Thermoplastic Pipe in Oil and Gas Production

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INTRODUCTION

For a long time, a certain amount of confusion has surrounded the use of plastic pipe in the oil patch. Some of this was perhaps inevitable since to prematurely standardize a constantly improving product would have been to forfeit important later developments. On the other hand, some of the confusion could have been avoided, had some group within the oil field accepted the responsibility of building a bank of expertise and experience in the field of plastics.

Plastic pipe should not be regarded as simply something to use instead of steel pipe. It is, rather, an important option in the control of corrosion. It has unique advantages and strict limitations. It should be considered by the petroleum engineer or superintendent as a tool to save money. Like any other cost saving innovation, it should warrant careful study and proper application.

It is the purpose of this discussion to strip some of the mystery from the technical aspects of plastic pipe, to provide some suggestions on engineering and installation, and to offer a few special tips on evaluation of the various plastics available to oil and gas producers. Given this information, a corrosion engineer will be quite capable of a thorough and sound evaluation and engineering job for any prospective plastic piping project.

The discussion will be limited to thermoplastic pipes, or those made of that class of plastic materials which can be softened and re-formed. The thermosetting materials which are formed, broadly speaking of material which, once polymerized cannot be reshaped, are a different class and will not be considered.

One of the first things which must be accepted concerning thermoplastics is that the different kinds vary vastly from each other in many important properties, in different conditions. Thus, it is futile to try to categorize them "for once and for all". A far more workable and valuable approach is to learn the basic, more important variables which influence the performance of thermoplastics as piping materials and to know how to estimate the relative merit to assign to each factor for a given job.

BASIC PHYSICAL PROPERTIES

A few of the basic properties of thermoplastics have direct and important bearing on their performance as piping materials. These, taken individually, may or may not influence selection of a pipe for a particular job; hence, a working knowledge of each is a necessity to the prospective user. We will take these properties one at a time and establish the guides which determine the weight which should be accorded to each.

Tensile Strength

This property is used in establishing a rating for each plastic pipe. There are two kinds of tensile strength, short-term and long-term. Short-term strength, usually determined as suggested in ASTM test #D638, is measured at various temperatures. The test is straightforward, consisting of pulling apart a number of tensile samples.

The long-term value is harder to obtain. It is a characteristic of all thermoplastics that the allowable stress decreases with the time for which it must be imposed. Thus it is necessary to select an arbitrary "life" desired in service and determine the allowable stress for this amount of time. The plastics industry has settled on 11.43 yrs, or 100,000 hrs as the time under stress for which a stress value must be determined. Next comes the problem of predictating this stress value. One can quickly recognize the practical difficulty of maintaining a constant hoop stress, at a constant temperature, on many samples of plastic pipe for 11-1/2 yrs. Extrapolation is the answer. Samples of pipe are burst at various pressures, or hoop stresses, and the resulting curve is plotted and extrapolated to determine a long term allowable hoop stress. Fig. 1 illustrates typical machinery needed to obtain this information. This apparatus maintains the required constant temperature and constant pressure (or hoop stress) on samples of the pipe under test, until failure occurs. Many samples must be tested. The pressures must be programmed to provide a curve of burst pressure versus time to failure sufficient to define the characteristic curve of the material under test and thus permit reliable extrapolation.

The number of burst points, the duration of the tests, the standard temperatures, etc., are tentatively agreed upon within the plastics industry, and minimum procedures are defined for the use of all. Of course, any manufacturer who provides more points, and points of burst values from pipe under stress for greater lengths of time than the minimum provides extra confidence in the extrapolation of these data.

For a picture of how these data are utilized, note Fig. 2.

Note on this plot of burst values that the horizontal axis is time, while the vertical axis is hoop stress. Hoop stress, rather than pressure, is used so that allowable pressures can be calculated for various sizes and wall thicknesses of the plastic being tested.

Two formulas are now in common use for making this conversion: the Barlow and the ISO formulas. If the same formula is used to get a pressure rating as was used to convert a burst pressure to a hoop stress, the answers will be identical. In the interests of standardization, a single formula will probably eventually become standard, but in the meantime, the only requirement is that the same formula be used to obtain ratings from allowable hoop stresses that was used to convert the original burst values to the allowable hoop stresses.

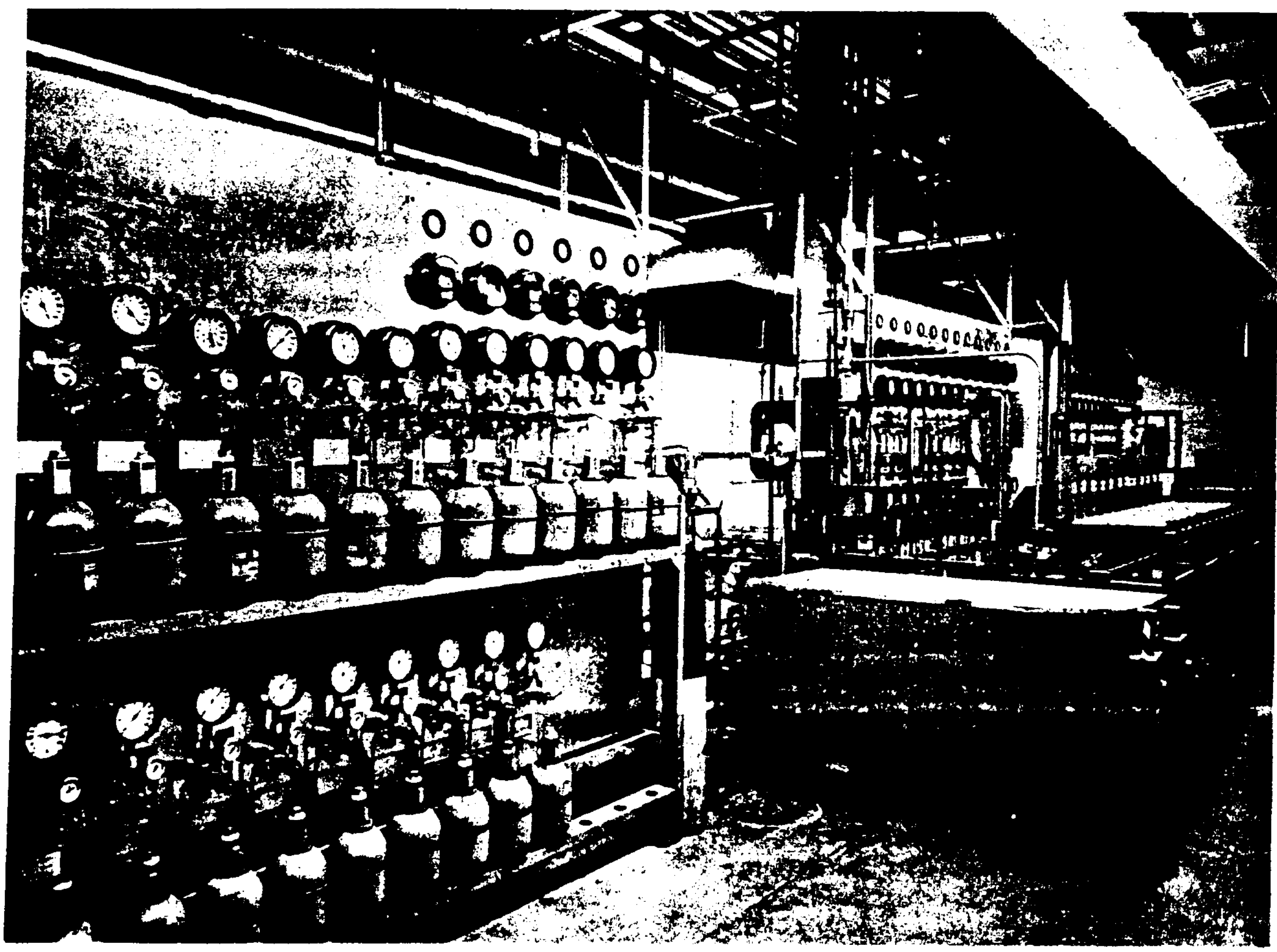
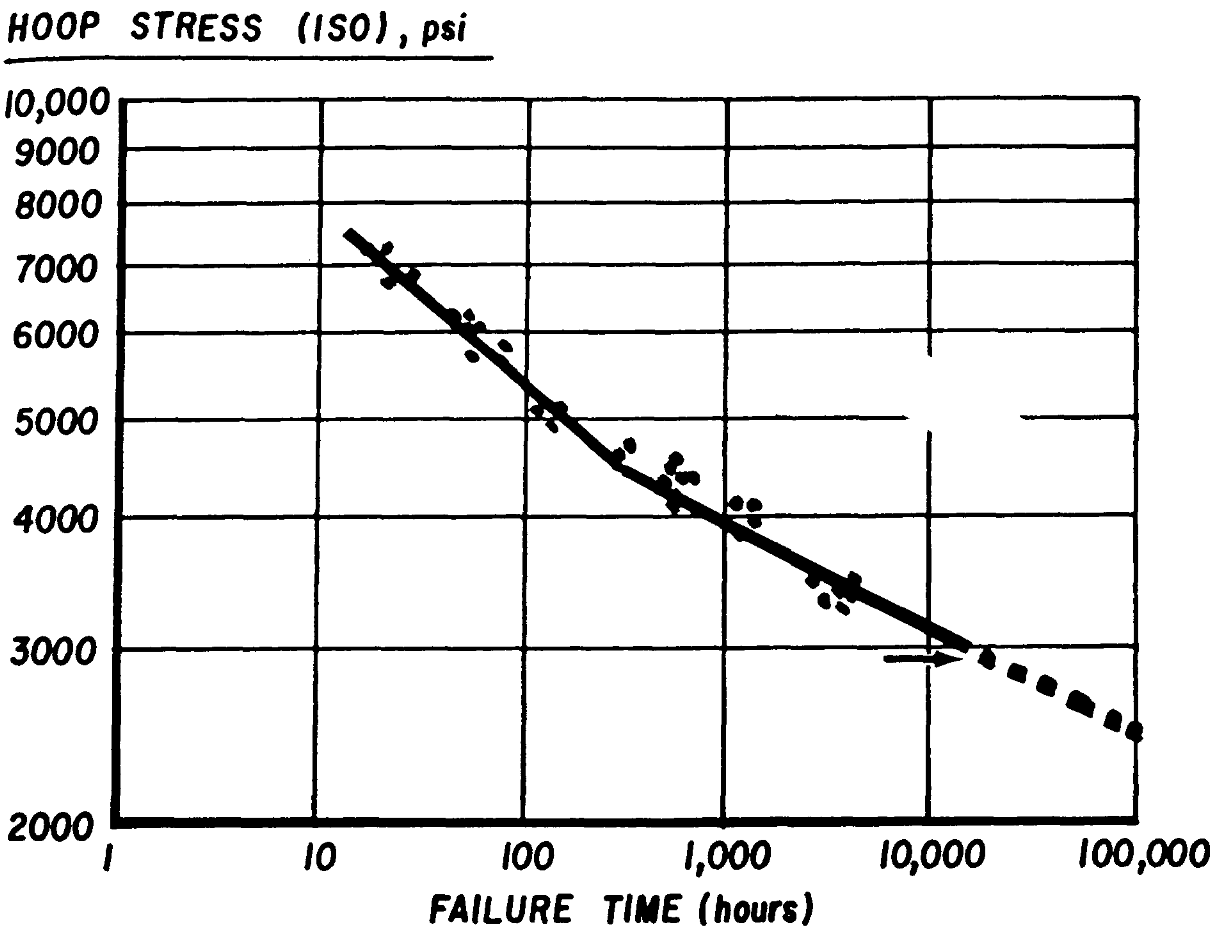


Fig. 1

DELRIN PIPE 2 x 100 73°F



It would be nice if this were the end of the pressure rating problems! However, one curve cannot tell the story. Temperature is a big variable, and there is no reliable way to obtain a long term hoop stress value at a given temperature above standard, unless some tests are run at increased temperatures. Most manufacturers provide curves run at 73°F., 113°F, and 140°F. Interpolation between these temperatures is permissible and fairly accurate.

In like manner, the action of various fluids can have dramatic results, and an oil field plastic piping product should be rated by tests performed in a crude oil environment.

Surging pressures are deleterious in the case of some plastics, and when surging is anticipated, the effect on the burst curve should be ascertained.

Suppose a curve is obtained for all plastics, considering temperature, solvent effect, and pressure surging. We still have not extracted all we need to know from long term tensile testing! There are two more main things to check. These are (1) any drastic change of the shape of the curve at elevated temperatures and (2) whether we desire to consider short-term values. Some plastics, at high temperatures show a "knee" or drastic and sudden loss of strength at increased temperatures, the knee moving in, timewise, with increased temperatures. The significicance here is that at service temperatures we may not see the "knee", if one exists, because it is located in the area we have generously extrapolated as a straight line! This may suggest that some arbitrary "de-rating" is in order. As to the short-term area, this becomes significant if pigging and hot oiling should be anticipated. A relatively high tensile "short-term" curve (in the "minutes" range) would permit much more severe testing, pigging, steaming, etc., regardless of the long term value. Note the variation in the slope and "shape" of the curves of four common plastics in Fig. 3.

Can the full extrapolated long-term tensile stress value be used undiminished to get a pressure rating? On this point we move immediately from theoretical to practical considerations. There are some good reasons for rating some materials at less than this full value. Some of these are:

(1) Sparse data which decrease confidence in the extrapolation.
(2) Non-rigorous interpretation of these data.
(3) Quality control in manufacture of both plastic and pipe which permits wide variation in lot-to-lot reproducibility of test results.
(4) A suspicious "knee" or sudden and drastic loss of strength in the high temperature curves.
(5) A joining system which makes it likely that field joints will be substantially weaker than theoretical full pipe strength.
(6) Anticipated solvent effect from hydrocarbons.
(7) Anticipated fatique effect from pres-sure surging.
(8) A flat, low slope, characteristic curve, which places full longterm value uncomfortably close to the short-term burst value.

Manufacturers, in consideration of these and other factors, do indeed recommend a de-rating of some plastics. In the final analysis, it is up to the engineer to decide, and a basic understanding of burst testing should enable him to do so with confidence. It should be remembered that any de-rating is primary to cover unforeseen contingencies, and that various plastics may be influenced differently by the contingencies. For example, surging and hydrocarbons may affect one and not another. Hence, an arbitrary de-rating of the plastic adversely affected by oil and

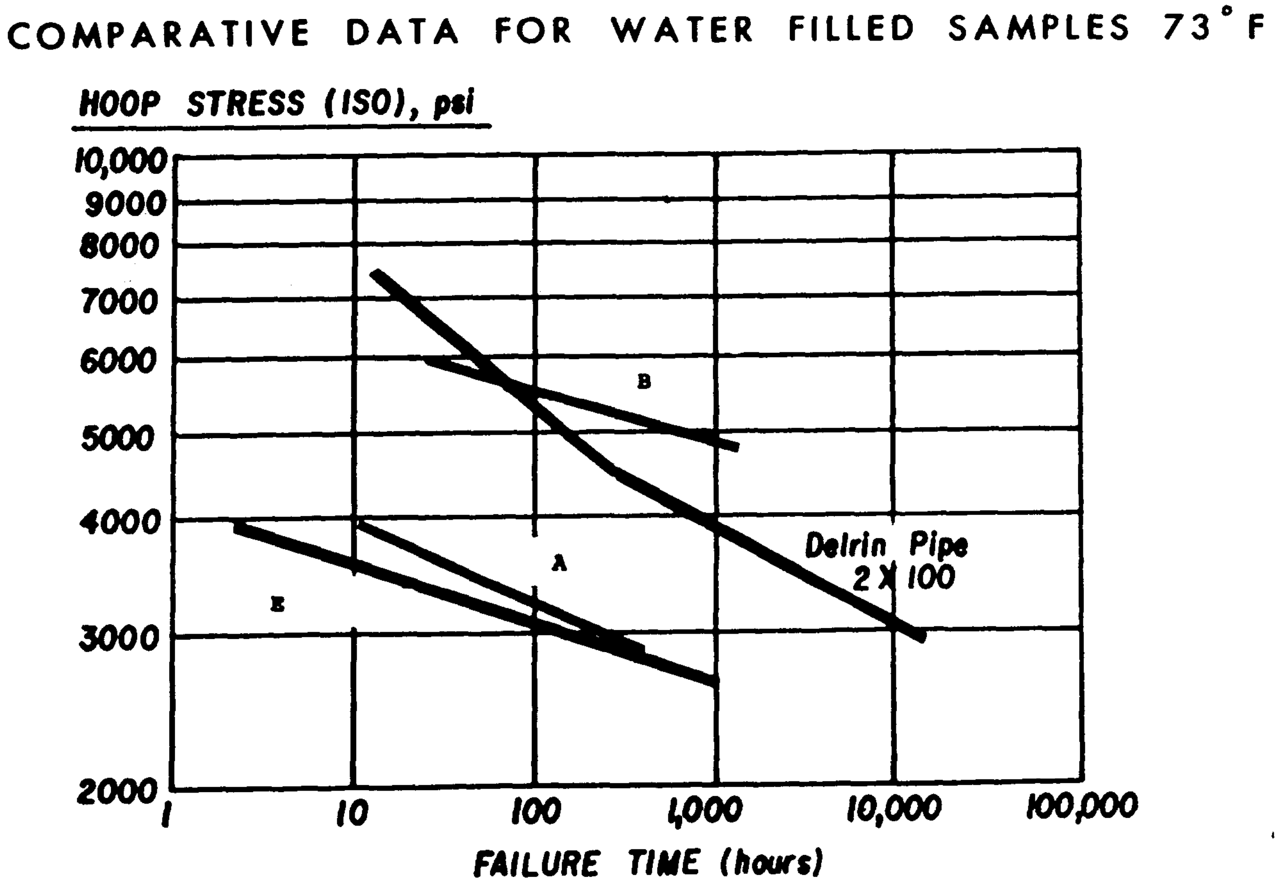


Fig. 3

surging would simply bring its rated pressure down to what one could expect of it in that service. The same factor applied to a plactic not affected by surging pressures or hydrocarbons would provide a true margin against contingencies. This is why a standard de-rating factor arbitrarily applied to all plastics gives the illusion of providing a safety factor when it may not, and simultaneously penalizes plastics subject to fewer or none of the "reasons for de-rating" listed earlier.

Impact Resistance

Impact resistance, or toughness, is a property quite distinct from tensile strength. In fact, in the case of many plastics, one must be achieved at the expense of the other. A strong, brittle plastic is toughened, at the expense of strength, through modification of the basic plastic in its manufacture, or through softening with a controlled solvent, or plasticizer. This is basically the explanation of the "Type I" versus "Type II" plastics. A compromise between strength and toughness is struck.

Speaking very generally, impact resistance is important in oil patch applications only during the installation phase, when excessive breakage, or its alternate, excessive care in handling can increase cost of a job. Impact testing is quite empirical. It usually is done by drop weight testing, wherein weights of semi-standardized mass and geometry are dropped on pipe nipples resting on beds of semi-standard design. Fig. 4 shows a typical drop weight tester.

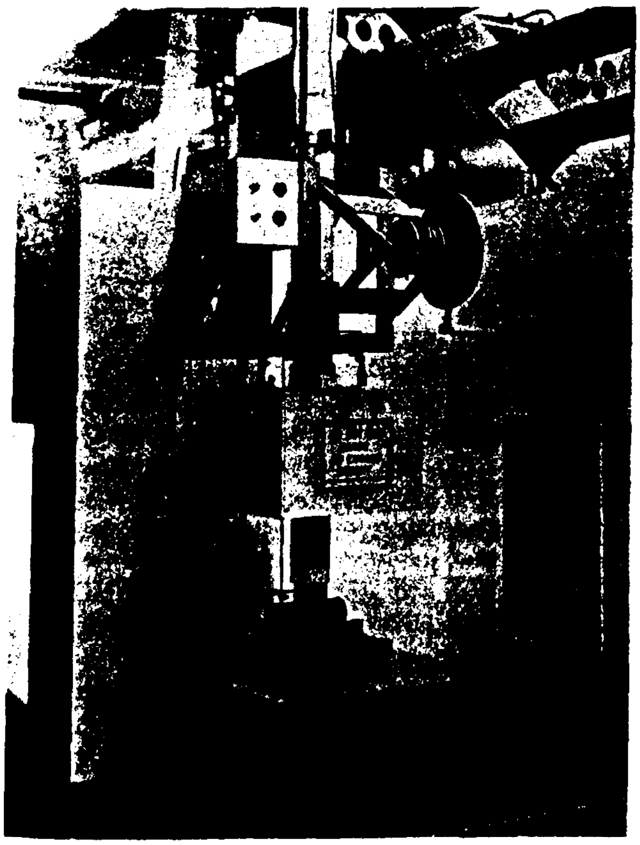


Fig. 4
EQUIPMENT FOR DROP WEIGHT IMPACT TEST

Impact strength is then expressed as the ft-pounds of energy expended which, in a single drop, will break one half of the samples tested. The resulting figures are reasonably valid for comparison of plastics, but are not quantitatively important in design of a pipe line. The tests are perhaps only of "screening" value and are valuable only to catch an extreme deficiency, such as shows up in low temperature impact testing of some plastics.

Creep Resistance

"Creep" is variously known as "cold flow" or "ballooning". It is simply the change of dimension under stress to which all thermoplastics are subject to a greater or lesser degree. "Creep" is tested by various schemes, imposing a stress less than that required to cause failure and measuring temporary and permanent (load relaxed) deformation. "Creep" is undesirable in an oil field pipe for four main reasons:

(1) A permanently deformed pipe is stretched hence, its wall thickness is reduced, and allowable pressure is decreased.

(2) Such a pipe becomes a non-standard size. Repair of accidental damage, change or addition to the system, etc., is different since neither standard steel compression and repair fittings, nor the appropriate plastic fittings will fit without expensive and possibly unsatisfactory modification.

(3) Since occasional overpressure to failure of plastic lines in the oil field is probably inevitable, a really creep-resistant pipe provides insurance in that its failure mechanism will tend to be a randomly situated local rupture. This type failure can be repaired without loss of the entire line through ballooning.

(4) A creep resistant plastic will give the most reliable performance with the handy standard compression type steel fittings commonly used for oil field repairs. A creep resistant pipe will allow a better "bite" and hence, less likelihood of pullout at a future time.

Creep resistance is an important property and should warrant consideration in the selection of an oil field pipe. Creep resistance comparisons of various common plastics are available from manufacturers. To be meaningful, naturally, the comparison must be made on the basis of identical tests, at common temperatures, and the resulting numbers are useful only relatively, rather than as a design parameter.

Fatigue Resistance

Fatigue resistance is a property somewhat difficult to define but easy to measure. It is the resistance to premature failure due to weakening by flexing, surging, vibration, or other cyclic loading. It is stated in terms of "fatigue endurance limit". This test shows relative fatigue resistance, but results of some non-standard but more realistic tests of flexing pipe joints are more dramatic than the standard tests. There are huge, orders of magnitude differences in the amount of flexing cycles common thermoplastic pipes can stand.

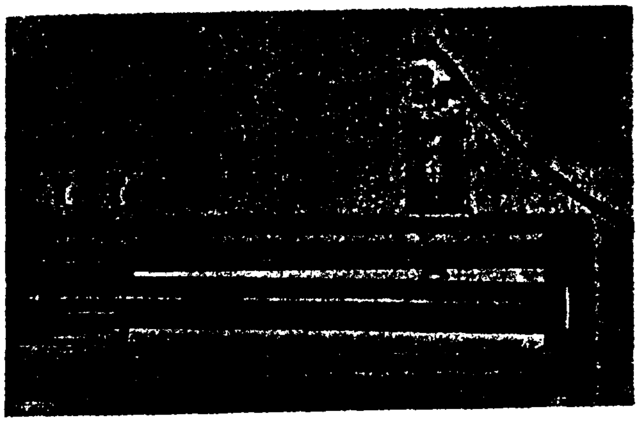


Fig. 5

Fig. 6

EQUIPMENT FOR FATIGUE TESTS ON PIPE

Note Figs. 5 and 6. Theseillustrate a machine which was used to alternately flex and relax a cantilevered sample of several common plastic pipes. Table 1 shows the number of hours each pipe tolerated this flexing before failure.

TABLE 1

FLEXURAL FATIGUE OF TWO-INCH PIPE

Material	Time To Failure, Hours	Cycles To Failure
D	220	198,000
B	1.7	1,520
B	1.2	1,080
C	1.7	1,520
B	1	900
B	0.5	450
A	0.2	180
A	0.03	27

This property is important in vibration situations around pumps, under traffic loads, in situations where wide variations in temperatures will cause a pipe installation to flex repeatedly.

Fatigue resistance shows up most dramatically and probably most importantly in resistance, or lack of it, to pressure surging. Some thermoplastic pipes must be severely de-rated when surging is to be imposed. Manufacturers are quite aware of this. When a pipeline design is known to include pressure surging, such as on a pumping well flow-line, or a reciprocating water pump, a recommendation should always be obtained. Some thermoplastics exhibit excellent fatigue resistance, and can be used in conditions with severe surging, up to rated pressure. Fig. 7 is a burst value curve comparison of two plastics subjected to surging pressures. One is even stronger under surging conditions than under constant pressure while the other shows severe loss of strength.

This is the same curve that was developed earlier in the paper, except that the line represents the peak pressure in a surging situation. On this particular curve, surges, at a frequency of 26 times per minute, were used to simulate a typical down-hole pump action. If the loss of strength through fatigue, sustained by most of these plastics, is added to the loss due to hydrocarbon absorbtion (which will be discussed in the next section), the reason for many oil field failures of plastic pipe will be obvious. Standard ratings of these pipes, obtained in water, under steady pres-

COMPARISON OF CONTINUOUS PRESSURE AND SURGING PRESSURE AT 73° F

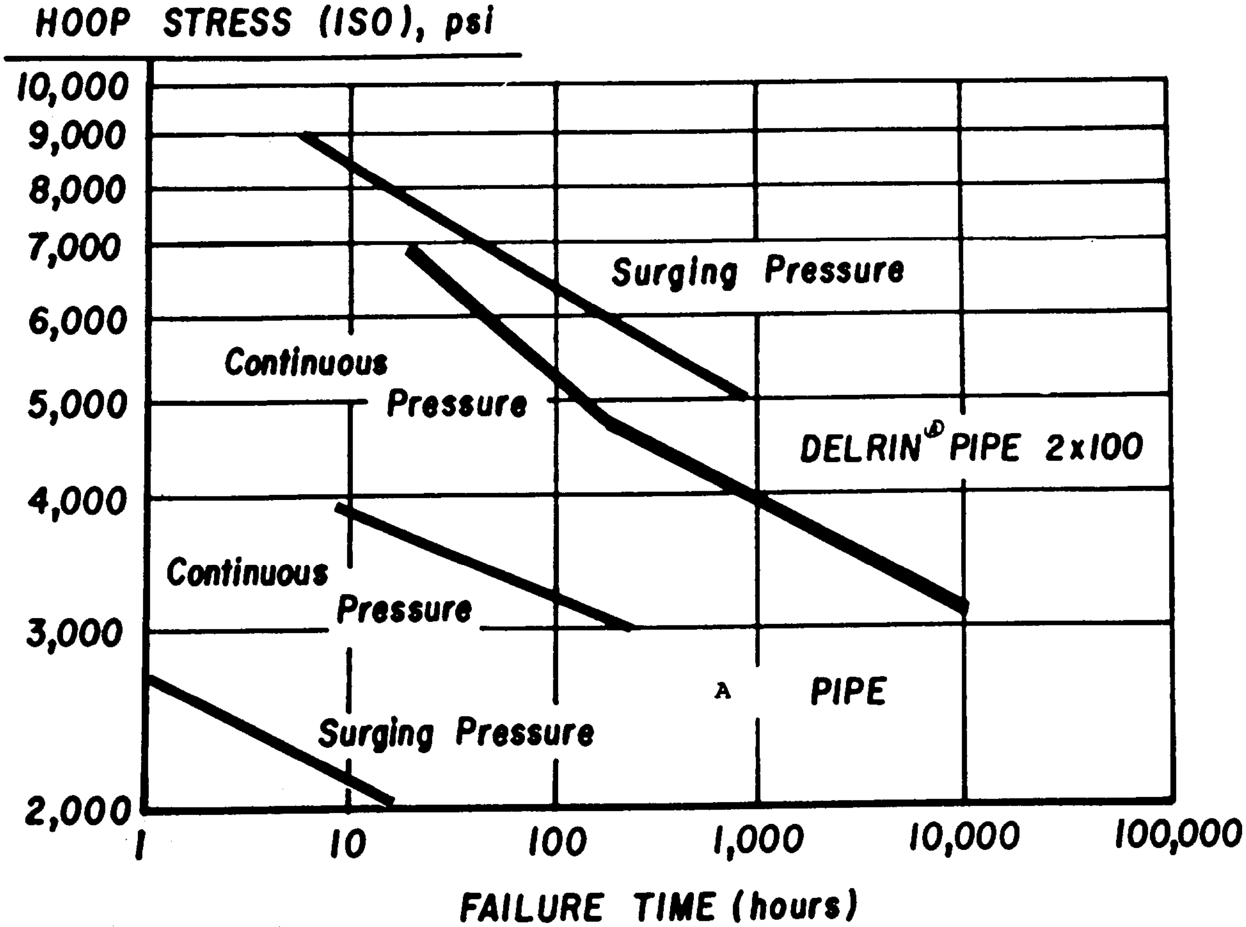


Fig. 7

sure at 73° F, would show less difference. This is why, for typical oil field applications, you cannot compare a "standard" rating versus price and select a suitable plastic. You should insist upon seeing a rating for your pipe for oil and surging pressure service and, if possible, this should be obtained for the anticipated service temperature.

Chemical and Solvent Resistance

Chemical action of a given fluid is usually either a "go or no go" situation. Specific information on the resistance to all common chemicals of each available thermoplastic is usually available, with a clear "satisfactory" or "unsatisfactory" rating. Simple tests can be performed for unusual cases. Acidity or alkalinity of a natural soil is probably never a deterring factor to the use of oil field thermoplastic pipe. Unusual conditions can be tested.

More subtle and less often considered is the solvent action of hydrocarbons and aromatic hydrocarbons. Ordinary sweet crude oil can cut the allowable stress levels by half in some thermoplastics, while aromatic components can be quite severely deleterious. The effect of hydrocarbons is pinpointed by running the standard long term tensile tests in a crude oil environment.

Note the change in the burst value curves for several common plastics when they are tested in water (Fig. 8) and oil (Fig. 9). Only one remains unaffected. Resistance to aromatics is best tested by accelerated testing in simple mixtures of solutions such as benzene, toluene, and xylene. Visual examination of samples soaked in these solutions will weed out unsatisfactory candidates for service in aromatics in a matter of days, or weeks. It might be well to note that some corrosion control chemicals used in the oil patch contain aromatic hydrocarbons. The possible effect of trace amounts of these aromatics carried over into plastic systems should be considered. It would be good insurance in making your plastic pipe selections if you could either obtain from the manufacturer results of aromatic hydrocarbon tests, or if these are not available, run your own in the aromatics listed above. A simple soak test for a few days will suffice.

Natural soil conditions are rarely, if ever, a deterrent to the use of plastic pipe. Unusual conditions can be tested.

ENGINEERING A PLASTIC PIPE LINE

Considerations Common to Any Pipe

The first thing one should do in engineering a plastic pipe line is exactly the thing which should be done in the case of a steel line, but which can usually be ignored: get the facts. An over-sized steel line represents wasted investment, but to achieve the best economy with a plastic line, it is necessary to size correctly. An under-sized steel line may cause increased pumping costs, pump wear, etc., but the line itself will take the increased pressure quietly. A plastic line will quickly call attention to extreme undersizing by failing in service. Thus it pays to really design a plastic line to give proper service.

As the earlier "physical properties" section illustrated, temperature is a highly important variable in establishing the strength which can be expected of a plastic. In the field, fluids leaving a heater treater may be substantially cooler than the treater setting, due to intercooling effect in the treater leg. Well head temperatures may be much hotter than one would estimate by feeling the header at the end of an existing steel line. Select the temperature the line is expected to handle.

The exact flow requirements for a line must be known. 400 BPD average is quite a different flow rate than 400 barrels to be handled in four hours each day, for operational reasons. It is characteristic of reciprocating pumps that their "peak" or surge flow is at least double the daily average,

COMPARATIVE DATA FOR WATER FILLED SAMPLES 113°F

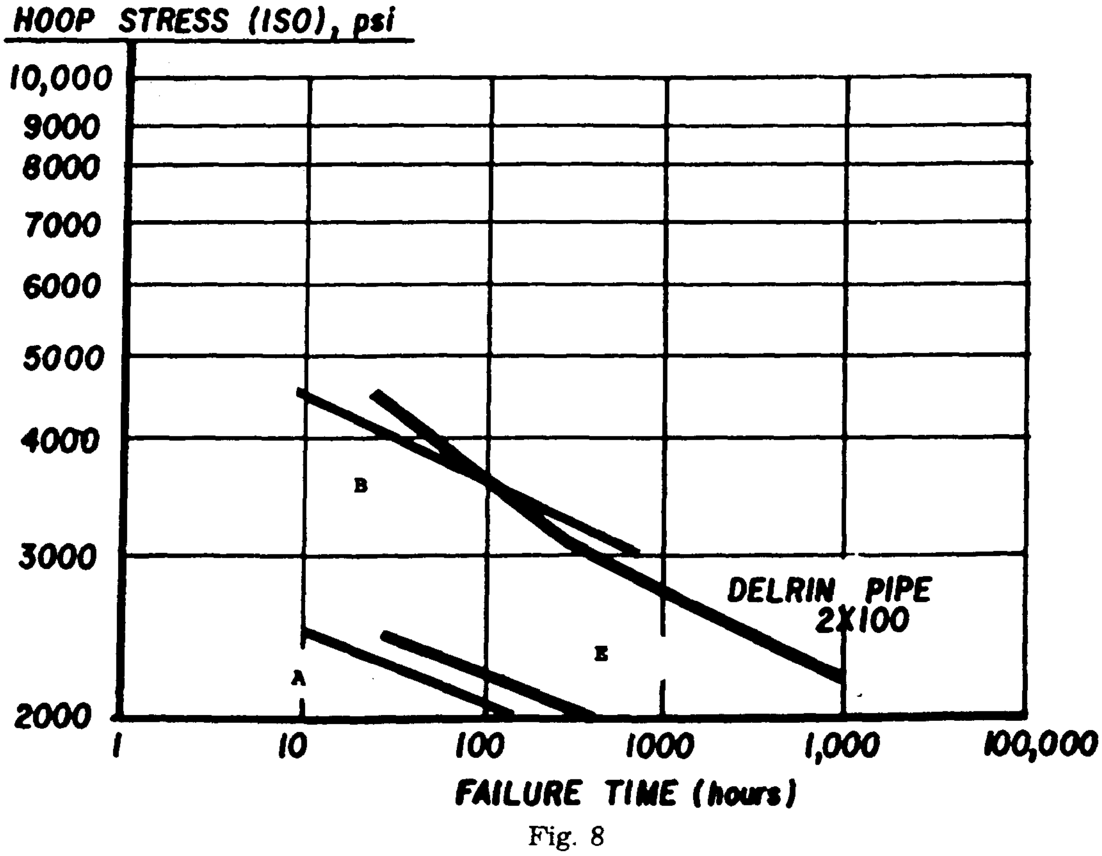


Fig. 8

and usually more. So the actual peak flow must be known accurately to select and size a plastic line.

Fluid viscosity is important in line sizing. Single phase flow is easy to handle but multi-phase flow needs either very rigorous theoretical treatment or heavy reliance on field experience.

Elevation changes should be noted on the proposed right of way to determine the possibility of vacuum or excessive fluid head at intermediate points along a line.

Contingencies, or future changes, should be noted—such as the need to "double up" on a line if another line, disposal well, pit, or battery, etc. is temporarily out of service.

Special Plastic Pipe Considerations

The decision as to whether or not to bury a plastic line involves consideration of vulnerability to mechanical damage, and the resulting consequences. In addition, the weatherability of the plastic pipe in question should be ascertained, as some suffer from exposure over long periods of time. In lines which are exposed, the temperature effect of sunlight must be considered.

It may be well to consider protective devices such as over pressure switches or relief valves for a plastic line. These devices are relatively inexpensive - - a typical plastic line can probably be permanently protected for the cost of two leak repairs.

Terrain should be considered. Usually, bad terrain shows plastic pipe to advantage, but rocks, frequent creek crossings, etc. may modify selection and job planning.

The weather at the time of installation is important in that some thermoplastic pipes become brittle in cold weather. In addition, some joining techniques become troublesome or time-consuming in cold or wet weather.

Road crossings, creek crossings, etc. should be noted and planned for. The possibility of future work, ditching, etc., in an area may be a consideration in the use of plastic pipe. It may be well to consider indoctrination of field personnel from the start of a design job, to insure a successful application.

COMPARISON OF HYDROCARBON OIL FILLED SAMPLES TESTED AT 113°F

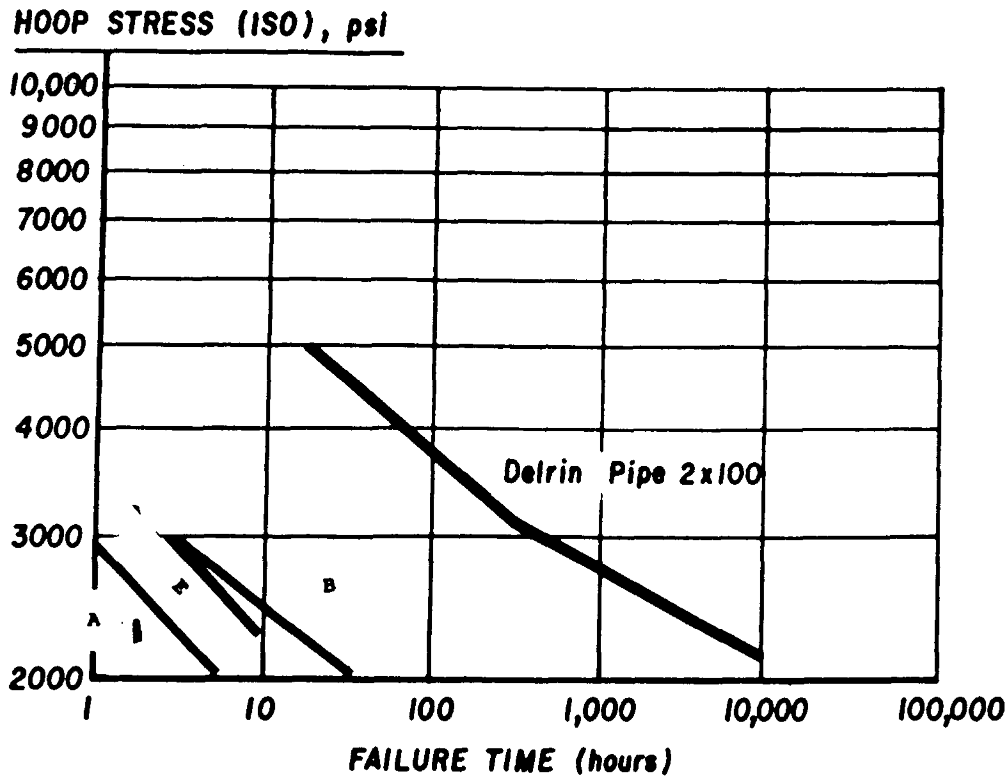


Fig. 9

INSTALLATION OF PLASTIC PIPE

Pre-planning a plastic pipeline job is important. This requirement is not unique to plastic—the difference is that it is done without deliberate mental action as in the case of more standard materials. Pipe, fittings, tools, etc. must be on hand and in order. The routine of hauling, ditching, stringing, laying, pressure testing, and backfilling and connection work should be considered to maximize the installation cost savings possible with plastic pipe.

Except in extreme cases, normal care in handling plastic pipe is sufficient. It is not necessary to treat plastic pipe as roughly as steel. For instance, it may be a highly practical unloading technique for a man to kick steel joints off a float bed. The same man could easily lift off five joint bundles of plastic pipe and get the job done faster, in spite of reasonable care in handling the plastic pipe. In the field, the toughness of plastic pipe rarely limits speed of installation or imposes special manpower requirements. It is sometimes necessary to guard against abrasion of plastic pipe in hauling, but this is a simple field jury-rigging problem and is easy to cope with at little or no expense or loss of time.

In joining plastic pipe, the manufacturer's recommendations should always be followed. Deviation from standard techniques invites trouble. The laying technique utilized for plastic pipe should be suited to the pipe and the terrain. It may be possible to make joints in a series of spots along the right of way a few hundred feet apart, dragging the growing line as each joint is made, thus avoiding a large part of the stringing operation.

Expansion and contraction of all thermoplastics is about the same, several times that of steel pipe. The actual value of the expansion coefficient may be of interest in designing short runs of pipe, headers,etc., but in the case of long field lines, the problem is easily handled by approximate compensation in the installation phase. The ditch should be wide enough to accommodate some "snaking" of the pipe if required. When pipe is laid under hot conditions (for example, in the sunlight on a summer day) but must handle a cool fluid, slack should be left in the line. Conversely, should the pipe be laid in cold weather, with the anticipation of expansion created by warm fluid, the pipe can be pulled tight.

The plastic line will be in most favorable stress equilibrium if the fluid to be handled is allowed to bring the pipe to an approximate service condition before and during backfilling, and if timing is such that the line can be kept in service during the settling period of the backfill.

When plastic pipe in an open ditch is subjected to drastic temperature changes, it should come as no surprise to see the line "crawl", or change in length.This is harmless and represents the line assuming its most stress free condition for service conditions. If a line, when placed in service in an open ditch, expands enough to leave the ditch, it can be worked back in or shortened by cutting. If it pulls too tight, this can be remedied by adding pipe.

Pressure testing is important in the satisfactory installation of plastic pipe. Manufacturer's recommendations should be secured concerning times and durations, but a good arbitrary minimum would be one half the rated pressure of the pipe being tested; full rated pressure would be preferable. Air in a line can render a hydrostatic test hard to interpret, so it should be flushed out if possible.

An air test is satisfactory for plastic pipe, and perhaps preferable for gas lines. Common sense should dictate reasonable safety precautions as compressed air is a reservoir of energy which can become dangerous.

Backfilling plastic pipe lines is an operation which will reward slight extra care. Large rocks or frozen earth can rupture most all plastics. Some installers like to backfill with the line under pressure so that backfilling damage is immediately obvious.

Tips from the Writer's Experience

In this section we will treat a conglomeration of bits of information which may suggest extra ways in which plastic pipe can provide cash savings other than those realized by eliminating corrosion as a factor. Also included are a couple of suggestions, based on the writer's experience which will help if they are borne in mind during the "phasing-in" period of a company's adoption of plastic pipe.

It is well known that plastic pipe offers flow advantage over corresponding sizes of steel, due to better friction characteristics and larger inside diameters. It may prove advantageous to take this savings in power cost, rather than decreasing line size to lower investment In addition, those plastic pipes having superior fatigue resistance actually lower peak surges in reciprocating pump applications, even lower than flow calculations would indicate, through flexing of the pipe wall. Watt-hour meters have been used to prove, in actual field installations, that over a typical oil field life expectancy, a given size plastic flow line, used rather than the same size steel, will actually pay for itself in power cost savings! The savings varies with power cost, flow quantity, etc. but is a nice bonus in addition to corrosion savings.

Acidizing costs for injection wells have been dramatically reduced by the use of plastic lines, eliminating the contribution of piping corrosion products to the plugging of the formation.

Ditching a plastic line can be surprisingly less costly than that for less flexible types of pipe if grading requirements are eliminated, or if the plastic's flexibility saves a few trees by eliminating the requirement of a straight ditch.

Paraffin resistance of a given plastic is not proved until tried in a given location. Chances are, plastic pipe will always reduce line maintenance costs. However, if build-up should occur in a given locality, it constitutes a catastrophe only if the plastic in service cannot take paraffin removal treatment. Thus, it is insurance in paraffin base crude lines to select a plastic having several specific characteristics:

(1) Solvent resistance so that pariffin solvents can be used.

(2) Good short-term, high temperature strength, so that hot oiling, steaming, "bugging" or a combination can be used.

Small diameter plastic pipe coils represent a fast and economical answer to oil field service piping, such as treater gas supply lines, gas engine lines, etc.

On very low volume wells, 1-1/2 in. or even 1 in. plastic lines can be an economical flow line design, particularly when combined with surge chambers. There is nothing forbidding or untouchable about 2 in. as a flow line size. It is simply a problem of sizing.

When comparing plastic pipes, the inside diameter should be checked, along with nominal size. Stronger plastics permit thinner walls and hence, more flow through a given nominal size. A heavy walled pipe of weak plastic may offer less than a thinner walled pipe of strong plastic.

With regard to the so called old-timers who supposedly resist change, it is the writer's observation that they welcome change and show a commendable tolerance for small problems, but are relentlessly unforgiving of large scale disruptions. The simple measures of explaining to field men the need for and capabilities of plastic pipe, designating engineering contacts for them, and outlining repair techniques, etc., often convert these men into enthusiastic boosters of plastics. These men have many more "small problems" with their standard equipment than engineers likely ever know about. A plastic problem is not likely to bother them, unless they have been left, by the specifying engineer, "paralyzed" with regard to technique and in the dark about where to go for advice.

It is hoped that this paper has thrown a few rays of light into an unnecessarily dark area. Plastics have a place in the oil patch; several million feet are used in the oil fields of America annually. If they save money for part of the producers, this in itself is incentive for all producers to learn where and how plastics can do this increasingly important job for them.