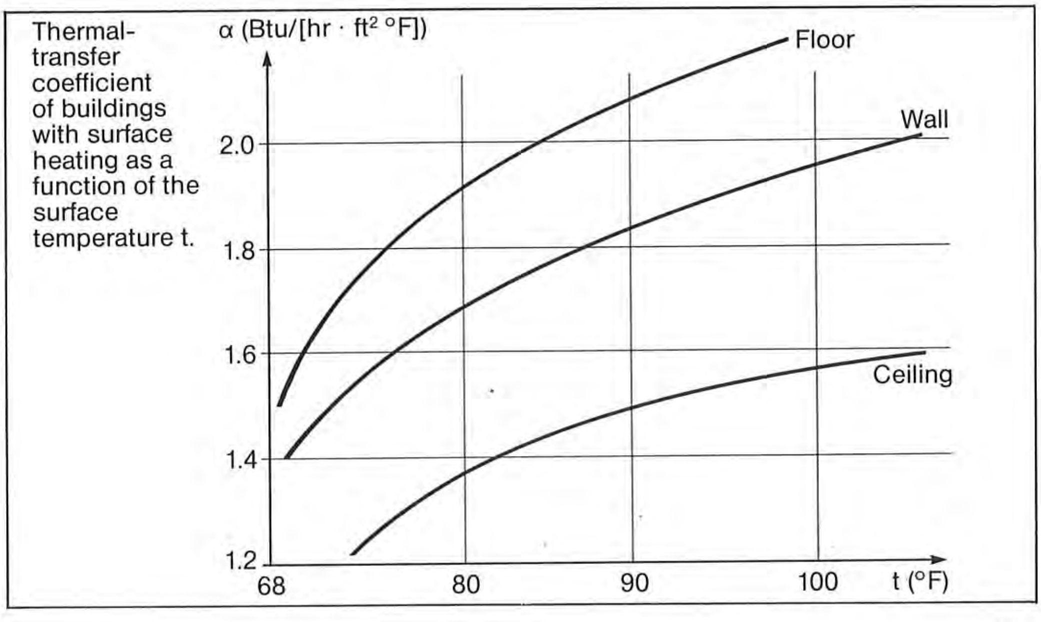


$$Q = \frac{A \cdot \Delta T}{1/\alpha_1 + \delta_1/(12 \cdot \lambda_1) + \delta_2/(12 \cdot \lambda_2) + 1/\alpha_2} = K \cdot A \cdot \Delta T \qquad \text{(Btu/hr)} \quad A = 1\ \text{ft}^2$$

9.1 k is the thermal-penetration coefficient. Its reciprocal value 1/k is the thermal-penetration resistance.

$$1/k = 1/\alpha_1 + \delta_1/(12 \cdot \lambda_1) + \delta_2/(12 \cdot \lambda_2) + 1/\alpha_2 \qquad (\text{hr} \cdot \text{ft}^2 \cdot {}^\circ\text{F/Btu})$$

9.2 The thermal-transfer coefficient takes into account the transfer of heat due to convection and due to radiation. The following graph illustrates with adequate precision the sum of the thermal-transfer coefficients on smooth surfaces without any forced air movement and at a surrounding temperature of 68°F.



10.2 The relationship between the dimensions of a pipe, the internal pressure and the pressure on the piping wall (circumferential stress, hoop stress σ). According to international agreement the following equation is valid:

10.1 $p = 2 \cdot \sigma \cdot s/(d - s)$ (psi)

or transposed

10.2 $\sigma = p \cdot (d_o - s)/2\ s = p \cdot r_a/s$ (psi)

or transposed

10.3 $s = p \cdot d_o/(2 \cdot \sigma + p)$ (in)

or transposed from 10.2

10.4 $2\ \sigma/p = d_o/s - 1 = R\ - 1$ (dimensionless)

For the relationship between the outside diameter and the wall thickness, we have introduced here the value $R = d_o/s$. In English speaking countries and especially in United States, it is also referred to as the SDR or Standard Dimension Ratio.

10.5 Another relationship between the diameter and the wall thickness is shown in the equation $P = d_1/s$. This is also sometimes referred to as the SDR but that is incorrect. If we add the equation in 10.2 the result is the following equation:

$2\ \sigma/p = d_i/s + 1 = P + 1$ (dimensionless)

11. The following are various ways of expressing the throughput volume of pipelines. They are all derived from formula 2 without taking length into account.

11.1 $\dot{V} = 1/77.01 \cdot \pi \cdot d_i^2 \cdot v$ (gallons/sec)

11.2 $\dot{V} = 1/576 \cdot \pi \cdot d_i^2 \cdot v$ (ft/sec)

11.3 $\dot{V} = 6.25 \cdot \pi \cdot d_i^2 \cdot v$ (ft/hr)

11.4 $\dot{V} = .7791 \cdot \pi \cdot d_i^2 \cdot v$ (gpm)(gallons/min)

11.5 $\dot{V} = 46.75 \cdot \pi \cdot d_i^2 \cdot v$ (gallons/hour)

In the preceding formulas it is possible to insert $d_i = d_o - 2\ s$ as an alternative.

12. Heat loss for water as a function of the throughput volume and the difference in temperature.

12.1 $Q_l = 8.324\ \dot{V} \cdot \Delta T$ (Btu/hr)

when V is expressed in gallons/hour and ΔT equals the drop in temperature along the line.

12.2 $Q_l = 1222 \cdot d_i^2 \cdot v \cdot \Delta T$ (Btu/hr)

CONVERSION FACTORS

Metric and nonmetric (English and American) equivalents

1. Length (l)

meter m	inch in	foot ft	yard yd	mile ml	nautical mile
1	39,370	3,280 8	1,093 6	0,621 37 · 10^{-3}	0,539 96 · 10^{-3}
25,4 · 10^{-3}	1	83,333 · 10^{-3}	27,778 · 10^{-3}	15,783 · 10^{-6}	13,715 · 10^{-6}
0,304 8	12	1	0,333 33	0,189 39 · 10^{-3}	0,164 58 · 10^{-3}
0,914 4	36	3	1	0,568 18 · 10^{-3}	0,493 74 · 10^{-3}
1,609 3 · 10^{3}	63,36 · 10^{3}	5,28 · 10^{3}	1,76 · 10^{3}	1	0,868 98
1,852 · 10^{3}	72,913 · 10^{3}	6.076 1 · 10^{3}	2,025 4 · 10^{3}	1,150 8	1

1 micron (μ) = 10^{-6} meters, 1 ångström (Å) = 10^{-10} meters

2. Surface (A)

m^2	in^2	ft^2	yd^2	acre	$mile^2$
1	1,550 0 · 10^{3}	10,764	1,196 0	0,247 10 · 10^{-3}	0,386 10 · 10^{-6}
0,645 16 · 10^{-3}	1	6,944 4 · 10^{-3}	0,771 61 · 10^{-3}	0,159 42 · 10^{-6}	0,249 10 · 10^{-9}
92,903 · 10^{-3}	144	1	0,111 11	22,957 · 10^{-6}	35,870 · 10^{-9}
0,836 13	1,296 · 10^{3}	9	1	0,206 61 · 10^{-3}	0,322 83 · 10^{-6}
4,046 9 · 10^{3}	6,272 6 · 10^{6}	43,56 · 10^{3}	4,84 · 10^{3}	1	1,562 5 · 10^{-3}
2,590 0 · 10^{6}	4.014 5 · 10^{9}	27,878 · 10^{6}	3,097 6 · 10^{6}	640	1

1 hectare (ha) = 10^4 m^2

3. Volume (V)

m^3	in^3	ft^3	yd^3	imp. gallon	US gallon
1	61,024 · 10^{3}	35,315	1,308 0	219,97	264,17
16,387 · 10^{-6}	1	0,578 70 · 10^{-3}	21,434 · 10^{-6}	3,604 6 · 10^{-3}	4,329 0 · 10^{-3}
28,317 · 10^{-3}	1,728 · 10^{3}	1	37,037 · 10^{-3}	6,228 8	7,480 5
0,764 56	46,656 · 10^{3}	27	1	168,18	201,97
4,546 1 · 10^{-3}	277,42	0,160 54	5,946 1 · 10^{-3}	1	1,201 0
3,785 4 · 10^{-3}	231	0,133 68	4,951 1 · 10^{-3}	0,832 68	1

1 liter (l) = 10^{-3} m^3

4. Mass (m), weight

kg	pound lb	slug	ounce oz	brit. hundred-weight cwt	brit. ton	US cwt sh cwt	US ton sh tn
1	2,204 6	68,522 · 10^{-3}	35,274	19,684 · 10^{-3}	0,984 21 · 10^{-3}	22,046 · 10^{-3}	1,102 3 · 10^{-3}
0,453 59	1	31,081 · 10^{-3}	16	8,928 6 · 10^{-3}	0,446 43 · 10^{-3}	10 · 10^{-3}	0,5 · 10^{-3}
14,594	32,174	1	514,79	0,287 27	14,363 · 10^{-3}	0,321 74	16,087 · 10^{-3}
28,350 · 10^{-3}	62,5 · 10^{-3}	1,942 6 · 10^{-3}	1	0,558 04 · 10^{-3}	27,902 · 10^{-6}	0,625 · 10^{-3}	31,25 · 10^{-6}
50,802	112	3,481 1	1,792 · 10^{3}	1	50 · 10^{-3}	1,12	56 · 10^{-3}
1,016 1 · 10^{3}	2,24 · 10^{3}	69,621	35,84 · 10^{3}	20	1	22,4	1,12
45,359	100	3,108 1	1,6 · 10^{3}	0,892 86	44,643 · 10^{-3}	1	50 · 10^{-3}
907,19	2 · 10^{3}	62,162	32 · 10^{3}	17,857	0,892 86	20	1

1 slug = 1 lbf · s^2/ft
Measurements used in the USA:
US cwt: short hundredweight; british cwt: long hundredweight
US ton: short ton; british ton: long ton

5. Velocity (v)

m/s	km/h	ft/s	mile/h	Knots kn/h
1	3,6	3,280 8	2,236 9	1,943 8
0,277 78	1	0,911 34	0,621 37	0,539 96
0,304 8	1,097 3	1	0,681 82	0,592 48
0,447 04	1,609 3	1,466 7	1	0,868 98
0,514 44	1,852	1,687 8	1,150 8	1

6. Density (ρ)

kg/m^3	lb/in^3	lb/ft^3
1	36,127 · 10^{-6}	62,428 · 10^{-3}
10^{3}	36,127 · 10^{-3}	62,428
27,680 · 10^{3}	1	1,728 · 10^{3}
16,019	0,578 70 · 10^{-3}	1

7. Force (F), Gravity (G)

Newton N	dyne	kilopound kp	pound-force lbf
1	0,1 · 10^{6}	0,101 97	0,224 81
10 · 10^{-6}	1	1,019 7 · 10^{-6}	2,248 1 · 10^{-6}
9,806 6	0,980 66 · 10^{6}	1	2,204 6
4,448 2	0,444 82 · 10^{6}	0,453 59	1

8. Momentum (M)

Nm	kpm	lbf – in	lbf – ft
1	0,101 97	8,850 8	0,737 56
9,806 6	1	86,796	7,233 0
0,112 99	11,521 · 10^{-3}	1	83,333 · 10^{-3}
1,355 8	0,138 26	12	1

9. Pressure (p), normal stress (σ)

Pascal Pa	bar	Technical atmospheres	kp/mm^2	Torr (mm HG)	Physical atmospheres	lbf/in^2
1	10 · 10^{-6}	10.197 · 10^{-6}	0,101 97 · 10^{-6}	7,500 6 · 10^{-3}	9,869 2 · 10^{-6}	0,145 04 · 10^{-3}
100 · 10^{3}	1	1.019 7	10,197 · 10^{-3}	750,06	0,986 92	14,504
98,066 · 10^{3}	0,980 66	1	10 · 10^{-3}	735,56	0,967 84	14,223
9,806 6 · 10^{6}	98,066	100	1	73,556 · 10^{3}	96,784	1,422 3 · 10^{3}
133,32	1,333 2 · 10^{-3}	1,359 5 · 10^{-3}	13,595 · 10^{-6}	1	1,315 8 · 10^{-3}	19,337 · 10^{-3}
101,32 · 10^{3}	1,013 2	1,033 2	10,332 · 10^{-3}	760	1	14,696
6,894 8 · 10^{3}	68,948 · 10^{-3}	70,307 · 10^{-3}	0,703 07 · 10^{-3}	51,715	68,046 · 10^{-3}	1

1 mWs = 9,81 · 10^{3} Pa

10. Energy (E), Work (W)

Joule J	Kilowatt hours kWh	kpm	Kilocalories kcal	Horsepower hours hp/h	ft · lbf	Brit. thermal unit Btu
1	0,277 78 · 10^{-6}	0,101 97	0,238 85 · 10^{-3}	0,377 67 · 10^{-6}	0,737 56	0,947 82 · 10^{-3}
3,6 · 10^{6}	1	0,367 10 · 10^{6}	859,85	1,359 6	2,655 2 · 10^{6}	3,412 1 · 10^{3}
9,806 6	2,724 1 · 10^{-6}	1	2,342 3 · 10^{-3}	3,703 7 · 10^{-6}	7,233 0	9,294 9 · 10^{-3}
4,186 8 · 10^{3}	1,163 · 10^{-3}	426,94	1	1,581 2 · 10^{-3}	3,088 0 · 10^{3}	3,968 3
2,647 8 · 10^{6}	0,735 50	0,27 · 10^{6}	632,42	1	1,952 9 · 10^{6}	2,509 6 · 10^{3}
1,355 8	0,376 62 · 10^{-6}	0,138 26	0,323 83 · 10^{-3}	0,512 06 · 10^{-6}	1	1,285 1 · 10^{-3}
1,055 1 · 10^{3}	0,293 07 · 10^{-3}	107,59	0,252 00	0,398 47 · 10^{-3}	778,17	1

1 erg = 0,1 10^{-6} J

11. Power (P)

Watt W	kp/s	kcal/s	kcal/h	Horsepower (metric)	Horsepower – HP	ft · lbf/s	Btu/h
1	0,101 97	0,238 85 · 10^{-3}	0,859 85	1,359 6 · 10^{-3}	1,341 0 · 10^{-3}	0,737 56	3,412 1
9,806 6	1	2,342 3 · 10^{-3}	8,432 2	13,333 · 10^{-3}	13,151 · 10^{-3}	7,233 0	33,462
4,186 8 · 10^{3}	426,94	1	3,6 · 10^{3}	5,692 5	5,614 6	3,088 0 · 10^{3}	14,286 · 10^{3}
1,163	0,118 59	0,277 78 · 10^{-3}	1	1,581 2 · 10^{-3}	1,559 6 · 10^{-3}	0,857 79	3,968 3
735,50	75	0,175 67	632,42	1	0,986 32	542,48	2,509 6 · 10^{3}
745,70	76,040	0,178 11	641,19	1,013 9	1	550	2,544 4 · 10^{3}
1,355 8	0,138 26	0,323 83 · 10^{-3}	1,165 8	1,843 4 · 10^{-3}	1,818 2 · 10^{-3}	1	4,626 2
0,293 07	29,885 · 10^{-3}	69,999 · 10^{-6}	0,252 00	0,398 47 · 10^{-3}	0,393 02 · 10^{-3}	0,216 16	1

12. Temperature, thermodynamic (T), other temperature scales

	Kelvin scale (T_K) K	Celsius Scale (t_c) °C	Rankine scale (T_R) °R	Fahrenheit scale (t_F) °F	Physical state
Correlating temperature	0 K	–273,15°C	0°R	–459,67°F	Absolute zero
	255,372 K	–17,778°C	459,67°R	0°F	
	273,15 K	0°C	491,67°R	32°F	Melting point of ice
	273,16 K	0,01°C	491,688°R	32,018°F	Triple point T_{tr} of water
	373,15 K	100°C	671,67°R	212°F	Boiling point of water
Correlating temperature differential	1 K	1°C	1,8°R	1,8°F	
	0,4555 56 K	0,4555 56°C	1°R	1°F	

$t_c = 5/9\ (t_F - 32)$

PHYSICAL AND TECHNICAL RATINGS OF SOME SPECIFIC MATERIALS

Tensile strength and elasiticity modulus of Wirsbo-PEX tubing

The tensile-strength and E-modulus ratings were supplied by the Technological University of Stockholm, Institute for Light Construction. The tests were based essentially upon DIN 53455 and DIN 53457. The samples were pieces of tubing.

1. Tensile strength at the highest force σ_B (N/mm^2)

t (°C) $\dot{\varepsilon}$ (%/min)	23	60	80	100
1	13,7	10,4	8,4	6,6
10	16,8	11,5	9,2	7,2
100	20,2	14,7	10,0	8,0

2. Elasticity modulus E (N/mm^2)

	Secant modulus E_s N/mm^2			Tangent modulus E_t N/mm^2		
t (°C) ε (%)	23	60	80	23	60	80
1	630	250	150	350	155	105
2	470	195	125	215	115	90
5	275	130	95	90	60	50
10	160	85	60	30	22	17
50	–	20	15	–	5	3

Elongation speed $\dot{\varepsilon} = 10$ %/min

3. Secant modulus E_s (N/mm^2)

t (°C)	23°C			60°C			80°C		
$\dot{\varepsilon}$ (%/min) ε(%)	1	10	100	1	10	100	1	10	100
1	505	630	855	190	250	320	130	150	185
2	380	470	635	165	195	250	110	125	155
5	225	275	370	110	130	165	80	95	110
10	130	160	195	70	85	100	50	60	70

4. Tangent modulus E_t (N/mm^2)

t (°C)	23°C			60°C			80°C		
$\dot{\varepsilon}$ (%/min) ε (%)	1	10	100	1	10	100	1	10	100
1	285	350	585	125	155	240	90	105	140
2	190	215	285	100	115	165	75	90	100
5	80	90	115	50	60	85	40	50	55
10	20	30	50	18	22	30	15	17	20

5. Density and thermal conductivity of various materials

Piping, shaped pieces	ρ lb/ft³	Btu/h°F
Metals		
Steel	,48	48,5
Copper	,556	170,
Copper		210,
Stainless stell	,556	9,2
Brass	,531	69,
Bronze	,543	35,
"Esmatur" (dezincification-free brass)	,512	58,
XLPE (PEX)	,059	0,22
Building materials		
Dry concrete	,14	0,81
Light concrete, dry	,031	0,069
Wood-fiber tiles*	,038	0,075
Mineral/glass wool	,0012 –,0025	0,029
Polyurethane (PUR), foamed*	,0025	0,021
Polystyrol (PS), foamed*	,0012	0,023
Cross-linked polyethylene (PEX), foamed*	,0019	0,023
Linoleum	,069	0,110
PVC coating, poured**	,087	0,046
Other		
Ice	,057	1,39
Water	,062	0,35
Air	,0008	0,014

* Varies according to density

** In the case of plastic coatings, the manufacturer's specifications should be consulted.

6. Characteristics of plastics in comparison to steel

Material	Linear thermal-expansion coefficient	Density lb/ft³	Heat conductivity Btu/h°F
LDPE	83	.057	0,18
HDPE	72	.060	0,24
XLPE (PEX)	78	.059	0,22
PP-C	56	.056	0,081
PB	72	,057	0,13
PVC	44	,087	0,104
Steel	6	,487	33,5

7. Air/water-vapor mixture

Temperature, saturation pressure and amount of water for each spatial unit of saturated air.

°C	Vapor pressure		g/m³	°C	Vapor pressure		g/m³	°C	Vapor pressure		g/m³
	mm Hg	millibar			mm Hg	millibar			mm Hg	millibar	
−30	0,280	0,373	0,333	18	15,48	20,63	15,41	86	450,9	601,0	366,7
−25	0,47	0,626	0,550	19	16,48	21,97	16,36	88	487,1	649,2	394,3
−20	0,77	1,03	0,88	20	17,54	23,38	17,34	90	525,8	700,8	423,5
−15	1,24	1,65	1,38	21	18,65	24,86	18,38	91	546,1	727,9	Rise in pressure: 98−99 °C: 25,97 mm Hg/34,62 mb 99−100 °C: 26,76 mm Hg/35,67 mb 100−101 °C: 27,6 mm Hg/36,8 mb
−12	1,63	2,17	1,80	22	19,83	26,43	19,47	92	567,0	755,8	
−11	1,78	2,37	1,96	23	21,07	28,08	20,62	93	588,6	784,5	
−10	1,95	2,60	2,14	24	22,38	29,83	21,82	94	610,9	814,3	
− 9	2,13	2,84	2,33	25	23,76	31,67	23,09	95	633,9	844,9	
− 8	2,32	3,09	2,54	26	25,21	33,60	24,42	96	657,6	876,5	
− 7	2,53	3,37	2,76	27	26,74	35,64	25,81	97	682,1	909,2	
− 6	2,76	3,68	2,99	28	28,35	37,79	27,28	98	707,3	942,8	
− 5	3,01	4,01	3,24	29	30,04	40,04	28,81	99	733,2	977,3	
− 4	3,28	4,37	3,51	30	31,83	42,43	30,37	100	760	1013,0	
− 3	3,57	4,76	3,81	32	35,7	47,5	33,8	101	787,6	1049,8	
− 2	3,88	5,17	4,13	34	39,9	53,2	37,6	102	815,9	1087,5	
− 1	4,22	5,62	4,47	36	44,6	59,4	41,8	104	875,1	1166	Vapor pressure kp/cm²
± 0	4,58	6,10	4,84	38	49,7	66,2	46,1	106	937,9	1250	
+ 1	4,93	6,57	5,18	40	55,3	73,7	51,2	108	1004,4	1339	
+ 2	5,29	7,05	5,55	45	71,9	95,8	65,4	110	1074,6	1432,3	1,460
+ 3	5,69	7,58	5,94	50	92,5	123,3	83,0	112	1148,7	1531,1	1,561
+ 4	6,10	8,13	6,35	55	118,0	157,3	104,1	114	1227,3	1635,9	1,668
+ 5	6,54	8,72	6,76	60	149,4	199,1	130,1	116	1309,9	1746,0	1,780
+ 6	7,01	9,34	7,35	62	163,8	218,3	141,8	118	1397,2	1862,3	1,899
+ 7	7,51	10,01	7,72	64	179,3	239,0	153,5	120	1489,1	1984,8	2,024
+ 8	8,05	10,73	8,26	66	196,1	261,4	168,0	130	2026	2700	2,754
+ 9	8,61	11,48	8,80	68	214,2	285,5	182,5	140	2710	3612	3,68
+10	9,21	12,28	9,39	70	233,7	311,5	198,0	150	3570	4758	4,85
+11	9,84	13,12	10,00	72	254,6	339,4	214,6	160	4636	6179	6,30
+12	10,52	14,02	10,66	74	277,2	369,5	232,4	180	7520	10023	10,22
+13	11,23	14,97	11,30	76	301,4	401,8	251,4	200	11659	15540	15,85
+14	11,99	15,98	12,03	78	327,3	436,3	271,7	250	29818	39744	40,53
+15	12,79	17,05	12,79	80	355,1	473,3	293,3	300	64433	85882	87,6
+16	13,63	18,17	13,60	82	384,9	513,0	316,2	374	165467	220551	224,9
+17	14,53	19,37	14,52	84	416,8	555,5	340,7				

Absorption Method

The relative humidity φ can be arrived at from the relationship between the amount of water by weight in a specific amount of air when compared with the amount of water by weight in the same amount of air at its saturation point. See the table above (under the heading (g/m³). Changes in the pressure and temperature of the mixture in the measuring equipment are to be taken into account if they occur.

Psychrometer method

The partial pressure p_D of the water vapor is arrived at from the semi-empirical Sprung psychrometer formula.

$p_D = p_f - 0.49\ (t - t_f)$ (mm Hg)

$p_D = p_f - 0.66\ (t - t_f)$ (millibars)

Where: t – is the temperature on dry thermometer

t_f – is the temperature on the wet thermometer

p_f – is the saturation pressure at t_f

The formula is valid for the temperature range from −20° C. to +30° C. Its preciseness should correspond to that of the temperature readings. The factor preceding the terms in parentheses (the psychrometrical difference in temperature) is proportional to the barometric pressure which here is assumed to be 760 mm Hg = 1013 millibars. In case the current value is quite different, that factor can be corrected to reflect the acutal barometric pressure.

The formula for the relative humidity would then be: $\varphi = p_D/p'$ where p' = the saturation pressure at the current temperature.