THE USE OF MAGNESIUM-ALLOY TUBING IN HEAT EXCHANGERS

By

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I. INTRODUCTION

Corrosion of metals has become one of the more important engineering problems in industry. This problem is of particular importance in the chemical industries where the majority of materials handled are corrosive liquids, solids and gases.

An accurate estimate of the loss of metal due to corrosion would be difficult to make, but an average estimate of the annual loss resulting from corrosion of iron and steel would be two per cent of the total tonnage in use. It has been estimated that over two billion long tons of iron and steel were in use in the world prior to World War II. In recent years the steel produced was about eighteen times the tonnage of all non-ferrous metals. From these quantitative figures, it can be seen that wastage due to corrosion of metals runs into an extremely large tonnage per year. Such wastage also causes a more rapid depletion of ore supplies. It is estimated that the reserves of iron in the United States will be exhausted within the next two hundred years. Sea water provides an almost inexhaustable reserve of magnesium, 4500 tons per cubic mile, but the corrosion problem limits the
use of this metal. It is not surprising that much attention has been given to the corrosion problem by research organizations and manufacturers.

Corrosion of heat exchanger tubes presents a problem in heating of liquids and gases with heat exchangers, necessitating frequent replacement of the tubes.

The object of this research is to study the corrosion resistance offered by commercial magnesium alloys used as heat exchanger tubes, and to determine if the corrosion resistance of magnesium can be increased by alloy additions and by protective coatings of silicone resin.
II. LITERATURE REVIEW

Corrosion

Introduction. Corrosion is broadly defined as the deterioration or wearing away of metals. This action usually takes place on the surface of metals but may take place along grain boundaries or other points of weakness. All metals, except some of the so-called noble metals, tend to corrode in certain environments. The principles of corrosion hold true for all metals and alloys. Corrosion depends both on the metal and its environment and includes a multitude of problems.

Principles of Corrosion. There have been many theories brought forth in an attempt to explain the process of corrosion. The accepted theories at present are divided into two general groups, an indirect electrochemical attack and a direct chemical attack. Other theories which have been proposed are the acid theory, the colloidal theory, the biological theory, and the peroxide theory. From Faraday's Law, Watts\(^{58}\) derives four types of corrosion:

(1) Corrosion by reduction in valence of some
metal already in solution, without displacement of any cation from the electrolyte.

(2) Corrosion by displacement of a metal.

(3) Corrosion by visible displacement of hydrogen.

(4) Corrosion by oxygen depolarization.

All of these types can be explained by the electrochemical theory. However, because of the number of factors involved in the mechanism of corrosion, it seems unwise to say that any one theory could satisfactorily explain the phenomenon of corrosion.

Champion (19) divides corrosion into two main classes; general and local corrosion, and further subdivides these classes as follows:

General corrosion

- even
- uneven

Local corrosion

- (even
- (uneven

- (even
- (uneven

- (wide
- (pitting
- (medium
- (narrow
- (cracking

Some of the factors which enter into the mechanism of corrosion are listed below: (43), (57)

(1) Metals tend to go into solution in the form of electrically charged particles or ions. Since
the solution must remain electrically neutral, the positive ions of some other element must be displaced. Therefore, all that a metal needs in order to corrode is the presence in an electrolyte of either hydrogen ions or some metal ions which it is able to displace from solution.

(2) If hydrogen ions are displaced, the hydrogen film formed must be removed. This may be brought about in two ways: the hydrogen may combine with oxygen to form water, or it may be evolved as hydrogen gas.

(3) The ability of metals to form protective coatings influences the rate of corrosion. This protective coating may be in the form of a film, or may be some chemical compound such as an oxide or hydroxide. Some metals readily form an adherent, impervious film which resists further corrosion. These films, which may be so thin as to be invisible, are presumably made up of layers of oxygen atoms attached to the surface metal atoms in the form of oxides. Little is known as to why some metals form an impervious protective sort of oxide while other metals are unable to form a film which resists further attack. The coating may be soluble in the corroding solution, or it may be spongy and porous.

(4) The chemical and physical homogeneity and texture of the metal surface may influence the rate of
corrosion. If the surface of a metal is non-homogenous, a difference in potential will be set up over the metal surface and the metal will corrode more at the anodic areas. This results in localized attack as pitting.

(5) Dissimilar metals in contact in the presence of a corroding solution sets up a galvanic cell and brings about corrosion by galvanic action. This action is also brought about by dissimilar solutions in contact with a metal.

Krikson(31) suggests further factors influencing the mechanism and rate of corrosion, namely:

(1) The presence of oxygen in solution and its ability to reach the metal surface.

(2) The metal potential or solution potential as established by the electrochemical series.

(3) Unequal distribution of dissolved substances in solution on the metal surface.

(4) Overvoltage of hydrogen on metal or other material in electrical contact with the metal.

(5) Segregation of impurities in the metal.

(6) Conductivity of the corrosive medium.

(7) Presence of oxidizing agents other than oxygen in the corrosive medium.
(8) Mechanical stress or strain within the metal body. Metal subjected to externally applied stress corrodes more quickly, probably due to damage of the protective film. (11)

Evans, (33) and others (21), (23), (47), (57), (58), all agree that the electrochemical theory is by far the more important of the thus far proposed theories, and comes closer to explaining the process of corrosion.

The electrochemical theory postulates the existence of corrosion cells which are the basic units of the corrosion process. A corrosion cell consists of two electrodes, one functioning as the anode and the other as the cathode. The anode is the electrode to which negatively charged ions flow and the cathode is the electrode to which positively charged ions flow. Besides the anode and cathode, a corrosion cell must contain a conducting liquid medium in which ions are carried. The cell must be electrically completed by means of a metallic connection between the electrodes. Finally, there must be a driving force or difference in potential which is capable of initiating and maintaining the flow of current.

Erikson (31) says that corrosion is almost entirely galvanic and illustrates galvanic action as follows:
When the corroding medium becomes concentrated differently at different locations on the metal surface, the formation of concentration cells occurs. If a small cavity exists in the surface of a metal into which oxygen cannot diffuse quickly, an outer shell of corrosive products will be formed. The portion under this shell, where the oxygen concentration is least, will become the anodic portion and may become decidedly acid. Where the deposit is thin and the oxygen concentration is greatest, a cathodic area will be established. The metal in the anode region tends to go into solution and at the same time hydrogen goes into solution in the cathodic area, thus keeping the solution neutral. If hydrogen is evolved or unites with oxygen to form water, the metal continues to go into solution.
Methods of Corrosion Testing

Laboratory Corrosion Tests. According to Burns, a corrosion test is a procedure for determining the rate of reaction between a metallic material and a nonmetallic element of the surrounding environment. The purpose for which laboratory corrosion tests are to be used may determine their general character. If a test is intended to be used as a control test to ascertain the degree of uniformity of successive lots of a given material, it is desirable to provide close control and standardization of conditions and procedures. If on the other hand the purpose of a test is to determine the relative suitability of materials for a certain application, then the test conditions should be patterned as closely as possible after the conditions of service.

Several different methods of attack can be employed in making corrosion tests. Some workers have sought a remedy to counteract the action of corrosion. Others have sought a means for testing or measuring the corrosibility of metals in order to determine which metal would be most satisfactory for a particular use. This last method is of more importance to the engineer who is interested in selecting materials of construction which will withstand the action of certain environments.
For systematic testing it is necessary to govern local conditions and other disturbances such as aeration, changes in electrolyte composition, slight mechanical abrasive actions, temperature fluctuations, etc.\(^{(36)}\), \(^{(44)}\), \(^{(55)}\) The oldest method for corrosion testing is the immersion test. This method is very slow and attempts to accelerate the test, such as increasing the concentration of the corrosive medium, produce results which bear little relationship to those where actual operating conditions are being reproduced. While it is permissible to increase within reason, the rapidity and to some extent the severity of the so-called weathering cycles in an effort to accelerate corrosion rate, it must be realized that the reliability of the result is inversely proportional to the amount of acceleration induced. "Corrosion tests which employ severe conditions may produce a degree of disintegration of metals or protective coatings which bears no relationship to corrodi-
bility under conditions of service."\(^{(26)}\) Burns\(^{(14)}\) states that it is preferable to carry out corrosion studies under nearly natural conditions and to use sensitive measuring techniques to determine the rate of reaction rather than to depend upon highly accelerated tests to furnish the larger effects which can be detected by less precise methods of measurement.
Calcott and Whetzel\(^{(17)}\) list the following conditions which affect the rate of the corrosion reaction:

1. Area of metal computed from its linear dimensions.
2. Rate of diffusion in corroding liquid.
3. Saturation concentration of metal in corroding liquid.
4. Movement or velocity of corroding liquid.

"For a given set of conditions, the rate is constant in most laboratory experiments only after an initial time period (48 hours) has elapsed. The rate is increased greatly by increase in temperature, the logarithm of the rate varying as a straight-line function of the temperature for the range encountered in practice (20°-100°C). More strictly, the logarithm of the corrosion rate is inversely proportional to the absolute temperature, as expressed by the following equation:

\[ \log R = A + B/T \]

where \( A \) and \( B \) are constants, \( R \) the rate of corrosion, and \( T \) the absolute temperature. The simpler relation is, however, convenient for ordinary use."\(^{(17)}\)

There are numerous special property tests, but the typical tests commonly used in determining the corrosibility are listed below:

1. Total immersion test with solution at rest.
(2) Total immersion test with moving solution.
(3) Partial immersion test with solution at rest or with moving solution.
(4) Atmospheric tests.
(5) Salt spray tests.
(6) Soil tests.

**Preparation of Test Specimens.** Grease, oil and other extraneous material which would interfere with the purpose of the test should be removed from the surface of the test specimen. This should include mill scale and other corrosion products with the exception of the oxide film which forms immediately upon any exposed metal surface. Grease can be removed by organic solvents or any alkali dip. Non-ferrous metals are usually only degreased, and protective coatings are not removed prior to testing.

**Testing Apparatus.** Many types of apparatus have been proposed to determine corrosion rates with moving solutions. The design of the apparatus depends chiefly upon the shape of the test piece. If the material is tubular, provisions must be made to circulate the corrosive liquid through the tube at the velocity desired. Glass apparatus is generally used in laboratory tests so that the specimen can be observed during the test.
Methods of Measuring and Reporting Amount of Corrosion. The amount of corrosion is usually determined by one of the following methods:

1. Loss in weight.
2. Depth of pitting.
3. Determination of metal dissolved.
5. Amount of corroding agent consumed.
6. Change in structure as measured by tensile strength or microscopic examination.
7. Increase in electrical resistance.

Speller(57) and Corey(20) state that since the purpose of most corrosion tests is to indicate the expected service from a given metal, the most logical method of reporting results is in terms of penetration in a given time. Penetration is generally expressed in inches per year or inches per month. This unit allows a quick estimate of the probable life of a metal. A standard unit of measurement is desired so that results of different experiments may be compared. The average depth of penetration of a test piece of known area can be determined from the loss in weight, the area exposed, the weight of metal per unit of volume and the duration of the experiment by use of the formula:
\[ P = \frac{WK}{SAT} \]

where:
- \( P \) = the average penetration in inches per year.
- \( W \) = the weight of metal removed in grams.
- \( A \) = the area exposed in square inches.
- \( K = 0.06102 \), a constant.
- \( S \) = the specific gravity of the metal.
- \( T \) = the duration of the test in years.

Perry\(^{(S1)}\) gives a similar formula but indicates that the calculation is based on a standard static corrosion test. "In all cases where the results of corrosion tests are reported it is desirable to give the metal structure and treatment, the condition and extent of the area exposed, the duration of the test, and data indicating the magnitude of the different important variables, such as variations in the corroding medium, temperature, velocity of motion, and volume of the corroding solution (in submerged corrosion), physical character of the corrosion products, etc."\(^{(57)}\)

**Pitting.** In case pitting occurs, a factor should be included in the results, since this form of corrosion may cause failure before 20 per cent of the metal has been removed by normal corrosion. The effect of pitting is determined by grinding down until all pits have just disappeared. The loss in weight during grinding is
determined and the maximum corrosion effect or pitting is calculated by the formula: (51)

\[ d = \frac{K}{\text{AST}} (W + p) \]

where:  
- \( d \) = rate of penetration of metal by both normal corrosion over the entire surface and by local action due to pitting expressed in inches per month.  
- \( p \) = loss in weight in grams due to grinding out pitts.  
- \( K = 43.9 \), a constant.  
- \( W \) = loss in weight in grams due to normal corrosion.  
- \( A \) = area of test piece in square inches.  
- \( S \) = density of metal in grams per cubic centimeter.  
- \( t \) = time of exposure in hours.

Speller (57) introduces a value termed the "pitting factor" which is determined by dividing the maximum penetration by the average penetration. Thus if the average penetration is 0.01 inch per year, and the maximum depth of pitting is 0.05 inch per year, the pitting factor is 5, and the metal will fail by pitting when the average penetration is only one-fifth of the metal thickness.

Fehm (35) had suggested much earlier that, as a better
standard of comparison, corrodeability should be represented by a factor \( K \), which was to be obtained by dividing the per cent loss in weight by the ratio of exposed surface in square centimeters to the volume of the specimen in cubic centimeters.

**Magnesium**

**Introduction.** In recent years the alloys of magnesium have come into prominence as a possible material of construction, particularly where weight is a factor of prime importance. Prewar uses of magnesium included equipment and parts in aeronautics, tools, general machinery and office equipment. Prewar production was in the neighborhood of 5000 tons per year. At the end of the war production capacity was approximately 290,000 tons per year, of which Government-owned plants accounted for 90 per cent.

Magnesium production reached a peak in February, 1944, at which time production began to drop rapidly. This was probably due to a drastic change in the construction of incendiary bombs, the new type not containing magnesium.

According to a Dow Chemical Company estimate, an
annual output of 30,000 tons of magnesium would be consumed as follows: in the manufacture of aircraft, 45 per cent; in the manufacture of automobiles, trucks and busses, 11 per cent; for industrial machinery, tools and manually handled equipment, 21 per cent; for furniture and other consumer goods, 8 per cent; as an alloying element for aluminum, 5 per cent; and for use in the chemical industries and photography, 10 per cent. No export demand of consequence is expected.

Magnesium is a metallic chemical element of silvery white appearance. It has an atomic number of 12, atomic weight of 24.32 with isotopes 24, 25 and 26. It is found in nature in forms of silicates, carbonates, chlorides and occurring in the minerals olivine, hornblende, talc, asbestos, meerschaum, augite, dolomite, magnesite, carnallite, kieserite and kainite. It is malleable and ductile, has a specific gravity of 1.75 at 20\(^\circ\)C, melts at 632.7\(^\circ\)C, and boils at 1100\(^\circ\)C. At high temperatures it acts as a reducing agent.

Magnesium constitutes approximately 2.1 per cent of the earth's crust, making it the eighth most abundant element or the sixth most abundant metal. It is surpassed in quantity as an engineering metal only by copper and iron.\(^{(40)}\) Dolomite, magnesite and sea water are the
principal sources of supply. Sea water gives up magnesium by an electrolytic process in the ratio of 4500 tons per cubic mile, or about 1/3 pound per barrel of sea water. In addition to being the lightest known structural metal, magnesium is tough, rigid, corrosion-resistant and easily machined. The following comparison of weight of structural metals is given in pounds per cubic foot of material:

- Magnesium .................. 112
- Aluminum .................... 175
- Steel .......................... 493
- Brass .......................... 531
- Lead ........................... 706

Inasmuch as magnesium has gained a prominent position as an industrial metal during the past few years, its future potentialities appear to be tremendous as long as researchers continue to look for new and better alloys. Corrosion of magnesium alloys presents a major problem in the utilization of the metal.

**Corrosion of Magnesium.** Magnesium is a very active metal as its position in the electromotive force series indicates, however, it is resistant to many organic and inorganic substances. "The subject of salt-water
corrosion resistance of magnesium is somewhat like that of the pitting of stainless steels, in that it involves a relatively small percentage of the applications but receives a much greater proportion of the publicity. Actually, magnesium alloys are in use in many exterior applications as well as interior with no trouble from corrosion. Magnesium and its alloys have a striking stability against atmospheric attack, being far superior to iron. Specimens exposed unprotected to atmospheric weathering for ten years show only a superficial surface-film formation.\(^{(41)}\) Magnesium corrodes in coastal areas much more rapidly than in inland areas. This is probably due to the formation of a bulky, non-adherent corrosion product.\(^{(10)}\) In industrial areas the air contains traces of sulfuric acid from sulfur in burning coal and salt air contains elements of hydrochloric acid, both of which are corrosive to magnesium.\(^{(43)}\)

Hanawalt, Nelson and Peloubet\(^{(41)}\) made extensive corrosion studies of magnesium and its alloys using an alternate immersion test in 3 per cent sodium chloride solution. They concluded that magnesium and its important alloys resist the attack of sea water even in the unprotected state, giving very slight weight loss over a period of one year. These researchers used very pure magnesium produced by a special vaporization process.
They point out that higher purity leads to greater stability. Almost all researchers who have worked with magnesium alloys have worked with base metal in which metallic impurities varied in uncontrolled amounts.

Commercial magnesium metal has the following typical analysis expressed as percentage by weight: (10), (41)

<table>
<thead>
<tr>
<th>Element</th>
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<tr>
<td>Fe</td>
<td>0.030</td>
</tr>
<tr>
<td>Al</td>
<td>0.01</td>
</tr>
<tr>
<td>Ni</td>
<td>0.0005</td>
</tr>
<tr>
<td>Mn</td>
<td>0.002</td>
</tr>
<tr>
<td>Cu</td>
<td>0.005</td>
</tr>
<tr>
<td>Pb</td>
<td>0.001</td>
</tr>
<tr>
<td>Si</td>
<td>0.004</td>
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<tr>
<td>Na</td>
<td>0.005</td>
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Iron in amounts up to 0.017 per cent has no effect on the corrosion rate. Above that percentage it has a marked effect in increasing the corrosion rate.

The fact that magnesium alloys sometimes are subject to atmospheric attack is attributed to their sensitivity to the presence of impurities. Any investigation as to the corrosion of magnesium should take into account the fact that the metal may be contaminated with impurities which may modify the behavior of the alloy. (49)

Frasch (39) contradicts the findings of Hanawalt, Nelson and Feloubet (41) by saying that magnesium is more corrodbible as it becomes more pure. "On immersing a bar of pure magnesium in 3 per cent NaCl solution, a strong evolution of hydrogen takes place with a resulting heat of chemical reaction. Oxygen has a retarding effect on
the corrosion of magnesium." This investigator does not indicate the exact purity of the magnesium metal used.

Boyer (22) states that pure magnesium is quite resistant to corrosion and that the rapid corrosion of magnesium alloys has been unjustly attributed to magnesium itself rather than to the nature and proportion of alloying ingredients. An excess of manganese over the critical amount slightly increases corrosion resistance but does very little harm. It is better to have too much manganese than too little.

Magnesium alloys in general resist attack by solutions of alkalies, fluorides, chromates and borates. The alloys are attacked in solutions containing nitrates or sulphates of heavy metals, ammonium or calcium salts, and in many inorganic and organic acids. If the solution pH is greater than about 6, a film of Mg(OH)₂ forms. This film is porous and retards corrosion, but does not stifle it. Where the pH is less than 6, corrosion is so rapid that the Mg(OH)₂ film cannot form. (15) One unexplained exception is the fact that hydrofluoric acid in concentrations greater than 5 per cent has practically no effect on magnesium alloys. (15)

In stagnant caustic alkalis, magnesium may be almost incorrodible because of a self-healing type film which is impervious to magnesium ions. In presence of alkali
chlorides the corrosion product is physically different and rapid corrosion occurs.\(^{(9)}\)

In installations where magnesium may come in contact with dissimilar metals such as copper, tin, lead, nickel or steel, electrolytic corrosion may occur as a result of electrical potential established between the unlike metals. Adequate insulation should be provided in assemblies of magnesium and other metals.

Bleiweis and Fusco\(^{(10)}\) give a detailed table showing the action of some chemicals on magnesium alloys. Recommendations, based on practical experience and laboratory experiments, are made concerning the use of magnesium alloys in certain corrosive environments.

Prevention of Corrosion. Many methods are used to try and prevent corrosion of magnesium or to increase its resistance to corrosion. The methods generally used fall into the following categories:\(^{(10)}, (27)\)

1. Inclusion within the alloy of constituents which produce a more corrosion-resistant alloy.
2. Exclusion of harmful impurities from the composition.
3. Special heat treatment.\(^{(53)}\)
4. Formation of chemical coatings in an
attempt to exclude the atmosphere.

(5) Application of organic finishes such as paints, lacquers, waxes, etc.

(6) Application of inhibiting coatings which are somewhat soluble and offer protection by their passivating or inhibiting action.\(^\text{22}\)

Any combination of the above listed types may be employed. For example, a special corrosion-resistant alloy may be chemically coated, primed and painted. No success has been obtained by coating magnesium with other metals, by spraying or by electro-deposition. Covering with metal of high purity, such as the process used in aluminum manufacture, has met with no success. Immersion in chromate bath seems to provide the best protection.\(^\text{22}\)

Watts\(^\text{59}\) states that a corrosion-resistant alloy could easily be made by melting together two highly resistant or noble metals. The problem is to take a cheap metal and add a small amount of some other element that will make the alloy resistant to corrosion. The simple addition of some noble metals only increases corrosion. There should be alloyed a metal which is more resistant to corrosion which forms a solid solution with the metal whose resistance to corrosion it is desired to increase.

Whenever magnesium alloys with other metals, it
forms what is described as a substantial solid solution. Several factors, such as atomic size, valence and the electrochemical factor govern the limit of solubility in alloy systems. Magnesium has a hexagonal crystalline form and complete solid solubility can be obtained with other metals which have a hexagonal crystalline form.\(^{18}\)

A large number of additions to magnesium have been proposed in order to increase the corrosion resistance of the alloy.\(^{(12), (29), (30), (38), (59), (61)}\)

Bushrod\(^{(15)}\) gives a table showing the effect of alloying which summarizes this information.
Table 1

The Effect of Alloying Elements on the Corrosion Rate of Magnesium

<table>
<thead>
<tr>
<th>Alloying Element</th>
<th>Effect</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkali metals</td>
<td>Acceleration</td>
<td>Recent works show that corrosion resistance is not increased as supposed before</td>
</tr>
<tr>
<td>Antimony</td>
<td>Acceleration</td>
<td></td>
</tr>
<tr>
<td>Beryllium</td>
<td>Retardation</td>
<td>Small additions only</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Acceleration</td>
<td>Not very marked</td>
</tr>
<tr>
<td>Calcium</td>
<td>Retardation</td>
<td>Small quantities added to elektron</td>
</tr>
<tr>
<td>Gerium</td>
<td>Acceleration</td>
<td>Very slight effect</td>
</tr>
<tr>
<td>Chromium</td>
<td>Doubtful</td>
<td>Japs say retardation</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Acceleration</td>
<td>Very pronounced</td>
</tr>
<tr>
<td>Copper</td>
<td>Acceleration</td>
<td>Cu content should not exceed 0.2%</td>
</tr>
<tr>
<td>Iron</td>
<td>Acceleration</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>No effect</td>
<td>Data limited to additions up to 0.2%</td>
</tr>
<tr>
<td>Nickel</td>
<td>Acceleration</td>
<td>Very pronounced</td>
</tr>
<tr>
<td>Silicon(52)</td>
<td>Acceleration</td>
<td>Only observed for concentrations &gt; 0.1%</td>
</tr>
<tr>
<td>Silver</td>
<td>Retardation</td>
<td>Retards in Cl solutions; accelerates in atmosphere</td>
</tr>
<tr>
<td>Tin</td>
<td>Retardation</td>
<td></td>
</tr>
<tr>
<td>Tellurium(50)</td>
<td>Retardation</td>
<td></td>
</tr>
<tr>
<td>Zirconium</td>
<td>Retardation</td>
<td></td>
</tr>
</tbody>
</table>
Silicones

Silicon is one of the most abundant elements in nature. In the form of silica and the silicate minerals, silicon and oxygen are familiar to us as the major constituents of rocks and sand. These materials have been used in the ceramic and building arts since the earliest civilization, and have been the chief concern in the chemistry of silicon.

During the past century, research has brought to light many new compounds of silicon which do not occur in nature. These organosilicon compounds range from liquids to rubbery solids, some being highly reactive and others being exceedingly stable and inert. Most organosilicon structures are very stable and unreactive, even more so than their analogs in carbon chemistry. The discovery of the silicone compounds has opened a field fully as broad as that of the organic polymers.

Silicone Chemistry. The organosilicon compounds have been named, as a matter of convenience, as derivatives of the hydrides, which are called silanes. Thus CH₃SiH₃ is methylsilane, and CH₃SiCl₃ is methyltrichlorosilane. When the units have the composition -R₂SiO- the substance is often called a silicone, because the structure was once thought to be similar to that of a ketone, R₂CO.
Rochow\(^{(54)}\) states that the analogy is not a useful one, because the ketones are monomeric compounds of the carbonyl group, while the silicones are always polymeric with the following unit structure:

\[
\begin{array}{c}
\text{R} \\
\text{Si-O-} \\
\text{R}
\end{array}
\]

However, like many organic nomers, the name silicone persists because it has the sanction of long usage.

The silicones, or polyorganosiloxanes are fundamentally oxides of silicon. They polymerize readily, the chief difficulty being that of checking and directing polymerization. One method to employ silicon groups in a polymer would be to form chains of silicon atoms, as is done with carbon. This is unsatisfactory, however, because the silicon-silicon bond becomes increasingly unstable as the number of atoms is increased. Chains of more than six silicon atoms have not been isolated. A silicon atom inserted in a carbon chain tends to weaken rather than strengthen the chain. The problem of polymerization, therefore, is to build a chain or network of the silicon radicals so as to preserve their stability and make the most of their heat-resistant properties.

One method is used which provides a polymer with less carbon content and greater distinction over the
purely organic polymers. This method makes use of the organosilicon oxides or organosiloxanes. A siloxane is a compound that has oxygen atoms between the silicon atoms:

\[-\text{Si}-\text{O}-\text{Si}-\text{O}-\text{Si}\-\]

Cross-linkage adds stability and affects other properties such as solubility, fusibility, etc. The mechanical and chemical properties change with the kind of radical which is attached to the silicon.

**Silicone Resins.** These resins are produced in the form of a viscous liquid which upon heating polymerize to a solid. These resins possess the thermal stability and the water repellancy common to all silicones. Phenyl silicone has exceptional thermal stability, but is thermoplastic and is brittle when cold. Some methyl silicone resins do not decompose or disintegrate over a period of years at 200°C and maintain their dielectric strength even at 300°C. The upper service limits of temperature of the silicone resins may be raised if oxygen is excluded, for it is oxidation of the methyl groups that imposes the limit. Methyl silicone insulation oxidizes to silica instead of forming a conducting carbonaceous residue. A copolymer of methyl and phenyl silicones may be cured to
a tougher, stronger mass than is possible with methyl silicone alone.

The methyl chlorosilanes make certain surfaces water-repellent. They react with hydrophilic surfaces, leaving a film which is hydrophobic. The film is tightly bound and is removed only by destructive reagents like hydrofluoric acid. Wood and cotton may be treated, leaving a water-repellent film which is wetted, but not removed, by organic solvents. The treatment has been partially investigated on leather and wool, and plastic surfaces have given variable results.

Application of Silicone Resins. These resins may be applied by spraying or dipping the surface or by exposing the surface to vapors of a silicone solution. Treating the surface before applying the resin improves the coating. Dow Corning\(^2\) recommends the Dow No. 7 treatment as an effective paint base for the silicone enamels on magnesium. This consists of a five-minute immersion in 30 per cent hydrofluoric acid followed by 45 minutes in 15 per cent sodium dichromate.

After the solution has been applied to the surface, it should be air-dried to eliminate excess solvent before curing. Film thickness depends on the concentration of the resin solution. Film thickness can be increased by repeated applications, but the surface should be
partially cured between applications.

**Curing of Silicone Resins.** Dow Corning recommends infrared curing at 480°F for periods up to three hours to remove tackiness and to complete polymerization. A quantity of cobalt equivalent to 0.5 per cent of the weight of the resin content should be added in the form of cobalt Nuodex drier. It has the property of decreasing the drying time without affecting flexibility after aging. Sixteen hours air-drying time should be allowed between coats before baking the surface.

**Silicone Resins as Protective Coatings.** Dow Corning is manufacturing a series of three resins for the protective coating industry. It is believed that these resins will find wide use as finishes on surfaces that are exposed to high temperatures and humidities. One resin blend is recommended for formulating paints to be used on smokestacks, furnace parts, oven doors, exhaust manifolds and radiators. In one application on a series of large gas engine mufflers, exposed to the weather and having a surface temperature of 500°F, the most heat-resistant organic aluminum paint lasted one month. The mufflers were cleaned and re-painted with aluminum paint pigmented with Dow Corning silicone resin, DC 301. After twelve months of exposure, the silicone aluminum paint was still in good condition.
III. EXPERIMENTAL

Purpose of Study

Corrosion of heat exchanger tubes presents a problem in the heating of liquids and gases with heat exchangers, necessitating frequent replacement of the tubes. The purpose of this investigation will be to determine the corrosion-resistant properties of Dowmetal magnesium-alloy tubing as compared to the corrosion-resistance offered by special magnesium-alloy tubing and silicone-coated magnesium-alloy tubing when used as heat exchanger tubes, and to determine if these tubes are practicable for use with sodium chloride solutions and sulfur-bearing fuel oil. Comparative results will be obtained for stainless steel, monel, and aluminum tubing.

Plan of Investigation

The plan of investigation is as follows:

Construction of Corrosion Test Equipment. Two single pass, double pipe heat exchangers will be constructed using pyrex glass tubes as outer shells, and
test specimen tubing as heat exchanger tubes. Pyrex tubes will be used so that corrosion action on the surface of the test heat exchanger tubes can be observed. The pyrex tubes will be fitted with flanged ends equipped with packing glands through which test specimens can be easily inserted and removed. The equipment will be constructed as shown in Figure 2, page 45.

Corrosion Tests. A series of seventy-two-hour tests will be made using the following tubing as heat exchanger tubes: magnesium-alloy, FS-1; silicone-coated magnesium-alloy, special magnesium-alloy; stainless steel, 316; aluminum, 3S and monel. Three special magnesium-alloys will be obtained, each containing one per cent of one of the following metals: silver, chromium and tin. The tubing will be cleaned and weighed prior to corrosion testing.

Tap water, three per cent sodium chloride, ten per cent sodium chloride and sulfur-bearing fuel oil will be used as corrosive mediums.

Equilibrium temperature conditions will be maintained during each test; inlet temperature of corrosive medium to heat exchanger will be 38°C, outlet temperature will be 65°C. Steam will be used as the heating medium and will be used at the pressure necessary to maintain the
required temperatures. After leaving the heat exchangers, the corrosive medium will be cooled in a cooler to a temperature of 330°C before being pumped back to the storage tank.

The rate of flow of corrosive medium through the annular space of the heat exchangers will be great enough to produce turbulent flow. Rate of flow will be measured by calibrated manometers.

Removal of Corrosion Products. Upon completion of a corrosion test, the heat exchangers will be dismantled, the tubes removed and chemically cleaned of corrosion products. The tubes will be reweighed to determine the loss of weight due to corrosion.

Calculation of Results. From the known weight losses, area of test specimens and duration of tests, the corrosion rates will be calculated in inches penetration per year. A comparison will be made of the corrosion resistance offered by each alloy, particularly the resistance offered by the special magnesium-alloys as compared to the Dowmetal magnesium-alloy.
Materials

Test Specimens. The following materials were used as corrosion test specimens:

Tubing, Magnesium-Alloy, F3-1. (Eight). Dimensions: length, 7 feet; outside diameter, 0.673 inches; inside diameter, 0.622 inches. Composition: aluminum, 2.5-3.5 per cent; manganese, 0.20 per cent (minimum); zinc, 0.7-1.5 per cent; silicon, 0.3 per cent (maximum); other impurities, 0.3 per cent (maximum); magnesium, balance. Specific Gravity: 1.77 grams per cubic centimeter. Thermal Conductivity: 0.25 C.G.S. units. Purchased from the Dow Chemical Company, 915 Shoreham Building, Washington 5, D. C.

Tubing, Aluminum-Alloy, 3S. (Four). Dimensions: length, 12 feet; outside diameter, 0.645 inches; inside diameter, 0.622 inches. Composition: manganese, 1.2 per cent; balance, aluminum and normal impurities. Specific Gravity: 2.73 grams per cubic centimeter. Thermal Conductivity: 0.37 C.G.S. units. Purchased from Whitehead Metal Products Company, 303 W. 10th Street, New York, New York, distributors for Aluminum Company of America, 213 Exchange Building, Richmond 19, Virginia.
Tubing, Monel Wrought. (Eight). Dimensions: length, 7 feet; outside diameter, 0.845 inches; inside diameter, 0.622 inches. Composition: nickel, 67.00 per cent; copper, 30.00 per cent; iron, 1.40 per cent; manganese, 1.00 per cent; silicon, 0.10 per cent; carbon, 0.15 per cent; sulfur, 0.01 per cent. Specific Gravity: 8.94 grams per cubic centimeter. Thermal Conductivity: 0.062 C.G.S. units. Purchased from The International Nickel Company, Inc., 67 Wall Street, New York 5, New York.

Tubing, Stainless Steel, Type 316. (Eight). Dimensions: length, 7 feet; outside diameter, 0.840 inches; inside diameter, 0.622 inches. Composition: carbon, 0.07 per cent; manganese, 1.65 per cent; silicon, 0.38 per cent; phosphorus, 0.031 per cent; sulfur, 0.009 per cent; chromium, 17.58 per cent; nickel, 11.00 per cent, molybdenum, 2.60 per cent. Sample Shop Order No. 23171. Specific Gravity: 8.05 grams per cubic centimeter. Thermal Conductivity: 128 BTU/sq.ft./hr./°F/in. Donated by The Carpenter Steel Company, Welded Alloy Tube Division, Kenilworth, New Jersey.

Corrosive Mediums. The following materials were used as corrosive mediums:

Sodium Chloride, Salt. (150 pounds). Jack-frost Fine Kiln Dried, Evaporated. Used in making sodium chloride corrosive solutions, 5 per cent and 10 per cent

Oil, Crude, Texas, Reduced. (Thirty gallons). Sulfur content: 2.69 per cent; Gravity, A.P.I.: 16.5; Flash: 230-290°F, with 400°F end point gasoline removed. Used as corrosive medium in making oil tests. Donated by Esso Laboratories, Standard Oil Company of New Jersey, Louisiana Division, Baton Rouge, Louisiana.

Tube Conditioning Reagents. The following materials were used as tube conditioning reagents:


Catalyst, Cobalt, Nuodex. (Twenty-five grams). Composition: 0.3 per cent cobalt by weight based on 100 per cent resin. Used as drying agent for silicone. Purchased from Nuodex Products Company, Inc., Elizabeth, New Jersey.


Reagents. The following reagents were used in making chloride determinations:


Ammonium Thiocyanate. (Thirty-eight grams). Obtained from Chemistry Department, V. P. I. Blacksburg, Virginia.
Indicator, $\text{Fe}_2(\text{SO}_4)_3$. (Ten grams). $\text{Fe}_2(\text{SO}_4)_3$ obtained from Chemistry Department, V. P. I., Blacksburg, Virginia. Indicator prepared as indicated in Fish\(^{(37)}\), page 49.

**Apparatus**

The following apparatus was used in the investigation:

**Heat Exchanger Equipment:**

**Tubing, Pyrex.** (Two). Two inches inside diameter with flanged ends, five feet long. Used as outer shell of double pipe heat exchangers. One obtained from Chemical Engineering Department Storage and one purchased from Corning Glass Works, Corning, New York.

**Flanges, Gland Packing.** (Four). Equipped with 0.84 inch packing gland and 0.75 inch port. (See figure 2). Used as packing glands on each end of pyrex tube heat exchangers. Two made in Chemical Engineering Department and two obtained from Norfolk and Western Railway, Roanoke, Virginia.

**Pump, Centrifugal.** (One). With electric motor. Fifty gallons per minute capacity. Used for pumping corrosive medium through system. Motor Pump manufactured by Ingersoll-Rand Company, Cameron Pump
Division, New York, U. S. A. Obtained from Chemical Engineering Department Storage.

**Cooler, Surface.** (One). Four pass. Twenty-six, one-half inch tubes, length: three feet. Used to cool medium to proper temperature before being pumped to storage. Manufactured by Ross Heater and Manufacturing Company, Buffalo, New York. Obtained from Chemical Engineering Department Storage.

**Trap, Steam, High Pressure.** (Two). Used on exit ends of steam lines. Manufactured by Strong, Carlisle and Hammond Company, Cleveland, Ohio. Obtained from Chemical Engineering Department Storage.

**Pipe, Valves, Fittings.** (Assorted). One inch, 3/4 inch, 1/2 inch and 1/4 inch black iron and galvanized iron pipe and fittings. Brass gate, globe and needle valves. Used in construction of heat exchanger apparatus. Partially available in Chemical Engineering Department Storage. Remainder purchased from the Tidewater Supply Company, Inc., P. O. Box 1829, Roanoke 8, Virginia.

**Drum, Storage, Thirty-Gallon, Iron.** (One). Used as storage tank for corrosive medium. Obtained from Chemical Engineering Department Storage.
Measurement and Control Instruments:


Thermometers, Laboratory, Bi-metallic. (Five). Graduations: 20°C, 0-250°C. Used to measure inlet temperature, outlet temperature and storage tank temperature. Manufactured by Weston Electrical Instrument Corp., Newark, New Jersey. Obtained from Chemical Engineering Department Storage.

Gage, Steam Pressure. (One). Graduations: 5 psi, 0-100 psi. Used to measure steam pressure. Manufactured by Crosby Steam Gage and Valve Company, Boston, Massachusetts. Obtained from Chemical Engineering Department Storage.


**Balance, Torsion.** (One). 4.5 KG. capacity. Used in weighing test specimens before and after corrosion testing. Obtained from Chemical Engineering Department Storage.

**Hydrometer Spindles.** (Two). Specific Gravity scale graduations 0.001 at 60°F. Range: 0.8 to 1.0. Used in making specific gravity determinations of oil. Obtained from Chemical Engineering Supply.

**Burettes.** (Two). 50 ml. capacity. Graduations: 0.1 ml. Used in making titrations to determine chloride content of NaCl solutions. Obtained from Chemical Engineering Department Storage.

**Glassware, Assorted.** Used in making titrations. Obtained from Chemical Engineering Department Storage.


**Tube Conditioning Equipment:**

**Gun, Spray, Devilbiss, Type MBC.** (One). Equipped with Suction Feed Cup, Type KR-501. Used for spraying silicone resin coating on magnesium-alloy tubing. Manufactured by the Devilbiss Company, Toledo, Ohio. Loaned by the Speedway Esso Station, Blacksburg, Virginia.
Regulator, Air. (One). Capacity: 50 pounds.
Calibration: 1.0 pound per square inch. Used to regulate
air pressure for spray gun in spraying silicone resin
coating on magnesium-alloy tubing. Manufactured by The
Devilbiss Company, Toledo, Ohio. Loaned by Speedway Esso
Station, Blacksburg, Virginia.

Oven, Infrared, Drying. (One). Maximum tem-
perature: 500°F. Used to cure silicone resin coatings
on magnesium-alloy tubing. Available in Chemical
Engineering Department.

Macrophotographic Equipment:

Camera. (One). 4 x 5 film holder and ground
glass plate. Adjustable bellows, 2x lens. Used in tak-
ing macroscopic pictures. Obtained from Metallurgy
Department, V. P. I., Blacksburg, Virginia.

Films, Photographic. (Six). 4 x 5 Commercial
Ortho. Used in taking pictures of specimens. Manufactured
by Agfa Ansco, Binghamton, New York. Available in
Chemical Engineering Department Dark Room.

Equipment, Dark Room. Used in developing and
printing macroscopic pictures. Available in Chemical
Engineering Department.

Paper, Photographic. (Twenty-four Sheets).
Kodabrome, F-3, 4 x 5 inches. Used in printing pictures

Method of Procedure

The following procedure was followed in making corrosion tests on heat exchanger tubes:

Construction of Corrosion Test Equipment. Two single-pass, double pipe heat exchangers were constructed using pyrex glass tubes as outer shells. The pyrex tubes were two inches inside diameter, 2.25 inches outside diameter, five feet long and had flared ends. Each end of the pyrex tubes was equipped with a flange containing a 0.375 inch packing gland and a 0.75 inch inlet, or outlet port. The corrosion test tubing could be easily inserted into or removed from the packing glands without damaging the surface of the test specimen.

The corrosive medium storage tank (35 gallon capacity) was placed on a platform six feet above the heat exchangers. Three-quarter inch black iron pipe was used to connect the storage tank to a centrifugal pump which had a capacity of fifty gallons per minute. The outlet side of the pump was connected to a by-pass line leading directly back to
the storage tank and to a header from which feed was supplied to each heat exchanger. A 3/16 inch orifice was placed in each feed inlet line and mercury manometers were placed across the orifices. The corrosive liquid was made to flow through the annular space of each heat exchanger on the outside of the test specimens. High pressure steam (50 pounds per square inch gage) was passed through the inside of the test tubing and was exhausted to the drain through a steam trap. A by-pass was provided on the steam line so that condensate could be drained from the line. The exit end of each heat exchanger was connected to a surface cooler which had seventeen square feet heating area. The condenser was connected to the storage tank.

A schematic diagram of the corrosion test equipment is shown on Figure 3, page 45.

Preparation of Test Specimens. The tubing to be tested was cut to a length of six feet and threaded on each end with one-half inch standard pipe threads. The tubing was then degreased by wiping with a cloth saturated with methyl alcohol, and thoroughly dried with a soft cloth. The specimens were given no special treatment, such as pickling, prior to corrosion testing. After being cleaned and dried, the specimens were weighed on a torsion balance. Accuracy of weighing was to ten milligrams.
LEGEND

a. Steam Trap
b. By-Pass Valve
c. Condenser
d. Pump
e. Flanges
f. Packing Gland
g. Storage Tank
h. Manometers
i. Inlet Valves
j. Steam Pressure Gage
k. Test Corrosion Specimens
l. Inlet Temperature
m. Outlet Temperature
n. Steam Line By-pass Valve

VIRGINIA POLYTECHNIC INSTITUTE
Department of Chemical Engineering
Blacksburg, Virginia

Schematic Diagram
CORROSION TEST EQUIPMENT

Drawn By: CM
Checked: P.G.
File: 539
Scale: None
Approved: Date: 9-1-46

Fig. 2
Preparation of Silicone-Coated Magnesium-Alloy Tubing. The magnesium-alloy tubing which was to be coated with silicone resin was degreased with methyl alcohol, dried and weighed. A thin coating of silicone, 60 per cent resin and 40 per cent naphtha solvent, DC-801, containing 0.3 per cent by weight cobalt drier, was then sprayed on the outside surface of the tubing. An air pressure of forty pounds per square inch was used and the Devilbiss, type MBC, spray gun nozzle adjusted to give a fine spray. An apparent uniform coating was obtained by suspending the tubing in a vertical position during the spraying operation. The resin was allowed to air dry for sixteen hours prior to curing. Curing between coats was accomplished by baking the specimens for thirty minutes at 450°F in an infrared oven. Three coats of silicone resin were applied. After the last application, one specimen was cured for two hours and two specimens were cured for three hours. This produced a coating which would resist scratching when a 9H drawing pencil was used to draw a firm line on the surface of the resin. The coated tubing was reweighed to determine the weight of the coating. No attempt was made to measure the thickness or uniformity of the resin coating; the uniformity and thickness depended entirely upon the technique of spraying.
Preparation of Corrosive Medium. The sodium chloride solutions were prepared in the storage tank which had been calibrated in pounds of water. Two hundred and thirty pounds of tap water were run into the storage tank and enough salt added to give concentrations of 3 or 10 per cent sodium chloride as desired for the tests. These solution strengths were tested by use of the standard Volhard Method for chloride determinations as described by Fish. (37)

After the tests had been completed using water and sodium chloride solutions, the system was cleaned and drained before making tests using sulfur-bearing fuel oil as a corrosive medium. This oil was given no special treatment but was used as received. Thirty gallons of a Texas crude oil were put into the storage tank. This oil was very viscous at room temperature and had to be preheated to 80°C prior to being pumped through the system. Preheating was accomplished by inserting in the storage tank a steam heated coil, having one square foot heating area. High pressure steam, 60 psig, was used as the heating medium.

The pH of each corrosive medium was determined by use of a pH electrometer.
Operational Procedure. Figure 2, page 45, will be used to clarify the following procedures:

Steam Blank Test. The test specimens (s) were inserted through the packing glands (g) into the pyrex glass tubing and the packing glands were packed with graphite string packing. The tubes were connected to the high pressure steam line by means of unions, and exhausted to the drain through steam trap (a).

Two hundred and thirty pounds of tap water were run into the storage tank (i). This water was given no special treatment but was used as received.

The centrifugal pump (d) was primed and the water was pumped through the annular space of the heat exchangers, through the cooler (c) and back to storage tank (i); the rate of flow being measured by calibrated manometers (m) in conjunction with a 3/16 inch diameter orifice placed in each inlet line to the heat exchangers. The rate of flow through the annular space was adjusted by means of needle valves (n) to approximately 7.0 gallons per minute, equivalent to a velocity of 0.75 feet per second and a Reynolds's Number of approximately 39,000.

The steam supply line by-pass valve (v) was opened and condensate in the line allowed to drain. The steam by-pass valve (v) was closed and steam was admitted to
the inside of the heat exchanger tubes and maintained at a pressure of approximately 50 pounds per square inch gage.

The water was heated to 38°C, after which the flow of condenser water was adjusted so as to maintain a constant corrosive medium storage temperature of 38°C.

After the system had reached equilibrium, readings of inlet temperature ($t_1$), outlet temperature ($t_2$), rate of flow ($m$), and steam pressure ($p$) were made and recorded every eight hours. Tests were made at constant conditions for a duration of 72 hours. An additional test, 4.75 hours duration, was made on magnesium so that a steam blank correction factor could be determined for use in the magnesium-sodium chloride tests which were limited to 4.75 hours. Upon completion of a test, the pump (d) was turned off and the system drained.

**Sodium Chloride Corrosion Test.** The test specimens were placed in the heat exchangers as described above. The centrifugal pump (d) was primed and the solution was pumped through the by-pass line (b) to insure thorough mixing. The solution was then pumped through the annular space of the heat exchangers, the rate of flow being the same as those stated for steam blank tests.

Steam was passed through the heat exchanger tubes at a pressure of 50 pounds per square inch gage. A constant
corrosive medium storage temperature of 38°C was
maintained.

After the system had reached equilibrium, readings
of inlet temperature \( t_1 \), outlet temperature \( t_2 \), rate
of flow \( m \), and steam pressure \( p \) were made and recorded
every eight hours. Manganese-alloy tests were made at
constant conditions for 4.75 hours. Other tests were made
at constant conditions for 72 hours. Upon completion of
a test, the pump \( d \) was turned off, the system drained
and purged with fresh tap water.

Oil Corrosion Test. The test specimens \( (s) \) were
placed in the heat exchangers as described above.

The oil was preheated to 80°C in the storage tank
\( (i) \) and then pumped through the by-pass line \( (b) \). The
oil was passed through the annular space of the heat ex-
changers at a maximum rate of flow of 3.42 gallons per
minute, equivalent to 0.333 feet per second and a Reynold's
Number of 540. The manometers \( (m) \) had to be recalibrated
before being used to measure the rate of oil flow. How-
ever, before this could be done, it was necessary to
determine how the specific gravity of the oil varied with
changes in temperature. Results of this test are shown
in Figure 3, page 51.

Maximum temperature conditions were maintained,
refer to Figure 2: inlet temperature ($t_1$), 85°C; steam pressure ($p$), 60 psig. The oil was not cooled in the cooler (c) after leaving the heat exchangers.

The tests were made at constant conditions for 72 hours. After completion of a test, the oil was continuously pumped through the by-pass line (b), and was maintained at a temperature of 80°C by means of the steam coil in the storage tank. This was necessary to prevent the oil from becoming viscous and plugging the lines before the next test could be started.

Cleaning and Reweighing of Test Specimens. Upon completion of a test, the heat exchanger assembly was dismantled and the tubes were removed. Corrosion products adhering to the surface of the tubing were removed by use of chemical methods recommended by the A.S.T.M.\(^{(5)}\), \(^{(6)}\) The following methods were used:

1. **Monel.** Dipped for two minutes in $\text{H}_2\text{SO}_4$ (1:10) at 20-25°C. Scrubbed with bristle brush under running water and dried.\(^{(6)}\)

2. **Aluminum.** Dipped for two minutes in $\text{HNO}_3$ (sp. gr. 1.42) at 20-25°C. Scrubbed with bristle brush under running water and dried.\(^{(6)}\)
(3) **Stainless Steel.** Dipped for two minutes in 10 per cent HNO₃ in which no chlorine was present. Bath was operated at 20-25°C. Scrubbed with bristle brush under running water and dried.**(5)**

(4) **Magnesium-Alloys.** Dipped for one minute in 20 per cent H₂CrO₄ to which had been added 1 per cent AgNO₃. The bath was heated to 90°C prior to use. (The AgNO₃ was dissolved separately and added to boiling H₂CrO₄ to prevent excessive crystallization of silver chromate). Scrubbed with bristle brush under running water and dried.**(6)**

(5) **Silicone-Coated Magnesium-Alloys.** Silicone coating was removed by soaking in naphtha. The tubing was then cleaned as other magnesium-alloys.**(6)**

Only the outside surface of the tubing was cleaned of corrosion products. Steam blank tests took into account the change in weight due to steam-side corrosion and minute weight losses due to chemical cleaning. A clean, soft cloth was drawn through the inside of each tube to remove any surface deposits.

After cleaning and drying, the tubes were allowed to
air dry for twelve hours, wiped with a soft cloth and re-weighed on the torsion balance.

Calculations. From the known weight losses, area and density of test specimens and duration of tests, corrosion rates were calculated in inches penetration per year by using the formula given by Speller. (57)

Macroscopic Photographing of Specimens. Macroscopic photographs (4 to 1 enlargements) were made of the following tubing:

1. Magnesium-alloy tubing, as received.
2. Magnesium-alloy tubing after 20 hour corrosion test using 3 per cent NaCl.
3. Magnesium-alloy tubing after 4.75 hour corrosion test using 10 per cent NaCl.
4. Magnesium-alloy tubing coated with silicone resin before corrosion test.
5. Silicone-coated magnesium-alloy tubing after 4.75 hour corrosion test using 10 per cent NaCl.
6. Stainless steel tubing after 72 hour corrosion test using 10 per cent NaCl.
Data and Results

In order to study the corrosion resistance offered by heat exchanger tubes, a series of corrosion tests was made on two single pass, double pipe heat exchangers. The following tubing was used as test heat exchanger tubes: magnesium-alloy, FS-1; magnesium-alloy, FS-1, silicone-coated; aluminum, 3S; stainless steel, 316; and monel. The following solutions were used as corrosive mediums: three per cent by weight sodium chloride, ten per cent by weight sodium chloride and sulfur-bearing Texas crude oil.

The following data were obtained from these corrosion tests: the corrosive medium used, the alloy tubing used, the duration of tests, the average inlet and outlet heat exchanger temperatures, the average steam pressure required, the corroded areas, the initial weight of tubing prior to corrosion tests and the final weight of tubing after corrosion tests.

The following results were calculated from these data: alloy tubing weight loss, penetration due to corrosion expressed in inches per year and estimated probable life of tubing.

The data and results obtained are presented in the following tables:
# TABLE I

**CORROSION TEST DATA ON MAGNESIUM-ALLOY, FS-1, HEAT EXCHANGER TUBING**

<table>
<thead>
<tr>
<th>Test Number</th>
<th>5(a)</th>
<th>5(b)</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of Exposure (hrs)</td>
<td>72</td>
<td>20</td>
<td>4.75</td>
</tr>
<tr>
<td>Corrosive Medium</td>
<td>Water</td>
<td>NaCl*</td>
<td>Water</td>
</tr>
<tr>
<td>Alloy Dens. (gms/cu cm)</td>
<td>1.77</td>
<td>1.77</td>
<td>1.77</td>
</tr>
<tr>
<td>Corroded Area (sq in)</td>
<td>183.8</td>
<td>183.8</td>
<td>183.8</td>
</tr>
<tr>
<td>Initial Sample Wt. (gms)</td>
<td>656.48</td>
<td>629.30</td>
<td>646.50</td>
</tr>
<tr>
<td>Final Sample Wt. (gms)</td>
<td>643.25</td>
<td>---</td>
<td>645.55</td>
</tr>
<tr>
<td>Av. Steam Press. (psig)</td>
<td>47.9</td>
<td>48.0</td>
<td>50.8</td>
</tr>
<tr>
<td>Av. Inlet Temp. (°C)</td>
<td>32.0</td>
<td>37.3</td>
<td>33.0</td>
</tr>
<tr>
<td>Av. Outlet Temp. (°C)</td>
<td>52.0</td>
<td>47.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Av. Man. Read. (in Hg)</td>
<td>5.1</td>
<td>5.0</td>
<td>5.02</td>
</tr>
<tr>
<td>Av. Vel. (gal/min)</td>
<td>6.30</td>
<td>6.74</td>
<td>6.75</td>
</tr>
<tr>
<td>Type of Flow</td>
<td>Turb.</td>
<td>Turb.</td>
<td>Turb.</td>
</tr>
</tbody>
</table>

*Three per cent by weight NaCl

**Observations:**

(a) No apparent damage to outer surface of tubing. Slight formation of white, paste-like material on steam side surface of tubing.

(b) Tubing cut into three pieces by corrosive action; 3.7 inch ends remaining in each packing gland, center portion of tube lying on bottom of heat exchanger outer shell. Extreme corrosion on either end of tube probably due to erosion and galvanic action. See Figure 5, page 65. Final weight of sample not taken.
**TABLE II**

CORROSION TEST DATA ON MAGNESIUM-ALLOY, FS-1,
HEAT EXCHANGER TUBING

<table>
<thead>
<tr>
<th>Test Number</th>
<th>7(a)</th>
<th>8(b)</th>
<th>13(c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of Exposure (hrs)</td>
<td>4.75</td>
<td>4.75</td>
<td>72</td>
</tr>
<tr>
<td>Corrosive Medium</td>
<td>NaCl*</td>
<td>NaCl**</td>
<td>011</td>
</tr>
<tr>
<td>Alloy Dens. (gms/cm sq in)</td>
<td>1.77</td>
<td>1.77</td>
<td>1.77</td>
</tr>
<tr>
<td>Corroded Area (sq in)</td>
<td>183.8</td>
<td>183.8</td>
<td>183.8</td>
</tr>
<tr>
<td>Initial Sample Wt. (gms)</td>
<td>645.60</td>
<td>645.37</td>
<td>645.35</td>
</tr>
<tr>
<td>Final Sample Wt. (gms)</td>
<td>---</td>
<td>---</td>
<td>592.85</td>
</tr>
<tr>
<td>Av. Steam Press. (psig)</td>
<td>48.0</td>
<td>48.7</td>
<td>61.6</td>
</tr>
<tr>
<td>Av. Inlet Temp. (°C)</td>
<td>38.0</td>
<td>38.0</td>
<td>85.2</td>
</tr>
<tr>
<td>Av. Outlet Temp. (°C)</td>
<td>50.0</td>
<td>51.0</td>
<td>87.9</td>
</tr>
<tr>
<td>Av. Man. Read. (in Hg)</td>
<td>4.75</td>
<td>5.0</td>
<td>1.31</td>
</tr>
<tr>
<td>Av. Vel. (gal/min)</td>
<td>6.57</td>
<td>6.74</td>
<td>3.42</td>
</tr>
<tr>
<td>Type of Flow</td>
<td>Turb.</td>
<td>Turb.</td>
<td>Visc.</td>
</tr>
</tbody>
</table>

*Ten per cent by weight NaCl  
**Three per cent by weight NaCl

Observations:

(a) Tubing corroded through (1/8 inch diameter hole) beneath exit port; badly pitted in area under entrance port. Final weight of sample not taken due to severe pitting. See Figure 6, page 66.

(b) Tubing badly pitted beneath entrance and exit ports. Final weight of sample not taken due to severe pitting.

(c) Magnesium tubing had been used as steam blank sample in run number nine. No other magnesium tubing was available. White, paste-like film formed on steam side surface of tube.
## TABLE III
CORROSION TEST DATA ON SILICONE-COATED MAGNESIUM-
ALLOY, FS-1, HEAT EXCHANGER TUBING

<table>
<thead>
<tr>
<th>Test Number</th>
<th>10(a)</th>
<th>11(b)</th>
<th>14(c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of Exposure (hrs)</td>
<td>4.75</td>
<td>4.75</td>
<td>72</td>
</tr>
<tr>
<td>Corrosive Medium</td>
<td>NaCl*</td>
<td>NaCl*</td>
<td>Oil</td>
</tr>
<tr>
<td>Alloy Dens. (gms/cu cm)</td>
<td>1.77</td>
<td>1.77</td>
<td>1.77</td>
</tr>
<tr>
<td>Corroded Area (sq in)</td>
<td>183.8</td>
<td>183.8</td>
<td>183.8</td>
</tr>
<tr>
<td>Initial Sample Wt. (gms)</td>
<td>652.05</td>
<td>645.60</td>
<td>651.18</td>
</tr>
<tr>
<td>Final Sample Wt. (gms)</td>
<td>650.95</td>
<td>645.20</td>
<td>587.10</td>
</tr>
<tr>
<td>Av. Steam Press. (psig)</td>
<td>55.4</td>
<td>55.7</td>
<td>61.3</td>
</tr>
<tr>
<td>Av. Inlet Temp. (°C)</td>
<td>38.2</td>
<td>38.0</td>
<td>78.3</td>
</tr>
<tr>
<td>Av. Outlet Temp. (°C)</td>
<td>44.9</td>
<td>43.8</td>
<td>80.9</td>
</tr>
<tr>
<td>Av. Man. Read. (in Hg)</td>
<td>5.06</td>
<td>5.0</td>
<td>1.89</td>
</tr>
<tr>
<td>Av. Vel. (gal/min)</td>
<td>6.77</td>
<td>6.74</td>
<td>3.42</td>
</tr>
<tr>
<td>Type of Flow</td>
<td>Turb.</td>
<td>Turb.</td>
<td>Visc.</td>
</tr>
</tbody>
</table>

*Three per cent by weight NaCl

**Observations:**

(a) Sample given three spray coats of silicone resin, cured for thirty minutes between coats, cured for two hours (5-H pencil hardness) after last spray-coat. Silicone acted as insulation resulting in less heat transfer. Coating started disintegrating after forty minutes under test conditions. Coating completely disintegrated along an eighteen-inch section on both ends of the tubing and along a two-foot section in the center of the tubing, other sections being apparently unharmed. Metal was pitted where coating disintegrated. Failure probably would have been due to pitting rather than overall weight loss.

(b) Sample cured for three hours (9-H pencil hardness) after third spray-coat. Coating started disintegrating after two hours. Metal was pitted where coating disintegrated.

(c) Portions of coating removed by oil, some portions unharmed. White, paste-like film formed on steam surface side of tube.
# TABLE IV

## CORROSION TEST DATA ON ALUMINUM-ALLOY, 3S,

HEAT EXCHANGER TUBING

<table>
<thead>
<tr>
<th>Test Number</th>
<th>2</th>
<th>4(a)</th>
<th>6(b)</th>
<th>12(c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of Exposure (hrs)</td>
<td>72</td>
<td>72</td>
<td>72</td>
<td>72</td>
</tr>
<tr>
<td>Corrosive Medium</td>
<td>Water</td>
<td>NaCl*</td>
<td>NaCl**</td>
<td>Oil</td>
</tr>
<tr>
<td>Alloy Dens. (gms/cu cm)</td>
<td>2.73</td>
<td>2.73</td>
<td>2.73</td>
<td>2.73</td>
</tr>
<tr>
<td>Corroded Area (sq in)</td>
<td>177.73</td>
<td>177.73</td>
<td>177.73</td>
<td>177.73</td>
</tr>
<tr>
<td>Initial Sample Wt. (gms)</td>
<td>799.97</td>
<td>799.22</td>
<td>801.17</td>
<td>799.50</td>
</tr>
<tr>
<td>Final Sample Wt. (gms)</td>
<td>801.47</td>
<td>798.40</td>
<td>799.83</td>
<td>799.65</td>
</tr>
<tr>
<td>Av. Steam Press. (psig)</td>
<td>47.6</td>
<td>46.0</td>
<td>46.4</td>
<td>60.5</td>
</tr>
<tr>
<td>Av. Inlet Temp. (°C)</td>
<td>38.0</td>
<td>38.0</td>
<td>37.9</td>
<td>38.1</td>
</tr>
<tr>
<td>Av. Outlet Temp. (°C)</td>
<td>52.9</td>
<td>49.3</td>
<td>50.1</td>
<td>93.0</td>
</tr>
<tr>
<td>Av. Man. Read. (in Hg)</td>
<td>5.3</td>
<td>5.0</td>
<td>4.91</td>
<td>1.84</td>
</tr>
<tr>
<td>Av. Vel. (gal/min)</td>
<td>6.94</td>
<td>6.74</td>
<td>6.67</td>
<td>3.42</td>
</tr>
<tr>
<td>Type of Flow</td>
<td>Turb.</td>
<td>Turb.</td>
<td>Turb.</td>
<td>Visc.</td>
</tr>
</tbody>
</table>

*Three per cent by weight NaCl
**Ten per cent by weight NaCl

**Observations:**

(a) At start of test, before any corrosion deposit formed, tube was covered with small, clear bubbles, which upon breaking free were replaced by newly formed bubbles. Expansion of tube, due to heat, caused tube to bend appreciably. Corrosion deposit was not uniform along entire length of tubing indicating eddy currents and washing action at entrance and exit ends of heat exchanger.

(b) Reddish-brown film formed on top side of tube. Maximum film formation occurred in center section of tube.

(c) Visual observations indicated no apparent damage to tube. Tube was badly warped by steam during operation. Tube bent in middle on expansion because the ends were held practically stationary in packing glands.
TABLE V

CORROSION TEST DATA ON MONEL
HEAT EXCHANGER TUBING

<table>
<thead>
<tr>
<th>Test Number</th>
<th>2</th>
<th>4(a)</th>
<th>6(b)</th>
<th>12(c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of Exposure (hrs)</td>
<td>72</td>
<td>72</td>
<td>72</td>
<td>72</td>
</tr>
<tr>
<td>Corrosive Medium</td>
<td>Water</td>
<td>NaCl*</td>
<td>NaCl**</td>
<td>011</td>
</tr>
<tr>
<td>Alloy Dens. (gms/cu cm)</td>
<td>8.84</td>
<td>8.84</td>
<td>8.84</td>
<td>8.84</td>
</tr>
<tr>
<td>Corroded Area (sq in)</td>
<td>180.8</td>
<td>180.8</td>
<td>180.8</td>
<td>180.8</td>
</tr>
<tr>
<td>Initial Sample Wt. (gms)</td>
<td>2733.02</td>
<td>2738.00</td>
<td>2731.10</td>
<td>2740.62</td>
</tr>
<tr>
<td>Final Sample Wt. (gms)</td>
<td>2733.85</td>
<td>2737.76</td>
<td>2730.40</td>
<td>2739.40</td>
</tr>
<tr>
<td>Av. Steam Press. (psig)</td>
<td>47.6</td>
<td>46.0</td>
<td>46.4</td>
<td>60.5</td>
</tr>
<tr>
<td>Av. Inlet Temp. (°C)</td>
<td>33.0</td>
<td>33.0</td>
<td>37.9</td>
<td>86.9</td>
</tr>
<tr>
<td>Av. Outlet Temp. (°C)</td>
<td>52.1</td>
<td>51.8</td>
<td>51.5</td>
<td>99.4</td>
</tr>
<tr>
<td>Av. Man. Read. (in Hg)</td>
<td>5.7</td>
<td>5.7</td>
<td>5.64</td>
<td>1.84</td>
</tr>
<tr>
<td>Av. Vel. (gal/min)</td>
<td>6.62</td>
<td>6.62</td>
<td>6.60</td>
<td>3.42</td>
</tr>
<tr>
<td>Type of Flow</td>
<td>Turb.</td>
<td>Turb.</td>
<td>Turb.</td>
<td>Visc.</td>
</tr>
</tbody>
</table>

*Three per cent by weight NaCl  
**Ten per cent by weight NaCl

Observations:

(a) After chemical cleaning, there were several small areas of copper showing on surface of monel tubing. Brown, moss-like film formed on surface of metal.

(b) No traces of copper on surface of tubing after chemical cleaning. Brown, moss-like film formed on surface of metal.

(c) No film formation or apparent damage to tube after 72-hour test.
### TABLE VI

**CORROSION TEST DATA ON STAINLESS STEEL, 316,
HEAT EXCHANGER TUBING**

<table>
<thead>
<tr>
<th>Test Number</th>
<th>3(a)</th>
<th>5</th>
<th>7(b)</th>
<th>13(c)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time of Exposure (hrs)</strong></td>
<td>72</td>
<td>72</td>
<td>72</td>
<td>72</td>
</tr>
<tr>
<td><strong>Corrosive Medium</strong></td>
<td>Water</td>
<td>NaCl*</td>
<td>NaCl**</td>
<td>Oil</td>
</tr>
<tr>
<td><strong>Alloy Dens. (gms/cu cm)</strong></td>
<td>8.05</td>
<td>8.05</td>
<td>8.05</td>
<td>8.05</td>
</tr>
<tr>
<td><strong>Corroded Area (sq in)</strong></td>
<td>179.7</td>
<td>179.7</td>
<td>179.7</td>
<td>179.7</td>
</tr>
<tr>
<td><strong>Initial Sample Wt. (gms)</strong></td>
<td>2359.33</td>
<td>2348.93</td>
<td>2352.35</td>
<td>2354.37</td>
</tr>
<tr>
<td><strong>Final Sample Wt. (gms)</strong></td>
<td>2359.93</td>
<td>2349.32</td>
<td>2352.45</td>
<td>2354.30</td>
</tr>
<tr>
<td><strong>Av. Steam Press. (psig)</strong></td>
<td>47.9</td>
<td>49.3</td>
<td>49.3</td>
<td>61.6</td>
</tr>
<tr>
<td><strong>Av. Inlet Temp. (°C)</strong></td>
<td>38.0</td>
<td>37.7</td>
<td>38.0</td>
<td>84.2</td>
</tr>
<tr>
<td><strong>Av. Outlet Temp. (°C)</strong></td>
<td>52.3</td>
<td>51.6</td>
<td>52.3</td>
<td>100.5</td>
</tr>
<tr>
<td><strong>Av. Man. Read. (in Hg)</strong></td>
<td>5.7</td>
<td>5.66</td>
<td>5.56</td>
<td>1.75</td>
</tr>
<tr>
<td><strong>Av. Vel. (gal/min)</strong></td>
<td>6.62</td>
<td>6.61</td>
<td>6.56</td>
<td>3.42</td>
</tr>
<tr>
<td><strong>Type of Flow</strong></td>
<td>Turb.</td>
<td>Turb.</td>
<td>Turb.</td>
<td>Visc.</td>
</tr>
</tbody>
</table>

*Three per cent by weight NaCl
**Ten per cent by weight NaCl

**Observations:**

(a) When observed microscopically, stainless steel appeared same after corroding and cleaning as when observed prior to corrosion testing.

(b) Brown, moss-like film formed on surface of metal. No evidence of pitting. See Figure 9, page 69.

(c) No pitting or apparent damage to surface of metal.
Sample Calculations

The following sample calculation was made from data obtained on test number 4, Table IV, page 59; aluminum-alloy, 33, test specimen; three per cent sodium chloride corrosive medium, seventy-two-hour test:

Weight loss due to corrosion: 0.32 gms
Plus steam blank correction: 2.50 gms
Total weight loss: 3.32 gms

Using Speller's (57) corrosion formula:

\[ P = \frac{W \cdot K \cdot T}{A \cdot S} \]

\[ P = \text{average penetration (ipy)} \]
\[ W = \text{weight of metal removed: 0.32 gms} \]
\[ A = \text{area exposed: 177.73 sq in} \]
\[ K = \text{constant: 0.06102} \]
\[ S = \text{specific gravity: 2.73 gms/cu cm} \]
\[ T = \text{duration of test: 0.008 yrs} \]

\[ P = \frac{0.32 \times 0.06102}{2.73 \times 177.73 \times 0.008} \]
\[ P = 0.0508 \text{ ipy} \]

and: Life = \text{wall thickness} = \frac{0.109}{0.0508} = 2.1 \text{ yrs}
**TABLE VII**

**ESTIMATED PROBABLE LIFE OF HEAT EXCHANGER TUBING IN SODIUM CHLORIDE AND SULFUR-BEARING FUEL OIL CORROSIVE MEDIUMS**

<table>
<thead>
<tr>
<th>Alloy</th>
<th>3% NaCl</th>
<th>10% NaCl</th>
<th>Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>i.p.y.**</td>
<td>i.p.y.</td>
<td>i.p.y.</td>
</tr>
<tr>
<td></td>
<td>Life (yrs)</td>
<td>Life (yrs)</td>
<td>Life (yrs)</td>
</tr>
<tr>
<td>Mg, FS-1</td>
<td>Pitted</td>
<td>Pitted</td>
<td>0.897</td>
</tr>
<tr>
<td>Mg, Si Coat. 1</td>
<td>0.3330*</td>
<td>---</td>
<td>0.12</td>
</tr>
<tr>
<td>Mg, Si Coat. 2</td>
<td>0.1588*</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Al, 38</td>
<td>0.0508</td>
<td>0.0588</td>
<td>1.160</td>
</tr>
<tr>
<td>Monel</td>
<td>0.0050</td>
<td>0.0071</td>
<td>0.0095</td>
</tr>
<tr>
<td>S-Steel, 316</td>
<td>0.0013</td>
<td>0.0036</td>
<td>0.0029</td>
</tr>
</tbody>
</table>

**Inches penetration per year.**

*This tubing pitted at points where silicone coating disintegrated. Failure probably would have been caused by pitting rather than uniform overall weight loss.*
Fig. 4.— Macroscopic Photograph (4 x 1) of Magnesium-Alloy, FS-1, Tubing as Received.

The above macrophotograph shows the rough surface condition of the magnesium-alloy tubing as received. Extrusion die marks and non-conformities are discernible. Such conditions of metal surface area are conducive to formation of galvanic cells which tend to cause electrolytic corrosion.
Fig. 5.—Macroscopic Photograph (4 x 1) of Magnesium-Alloy, F3-1, Tubing Used as Corrosion Test Specimen in Three Per Cent Sodium Chloride Solution.

The tubing shown in the above macrophotograph was used as a corrosion test heat exchanger tube. Three percent by weight sodium chloride was used as the corrosive medium and the test was of twenty hours duration. The tubing was cut completely in two by corrosive action at the entrance and exit ends of the heat exchanger. Severe pitting was evident at these points, probably due to erosion and galvanic action. The center portion of the tube was pitted slightly.
Fig. 6.—Macroscopic Photograph (4 x 1) of Magnesium-Alloy, FS-1, Tubing Used as Corrosion Test Specimen in Ten Per Cent by Weight Sodium Chloride Solution.

The tubing shown in the above macrophotograph was used as a corrosion test heat exchanger tube. Ten percent by weight sodium chloride was used as the corrosive medium and the test was of 4.75 hours duration. The portion of the tube shown was located at the exit end of the heat exchanger. Note the extreme pitting action which was allowed to progress to such an extent that the tube fractured. Original tube thickness was approximately 1/8 inch. A similar action took place at the entrance end of the heat exchanger, but the tube did not wear completely through. The center portion of the tube was pitted slightly.
Fig. 7.— Macroscopic Photograph (4 x 1) of Magnesium-Alloy, FS-1, Tubing Coated with Silicone Resin.

The tubing shown in the above macrophotograph was given three spray coats of silicone resin and cured at 480°F for three hours in an infrared oven after the third coat. The opaque portions on the outer edge of the tube were not deformations in the coating, but were caused by a different angle of reflection of light from that portion of the tubing.
Fig. 8.— Macroscopic Photograph (4 x 1) of Silicone-Coated Magnesium-Alloy, FS-1, Tubing Used as Test Corrosion Specimen in Three Per Cent Sodium Chloride Solution.

The tubing shown in the above macrophotograph was used as a corrosion test heat exchanger tube. Three per cent by weight sodium chloride was used as the corrosive medium and the test was of 4.75 hours duration. The photograph shows the rupture of the coating and the resulting blister formed. Metal beneath rupture was pitted.
Fig. 9.- Macroscopic Photograph (4 x 1) of Stainless Steel, 316, Tubing Used as Test Corrosion Specimen in Ten Per Cent Sodium Chloride.

The tubing shown in the above macrophotograph was used as a corrosion test heat exchanger tube. Ten percent by weight sodium chloride was used as the corrosive medium and the test was of 72 hours duration. A brown, moss-like film formed on the metal surface. There was no evidence of pitting.
IV. DISCUSSION

Examination of Metal Surface of Test Specimens. The test specimens were examined under a twelve power microscope to determine the physical condition of the metal surface prior to corrosion testing. The surface of the magnesium-alloy, FS-1, tubing was non-homogenous and small pits were discernable. Extrusion die marks along the entire length of the tubing were visible. A macrophotograph of the magnesium-alloy tubing, as received, is shown in Figure 4, page 64. The surface of the aluminum tubing was irregular and extrusion die marks were visible although not so pronounced as on the surface of the magnesium tubing. The surface of the stainless steel tubing was the most irregular of the test specimens. The surface appeared very pitted under the microscope but was smooth to the touch. The monel tubing surface was homogenous and very few non-conformities were visible.

Control of Sodium Chloride Solutions. Three per cent by weight and ten per cent by weight sodium chloride solutions were used as corrosive mediums. During the course of a corrosion test, the sodium chloride solutions were
tested every twelve hours by use of the Volhard (37) method for chloride determinations. In order to simplify calculations, the per cent sodium chloride, or chloride ion, was expressed in terms of normality, and the solutions controlled to within plus or minus 0.1 normality. This gave a control of plus or minus 0.5 per cent sodium chloride by weight.

Control by Steam Blank Tests. Steam blank tests were made to determine the change in weight of the sample tubing caused by passing high pressure steam, fifty pounds per square inch gage, through the tubing for a time comparable to the duration of corrosion tests. As corrosion was not desired on the outside or heating surface of the sample tubing used in the steam blank tests, tap water was used as the non-corrosive medium which was pumped through the annular space of the heat exchangers. The steam blank tests also took into account any minute weight loss due to chemical cleaning of corrosion products from the surface of test specimens. Corrosion products formed due to steam side corrosion were not removed from the inside of the tubing by chemical cleaning. However, a soft cloth was drawn through the tubing two to three times. The steam blank tests caused the aluminum, stainless steel and monel tubing to gain weight. Refer to Table IV, V and VI,
The magnesium tubing lost more weight during the steam blank test than during the tests with sodium chloride solutions on silicone-coated tubing. Refer to Table I and III, page 56 and 58. Therefore, the steam blank test on magnesium-alloy tubing was discounted. Macroscopic examination of the magnesium-alloy tubing used in the steam blank test revealed no pitting due to the action of tap water.

Formation of Corrosion Products on Test Heat Exchanger Tubing. The corrosion products formed on the surface of the test heat exchanger tubes were examined by use of a twelve power microscope.

The sodium chloride solutions caused severe pitting of the magnesium-alloy tubing, particularly under the entrance and exit ports of the packing gland flanges: (See Figure 5, page 65 and Figure 6, page 66). A light brown, porous scale was formed in the center portion of the tubing. There was no scale formation on either end of the tubing indicating a wiping action due to eddy currents in the entrance and exit ends of the heat exchanger. The sodium chloride solutions caused the formation of a dark brown, adherent scale in the center portion of the aluminum, monel and stainless steel tubing; no pitting was observed. (See Figure 9, page 69).
The sulfur-bearing fuel oil stained the magnesium-alloy tubing a blackish-grey color which was removed by chemical cleaning. There was no evidence of corrosion scale due to the action of sulfur-bearing fuel oil on any of the corrosion test specimens.

**Effect of Corrosion of Heat Exchanger Tubes on Heat Transfer.** The formation of corrosion products caused by the action of sodium chloride solutions on the test heat exchanger tubes resulted in a reduced temperature differential between the entrance and exit ends of the heat exchangers. The average temperature differential during the first hour of operating conditions was 12°C. This temperature differential was reduced to an average of 10°C at the completion of the seventy-two-hour tests. This indicated that the heat transfer was reduced as corrosion tests progressed and a scale of corrosion products formed on the heat exchanger tubing.

**Cyclic Disintegration of Silicone Coating.** The silicone coating on the magnesium-alloy tubing did not withstand corrosive action of sodium chloride or sulfur-bearing fuel oil. Three per cent by weight sodium chloride solution caused the silicone coating, cured to 5-H pencil hardness, to start disintegrating after twenty
minutes of operating conditions. The same solution caused the silicone coating, cured to 9-H pencil hardness, to start disintegrating after two hours of operating conditions. This disintegration started with the formation of small blisters beneath the entrance and exit ports and at regular intervals of approximately twelve inches along the top surface of the tubing. The blisters became enlarged to approximately one-fourth inch in diameter, then split and spread. (See Figure 9, page 69). Disintegration of the silicone coating due to the action of sulfur-bearing fuel oil could not be observed during operation because the oil obscured the surface of the heat exchanger tube. However, upon removing the coated tube, it was discovered that the silicone coating had been softened and partially removed in approximately the same areas which had been affected by the sodium chloride solution. The coating had been completely removed from areas beneath the entrance and exit ports of the heat exchanger, and had been partially removed from portions approximately twelve inches in length at regular intervals of twelve inches along the tube surface. Other portions of the coating were apparently undamaged. The cyclic disintegration was probably caused by formation of eddy currents along certain portions of the tube.
Insulation Effect of Silicone Coating. John T. Castles, a post graduate student in Chemical Engineering at Virginia Polytechnic Institute, who was also interested in silicone-coated heat exchanger tubes, postulated that the silicone resin coating would increase heat transfer by forming a non-wetted tube surface, thus eliminating water film resistance. However, the silicone resin coatings used in this investigation acted as an insulating material and reduced the temperature differential over the heat exchanger from $11 \pm 1^\circ$C, obtained with uncoated tubing, to $6.25 \pm 0.45^\circ$C, obtained with coated tubing using three percent by weight sodium chloride solution. (See Table II, page 57 and Table III, page 58).

Salt Formation in Magnesium Tubing. A white, paste-like film was formed on the steam side surface of the magnesium-alloy tubing used in test 13 and 14 which were of 72 hours duration. (See Table III, page 58 and Table VI, page 61). A similar film was formed in test 3 (Table I, page 56), but not to as great an extent. This material, a white crystalline mass after air drying, was converted into a very soft white powder on drying for twelve hours in an oven at 120$^\circ$C. Upon analyzing, the powder proved to be magnesium hydroxide. This film did not form during the 4.75-hour tests using magnesium-alloy
tubing. It can be concluded, from the above mentioned tests, that large crystals of magnesium hydroxide are formed upon prolonged (72 hours) exposure of magnesium-alloy, FS-1, to the action of high pressure steam (50 psig).

Recommendations

**Alterations in Heat Exchanger Apparatus.** Refer to Figure 2, page 45. The following black iron pipe lines should be changed from three-quarter inch to one inch lines: line from bottom of storage tank (i) to pump (d), line from pump (d) to inlet valves (n), line from exit end of heat exchangers to cooler (c), line from the cooler (c) to storage tank (i). These alterations would allow a greater flow of fluid through the heat exchangers. Maximum flow obtained with three-quarter inch pipe lines was seven gallons per minute.

Shields should be placed in packing glands (g) to prevent direct impingement of corrosive medium onto test specimens. The packing glands would have to be redesigned to accommodate such shields.

**Alterations in Tube Conditioning Procedure.** The silicone resin used for coating magnesium-alloy tubing
was sixty per cent resin and forty per cent naphtha solvent. Three spray coats were used. It is recommended that more spray coats of a resin containing a greater per cent of solvent be used in order to obtain a more uniform coating. Uniformity and thickness of coating depended upon spraying technique and observations. Therefore, skill would have to be obtained by practice.

The available infrared oven used for curing the silicone resin coating was too small to accommodate the entire length of heat exchanger tube. A more uniform curing of the coating could be obtained in an oven designed to accommodate the entire length of tubing.

Further Investigation. From the results of this investigation, it can be seen that corrosion tests using commercial magnesium-alloys and sodium chloride solutions would be limited to 4-5 hours. Magnesium-alloy, FS-1, is listed as the most corrosion-resistant Dowmetal alloy, (7) therefore, it would seem useless to conduct further tests using the following commercial magnesium-alloys: 0-1, J-1, JS-1, FS-1, and M. However, from information obtained from the literature (see Table 1, page 25), it would seem highly practical to conduct tests using special alloys of magnesium, especially those containing approximately one per cent additions of silver, chromium or tin. [Note]
Admiralty metal should be used as a comparative corrosion test specimen due to the fact that admiralty metal is widely used in the manufacture of heat exchanger tubes.

A medium, other than tap water, should be used as the non-corrosive medium in steam blank tests on magnesium-alloy tubing. Possibly a weak potassium dichromate or sodium hydroxide solution would produce accurate results. It is also recommended that only the highest quality steam be passed through magnesium-alloy tubing so that reaction between the steam and the metal would be reduced.

Limitations

Corrosion Test Specimens. The thesis problem, as planned, was to include a comparison of the corrosion resistance offered by special magnesium-alloy tubing and commercial Dowmetal magnesium-alloys. Only one Dowmetal alloy could be obtained, this being alloy FS-1. The Dow Chemical Company(25) was unable to produce special magnesium alloys, each containing approximately one per cent additions of chromium, silver or tin. Admiralty metal heat exchanger tubes were to be used as corrosion test specimens but could not be obtained in time for use in this investigation. (34)
Temperature Differential over Heat Exchangers. A temperature differential of 27°C was planned. The maximum differential of 14.3°C was obtained.

Comparable Results. It was planned that conditions of time, temperature and velocity would be held constant for all tests. The duration of sodium chloride-magnesium tests was limited to 4.75 hours due to failure of specimen, whereas other tests were of 72 hours duration.

A 38°C inlet temperature and seven gallons per minute rate of solution flow through the heat exchangers was maintained for all tests except those using oil. In order to obtain a maximum rate of oil flow of 3.42 gallons per minute, the inlet temperature of the oil was approximately 85°C.
V. CONCLUSIONS

Using magnesium-alloy, FS-1; silicone-coated magnesium-alloy, FS-1; aluminum, 3S; stainless steel, 316; and monel as corrosion test heat exchanger tubes; in two single pass, double pipe heat exchangers constructed of five foot pyrex glass tubes, two inches inside diameter, and equipped on each end with a packing gland flange to facilitate insertion and removal of the test tubes; using three and ten per cent by weight sodium chloride solutions and sulfur-bearing Texas fuel oil as corrosive mediums; operating the unit at an average inlet temperature of $38 \pm 1^\circ C$ and an average outlet temperature of $50 \pm 5^\circ C$ for the sodium chloride solutions, and an average inlet temperature of $83 \pm 3^\circ C$ and an average outlet temperature of $94 \pm 6^\circ C$ for the sulfur-bearing fuel oil; maintaining an average rate of flow of corrosive medium through the heat exchangers of $6.7 \pm 0.2$ gallons per minute for the sodium chloride solutions and $3.42$ gallons per minute for the sulfur-bearing fuel oil; and operating the tests for a duration of 72 hours; the following conclusions may be drawn:

(1) Corrosion, expressed in inches penetration...
per year, due to action of three per cent by weight sodium chloride was as follows: magnesium-alloy, FS-1, pitted, no calculations made; silicone-coated magnesium-alloy, FS-1, 0.1388; aluminum, 3S, 0.0508; monel, 0.0050; and stainless steel, type 316, 0.0013.

(2) Corrosion, expressed in inches penetration per year, due to action of ten per cent by weight sodium chloride was as follows: magnesium-alloy, FS-1, and silicone-coated magnesium-alloy, FS-1, pitted, no calculations made; aluminum, 3S, 0.0588; monel, 0.0071; stainless steel, type 316, 0.0036.

(3) Corrosion, expressed in inches penetration per year, due to action of sulfur-bearing fuel oil was as follows: silicone-coated magnesium-alloy, FS-1, 1.160; magnesium-alloy, FS-1, 0.897; aluminum, 3S, 0.0361; monel, 0.0095; stainless steel, type 316, 0.0029.

(4) The magnesium-alloy, FS-1, heat exchanger tubing ruptured due to pitting action after 4.75 hours of the planned 72-hour corrosion test in ten per cent by weight sodium chloride solution. In order to obtain comparative results, other magnesium-alloy corrosion tests had to be limited to 4.75 hours.

(5) The action of three and ten per cent sodium chloride solutions caused severe pitting of the magnesium-
alloy tubing, particularly in the areas beneath the entrance and exit ports of the heat exchanger.

(6) Aluminum, 35; monel; and stainless steel, type 316, were not pitted by the action of the sodium chloride solutions. A brown, moss-like corrosion scale formed on the surface of these test samples.

(7) The silicone resin, DC 801, protective coating on magnesium-alloy, FS-1, tubing acted as an insulation and allowed an average temperature differential over the system of $6.25 \pm 0.45^\circ C$, whereas a temperature differential of $11 \pm 1^\circ C$ was obtained for uncoated tubing used in the sodium chloride tests.

(8) The silicone resin, DC 801, coating on magnesium-alloy, FS-1, cured to 5-H pencil hardness, ruptured after twenty minutes under operating conditions using three per cent sodium chloride.

(9) The silicone resin, DC 801, coating on magnesium-alloy, FS-1, cured to 9-H pencil hardness, ruptured after two hours under operating conditions using three per cent sodium chloride.

(10) Severe pitting occurred in areas where the silicone coating ruptured and exposed uncoated magnesium-alloy, FS-1, to the action of three per cent sodium chloride solution.
(11) The silicone resin, DC 801, protective coating on magnesium-alloy, FS-1, cured to 9-H pencil hardness, was softened and partially removed during the seventy-two-hour test using sulfur-bearing fuel oil.
VI. SUMMARY

THE USE OF MAGNESIUM-ALLOY TUBING IN HEAT EXCHANGERS

The purpose of this investigation was to determine the corrosion-resistant properties of commercial magnesium-alloy tubing as compared to the corrosion resistance offered by silicone-coated magnesium-alloy, aluminum, monel and stainless steel when used as heat exchanger tubes.

Two single pass, double pipe heat exchangers were constructed using pyrex glass tubes as outer shells. The pyrex tubes were two inches inside diameter, 2.25 inches outside diameter, five feet long and had flared ends. Each end of the pyrex tubes was equipped with a flange containing a 0.975 inch packing gland and a 0.75 inch inlet, or outlet port. The corrosion test tubing could be easily inserted into or removed from the packing glands without damaging the surface of the test specimen.

A series of corrosion tests was made in the heat exchangers using magnesium-alloy, FS-1; silicone-coated magnesium-alloy, FS-1; aluminum, 3S; stainless steel, type 316; and monel as heat exchanger tubes. Three and
ten per cent by weight sodium chloride solutions, and sulfur-bearing Texas fuel oil were used as corrosive mediums. The unit was operated at an average inlet temperature of $38 \pm 1^\circ C$ and an average outlet temperature of $50 \pm 5^\circ C$ for the sodium chloride solutions, and an average inlet temperature of $83 \pm 3^\circ C$ and an average outlet temperature of $94 \pm 6^\circ C$ for the sulfur-bearing fuel oil. Seventy-two-hour tests were made maintaining an average rate of flow of corrosive medium through the heat exchangers of $6.7 \pm 0.2$ gallons per minute for the sodium chloride and $3.42$ gallons per minute for the sulfur-bearing fuel oil.

Upon completion of the tests, the heat exchanger tubes were chemically cleaned of corrosion products. From the known weight losses, area and density of test specimens, and duration of tests, the corrosion rates were calculated. Corrosion rates expressed in inches penetration per year, due to the action of three per cent by weight sodium chloride was as listed in the following descending order: magnesium-alloy, FS-1, pitted, no calculations made; silicone-coated magnesium-alloy, FS-1, 0.1388; aluminum, 35, 0.0508; monel, 0.0050; and stainless steel, type 316, 0.0013. Corrosion, expressed in inches penetration per year, due to action of ten per cent by weight sodium chloride was as follows: magnesium-alloy, FS-1,
and silicone-coated magnesium-alloy, FS-1, pitted, no
calculations made; aluminum, 38, 0.0588; monel, 0.0071;
stainless steel, type 316, 0.0036. Corrosion, expressed
in inches penetration per year, due to action of sulfur-
bearing fuel oil was as follows: silicone-coated magnes-
ium-alloy, FS-1, 1.160; magnesium-alloy, FS-1, 0.897;
aluminum, 38, 0.0351; monel, 0.0055; stainless steel,
type 316, 0.0029.

Note: After completion of this thesis, an investigation by John T. Castles
concerning the use of silicone coating on steel evaporator tubes indicated
that the coating contained minute holes and therefore was not impervious.
These holes could have formed points of weakness and starting points
for disintegration of the silicone coating.

It is recommended that the metal surface be treated prior to
spraying in an attempt to obtain an impervious silicone coating. The
metal surface should be thoroughly dried to insure against moisture
remaining in nonconformities which would establish points of weakness
under the coating.
Some test should be devised which would indicate whether or
not a coating was impervious.
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VIII. ACKNOWLEDGEMENTS

The author wishes to take this opportunity to express his appreciation to Mr. Fred W. Bull, Professor in charge of the investigation, and for their helpful suggestions and guidance. The author also wishes to express his gratitude to for his aid in making the macroscopic photographs presented in this thesis.
Aluminum Company of America
213 Exchange Building
Richmond 19, Virginia
Gentlemen:

Please refer to my letter of February 25 concerning experimental quantities of aluminum tubing. This tubing, alloy 3 S, was purchased through the Whitehead Metal Products Co., New York.

Can you furnish information as to the density of your aluminum alloy 3 S? Your cooperation in furnishing this information will be greatly appreciated.

Very truly yours,

Clayton H. Hudson
Mr. Clayton H. Hudson  
Department of Chemical Engineering  
Virginia Polytechnic Institute  
Blacksburg, Virginia

Dear Mr. Hudson:

With reference to your letter of June 20 we will be glad to send you what information we have.

We are sending you under separate cover our booklet "Alcoa Aluminum and Its Alloys" and on page 95 you will find a table giving specific gravities of the various alloys.

We hope that this is the information that you desire but should you want more please let us hear from you and we will be very happy to do whatever possible.

Very truly yours,

ALUMINUM COMPANY OF AMERICA

By: T. R. Jones, Jr.

TRJ:vw
VIRGINIA POLYTECHNIC INSTITUTE
Department of Chemical Engineering
Blacksburg, Virginia
February 16, 1946

Aluminum Company of America
1820 Gulf Building
Pittsburgh, Pennsylvania

Gentlemen:

I am interested in obtaining several special magnesium alloys for use in research work. This magnesium alloy will have to be extruded to form 1/2" tubing of the same dimensions as standard gage iron pipe, namely 0.840" outside diameter, 0.622" internal diameter and 0.109" thick.

If your foundry does not produce extruded tubing, I can have the extruding accomplished at the White Metal Rolling and Stamping Corp., provided you can furnish the following listed alloys cast as billets between 6 1/2" and 7 3/8" in diameter by 32" maximum length with allowance made for scalping the exterior surface:

1. 2% Mn, 1% Te, Bal Mg.
2. 4% Al, 2% Cr, Bal Mg.

Please forward price quotations and time required for delivery of the cast billets, or if possible, for the following extruded tubing:

1. Special Mg. Alloy, 2% Mn, 1% Te, Bal Mg.
   Length .................... 6 ft.
   Outside Diameter .......... 0.840 in.
   Wall Thickness ............ 0.109 in.
   No. Required .............. 8 ea.

2. Special Mg. Alloy, 4% Al, 2% Cr, Bal Mg.
   Length .................... 6 ft.
   Outside Diameter .......... 0.840 in.
   Wall Thickness ............ 0.109 in.
   No. Required .............. 14 ea.

3. Special Mg. Alloy, 4% Al, 2% Cr, Bal Mg.
   Length .................... 31 in.
   Outside Diameter .......... 1 1/2 in.
   Wall Thickness ............ 0.109 in.
   No. Required .............. 32 ea.

Your cooperation in furnishing the above information will be greatly appreciated.

Very truly yours,

Clayton H. Hudson
(COPIES TO:)

✓ 1) BELMONT SMELTING & REFINING WORKS INC
   328 BELMONT AVE, BROOKLYN, N.Y.

✓ 2) ELECTRO REFRactories & ALLOYS CORP.
   776 ANDREWS BLDG, BUFFALO, N.Y. 14210

✓ 3) NATIONAL SMELTING CORP.
   6705 GRANT AVE, CLEVELAND, OHIO
February 25, 1946

Aluminum Company of America
2103 Gulf Building
Pittsburgh 19, Pa.

Gentlemen:

I am interested in obtaining aluminum alloy tubing for use in a research problem concerning corrosion of heat exchanger tubes. Hydrochloric and acetic acid will be used at temperatures ranging from 70°F to 150°F.

Request that you recommend the aluminum alloy which exhibits the best corrosion resistance and forward price quotations and time required for delivery of the following extruded tubing:

- Length -------------- 7'
- Outside Diameter ------ 0.840"n
- Wall Thickness -------- 0.109"
- No. Required ---------- 8 each

Your cooperation in furnishing the above information will be greatly appreciated.

Very truly yours,

Clayton H. Hudson

hh/
Mr. Clayton H. Hudson,
Virginia Polytechnic Institute,
Blacksburg, Virginia.

Dear Mr. Hudson:

This office has received your letter of Feb. 25, forwarded to us from our Main Office in Pittsburgh.

We will be glad to be of assistance to you in obtaining materials for your experiments but suggest that you refer to the attached booklet on "Aluminum in the Chemical Industry", since there is some question, under some circumstances, as to the feasibility of using aluminum in the presence of hydrochloric and acetic acids.

We will be glad to recommend the alloy most resistant to corrosive attack of these chemicals, but are very dubious of the results and would appreciate your advising us further if you wish to go ahead with your experiments.

Tubing in the dimension given is carried in stock by the Whitehead Metal Products Co., 303 W. 10th Street, New York, N. Y. in Alloy 2S, 3S, and 61S. On Page 47 of this booklet, you will find the nominal chemical composition of 2S, and 3S. For your information, 61S is composed of -

- .025% Copper
- .06% Silicon
- 1.0% Magnesium
- 0.25% Chromium
- Balance - Aluminum

Very truly yours,

ALUMINUM COMPANY OF AMERICA

By:

Harold A. Faisst
March 15, 1946

Whitehead Metal Products Co.
303 W. 10th Street
New York, New York

Gentlemen:

In connection with a research problem, I am interested in obtaining a small quantity of aluminum alloy tubing.

Please furnish price quotation and time required for delivery of the following aluminum alloy, 3 S (Aluminum Company of America), or the nearest equivalent:

Length ---------- 7.0'
Outside Diameter -- 0.840"
Wall Thickness ---- 0.109"
No. Required ------ 8 each

The time allotted for this research is very limited and your cooperation in expediting this matter will be greatly appreciated.

Very truly yours,

Clayton H. Hudson

hh/
The American Brass Company  
Waterbury, Connecticut  

Gentlemen:

In connection with a corrosion research problem, I am interested in obtaining experimental quantities of 1/2" admiralty metal pipe of the following composition: Copper - 70%, Zinc - 29%, Sn - 1%. The pipe would have to be of approximately the same dimensions as standard gage iron pipe, namely 0.840" O.D., 0.623 I.D., and 0.109" wall thickness. Eight pieces of pipe, seven feet in length will be required. I would also be interested in the physical properties of the metal such as density, analysis, metal treatment, etc.

Please forward price quotations and time required for delivery of the above listed quantity of pipe. Your cooperation in furnishing this information will be greatly appreciated.

Very truly yours,

Clayton H. Hudson

Copy to: Revere Copper & Brass, Inc.  
230 Park Ave.  
New York 17, N. Y.
In reply refer to
F. G. Evensen
Virginia Polytechnic Institute
Blacksburg, Va.

Attention: Mr. Clayton H. Hudson

Gentlemen:

In reply to your letter of June 19th we wish to quote for estimating purpose as follows:--

ANACONDA ROUND ADMIRALTY SEAMLESS TUBE:

8 pcs., abt. 52#, .840" OD x .109" wall x 7' long .................. 38.62¢ net per lb.

F. 0. B. Waterbury, Conn.

Delivery could be effected during the month of September, subject to prior commitments.

We would supply our Arsenical Admiralty tube which would meet the following composition limits:--

<table>
<thead>
<tr>
<th>Element</th>
<th>Composition Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>70.0 - 73.0</td>
</tr>
<tr>
<td>Tin</td>
<td>.90 - 1.20</td>
</tr>
<tr>
<td>Lead</td>
<td>&lt;.075 Max.</td>
</tr>
<tr>
<td>Iron</td>
<td>.06 &quot;</td>
</tr>
<tr>
<td>Arsenic</td>
<td>.02 - .06</td>
</tr>
<tr>
<td>Zinc</td>
<td>Remainder</td>
</tr>
</tbody>
</table>

Annealed with a grain size of .010 - .045 MM.
The density of this alloy is .308 pounds per cubic inch.

The terms and conditions as outlined on the reverse side of this letterhead will apply.

Firm orders are subject to negotiation and acceptance by this Company, dependent upon manufacturing schedules and facilities, or other conditions existing at the time orders are submitted.
The prices named in this quotation are those currently in effect. In the event of an order which can be scheduled for shipment within 60 days, the prices at which material will be billed will be those in effect on date of shipment. Orders that cannot be shipped within 60 days will be placed on file, to be entered and acknowledged as soon as shipment can be effected within a 60-day period.

Trusting the foregoing is the information desired, we remain,

Very truly yours,

THE AMERICAN BRASS COMPANY

(Signed) F. G. Evensen

Torrington-Waterbury Branches

FGE/RC
Virginia Polytechnic Institute
Chemical Engineering Dept.
Blacksburg, Virginia

Gentlemen:

Your valued Order No. A 392
of July 15, 1946 has been received. We regret we are not able to enter this order on our production schedule at this time and, therefore, are holding it in our active pending file. When manufacturing conditions permit, we will enter this for production and will at that time forward to you our formal acknowledgment advising you of the conditions of entry, terms of sale and expected shipping date.

It is our present estimate that this order will be included in our Oct.'46 schedule.

Very truly yours,

THE AMERICAN BRASS COMPANY
July 30, 1946

The American Brass Company
Waterbury 88, Connecticut

Attention: Mr. E. B. Hitchcock

Dear Sir:

Please refer to V. P. I. Requisition No. A392, July 15, 1946, an order for one-half inch admiralty metal tubing. This tubing was to be used in a corrosion research problem. The time allotted for this problem is very limited, and if the tubes are to be used it will be necessary that they be delivered not later than August 10, 1946.

If you are unable to deliver the tubes by the date stated above, please cancel the order. Your cooperation in this matter has been greatly appreciated.

Very truly yours,

Clayton H. Hudson
IN REPLY REFER TO
F. G. Evensen
Room #112

Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia

Attention: Mr. Clayton H. Hudson

Gentlemen:

In reply to your letter of July 30th regarding order A-392 dated July 15, 1946, we are very sorry to advise that we are unable to ship this material on August 10th as requested by you.

In accordance with your wishes, we are considering this order cancelled.

Regretting our inability to assist you in this instance, we remain

Very truly yours,
THE AMERICAN BRASS COMPANY

Torrington-Waterbury Branches

emc
The Carpenter Steel Company  
Kenilworth, New Jersey

Gentlemen:

In connection with a corrosion research problem, I am interested in obtaining experimental quantities of 1/2\(^{\text{\prime\prime}}\) stainless steel pipe, 0.840\(^{\text{\prime\prime}}\) O.D., 0.625 I.D., 0.109\(^{\text{\prime\prime}}\) wall thickness. Eight pieces of pipe seven feet in length will be required. I would also be interested in the physical properties of the pipe; namely type analysis and metal treatment.

Please forward price quotations and time required for delivery of the above tested quantity of pipe. Your cooperation in furnishing this information will be greatly appreciated.

Very truly yours,

Clayton H. Hudson

CHH/hh
May 7, 1946

Mr. Clayton H. Hudson  
Virginia Polytechnic Institute  
Department of Chemical Engineering  
Blacksburg, Virginia

Dear Mr. Hudson:

I have your letter of April 26th requesting information on 1/2" stainless pipe. While we make a great variety of analyses in stainless steel, it would be advantageous, I think, if you would inform us as to just what the corrosion testing is to consist of.

We would only be too happy to supply you with samples for testing and would be glad to co-operate in setting up testing procedures or any other work that may help you in your investigation.

We have available, generally, A.I.S.I. Types 304, 347, 309, 309 Columbium, 316, and 317, that we can supply you very promptly. Each of these alloys, however, have slightly different mechanical properties and somewhat different corrosion resisting qualities.

Upon receipt of your reply we will enter a sample order and furnish you with the necessary pipe for your work.

Very truly yours,

THE CARPENTER STEEL COMPANY

J. A. Deitrich  
Metallurgical Engineer  
WELDED ALLOY TUBE DIVISION  

JAD:MW
The Carpenter Steel Company  
Welded Alloy Tube Division  
Kenilworth, New Jersey  

Attention: Mr. J. A. Deitrich  

Dear Mr. Deitrich:  

Thank you for your letter of May 7th in regard to experimental quantities of stainless steel pipe.  

In connection with a research problem, I propose to study the corrosion resistance offered by several types of heat exchanger tubes when sulfur-bearing fuel oil and sodium chloride solutions (3 and 10%) are used as corrosive mediums. Particular attention will be given to special magnesium alloy tubing and comparative results will be obtained for stainless steel, monel, aluminum and admiralty metal tubing.  

The testing apparatus will consist of a double pipe heat exchanger with a pyrex outer tube and a metal alloy inner tube. The corrosive medium will be pumped through the annular space and the steam will be passed through the metal tube. Each sample will be tested for seventy-two hours, the metal tube removed and cleaned of corrosion products. From the loss in weight of the sample, inches penetration per year will be determined.  

Please advise as to the type of stainless steel pipe which will offer best corrosion resistance for such use and forward price quotations on the quantity and size of pipe listed in my letter of April 26th.  

I would be interested in knowing the process you recommend for cleaning corrosion products from stainless steel pipe. Thank you for your interest and cooperation in this matter.  

Very truly yours,  

Clayton H. Hudson
Mr. Clayton H. Hudson  
Virginia Polytechnic Institute  
Department of Chemical Engineering  
Blacksburg, Virginia  

Dear Mr. Hudson:

We have received your letter of May 10th and have entered a sample order to cover the 8 pieces of 1/2" IPS x 7' long Type 316 stainless steel.

From the information forwarded in your letter we would recommend Type 316 for experimental as well as service requirements. As far as the sodium chloride problem is concerned it has been our experience that Molybdenum bearing 18-8 is probably the best analysis available in stainless steel. We doubt, however, whether you will be able to measure corrosion in inches penetration per year in a sodium chloride solution. We say this because sodium chloride generally results in a pitting type of failure rather than an even over all wall loss. Under the circumstances the pits that develop may be relatively deep and still show only a small weight loss so that the tube might be close to failing or failing and the weight loss still only a minor problem. Then again with any chloride solution we want to caution you about having any traces of magnesium chloride in your solution. Magnesium chloride is capable of causing stress corrosion which results in longitudinal or circumferential cracks, especially when heated.

Concerning the sulfur-bearing fuel oil our experience has shown again that Type 316 is the best stainless steel for the job and has been perfectly satisfactory when used cold or warm below cracking temperature. If used at cracking temperature or above the sulfur reacts with the metal and causes a very roughened, attacked surface. This attack, however, could be recorded in inches penetration per year, we think.
Listed below are the approximate physical properties of the tubing that we will supply. At the time of shipment we will give you actual mechanical properties and actual chemistry of the material submitted.

<table>
<thead>
<tr>
<th>Element</th>
<th>Ultimate Strength in Thousands of Pounds psi.</th>
<th>Elastic Limit in Thousands of Pounds psi.</th>
<th>Elongation, percent in 2&quot;</th>
<th>Rockwell Hardness</th>
<th>Specific Gravity</th>
<th>Coefficient of Expansion deg. F 60° to 212° F.</th>
<th>Specific Electric Resistance Ohms per Cir. Mil. Ft. at 20° C</th>
<th>Structure</th>
<th>Is it Magnetic?</th>
<th>Max. for Continuous Service</th>
<th>Thermal Conductivity B.T.U./sq. ft./hr./°F/ in. @500° F</th>
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<td>.00000900</td>
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<td>Nickel</td>
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<td>40</td>
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<tr>
<td>Molybdenum</td>
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</tbody>
</table>

If we can be of any further service to you, please do not hesitate to call upon us.

Very truly yours,
THE CARPENTER STEEL COMPANY

J. A. Deitrich
Metallurgical Engineer
WELDED ALLOY TUBE DIVISION

JAD:MW
Virginia Polytechnic Institute  
Blacksburg, Virginia  

OUR RECORDS SHOW THAT THE TUBING ON YOUR ORDER WAS MANUFACTURED FROM HEAT GIVEN BELOW for tensile properties.  

<table>
<thead>
<tr>
<th>HEAT</th>
<th>C</th>
<th>Mn.</th>
<th>Si.</th>
<th>P.</th>
<th>S.</th>
<th>Cr.</th>
<th>Ni.</th>
<th>CB.</th>
<th>MO.</th>
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<tr>
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<td>.07</td>
<td>1.65</td>
<td>.38</td>
<td>.021</td>
<td>.009</td>
<td>17.58</td>
<td>11.00</td>
<td>2.60</td>
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</tbody>
</table>

ELASTIC LIMIT  
ULTIMATE STRAIN  
ELONGATION  
P.S.I. 50500  
P.S.I. 86100  
% in 2" 67.4

METALLURGIST - MANAGER, WELDED ALLOY TUBE DIVISION  
THE CARPENTER STEEL COMPANY

8 pcs. 1/2" IPS X 7'  
Type 316 56'

NOTARY PUBLIC, STATE OF NEW JERSEY  
MY COMMISSION EXPIRES FEBRUARY 24TH, 1949  
COUNTY OF UNION  
STATE OF NEW JERSEY  
SWORN TO BEFORE ME THIS  
15th DAY OF June 1946
Virginia Polytechnic Institute  
Blacksburg, Virginia  


Our records show that the tubing on your order, our shop order no. 23171 (Sample), was manufactured from heat given below and we have also completed laboratory tests for tensile properties.

<table>
<thead>
<tr>
<th>HEAT</th>
<th>C</th>
<th>Mn.</th>
<th>Si.</th>
<th>P</th>
<th>S</th>
<th>Cr.</th>
<th>Ni</th>
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<th>Mo</th>
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<td>17.58</td>
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<td>2.60</td>
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<table>
<thead>
<tr>
<th>ELASTIC LIMIT</th>
<th>ULTIMATE STRAIN</th>
<th>ELONGATION</th>
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<tbody>
<tr>
<td>P.S.I. 50500</td>
<td>P.S.I. 86100</td>
<td>% in 2&quot; 67.4</td>
</tr>
</tbody>
</table>

Notary Public, State of New Jersey  
My commission expires February 24th, 1949

County of Union  
State of New Jersey  
Sworn to before me this  
15th Day of June 1946
The Carpenter Steel Company  
Welded Alloy Tube Division  
Kenilworth, N. J.

Attention: Mr. J. A. Deitrich

Dear Sir:

I wish to thank you for the experimental quantity of stainless steel tubing furnished by your company and for the information furnished by your office.

Your interest and cooperation in this matter are greatly appreciated both by myself and the department in which I work.

Very truly yours,

Clayton H. Hudson
The Dow Chemical Company  
Midland, Michigan

Gentlemen:

I am interested in obtaining several special magnesium alloys for use in a research problem concerning corrosion of magnesium alloy tubing. The alloys will have to be extruded to form 1/2" tubing of the same dimensions as standard gage iron pipe, namely 0.840" outside diameter, 0.622" inside diameter and 0.108" thick; or made into billets of suitable size so that I might have the extruding accomplished elsewhere.

Please forward price quotations and time required for delivery of the cast billets, or if possible, for the following extruded tubing:

1. Special Mg alloy, 2% Mn, 1% Te, Bal Mg.  
   Length ------------ 7'  
   Outside Diameter -- 0.840"  
   Wall Thickness ---- 0.108"  
   No. Required ------ 8 ea.

2. Special Mg alloy, 4% Al, 2% Cr, Bal Mg.  
   Length ------------ 7'  
   Outside Diameter -- 0.840"  
   Wall Thickness ---- 0.108"  
   No. Required ------ 8 ea.

3. Special Mg alloy, 4% Al, 2% Cr, Bal Mg.  
   Length ------------ 21"  
   Outside Diameter -- 1 1/2"  
   Wall Thickness ---- 0.103"  
   No. Required ------ 64 ea.

4. Dowmetal alloy "J"  
   Length ------------ 7'  
   Outside Diameter -- 0.840"  
   Wall Thickness ---- 0.108"  
   No. Required ------ 8 ea.

Your cooperation in furnishing the above information will be greatly appreciated.

Very truly yours,

Clayton H. Hudson
Mr. Clayton H. Hudson
Department of Chemical Engineering
Virginia Polytechnic Institute
Blacksburg, Virginia

Dear Sir:

This is in reply to your letter of February 22 requesting quotation on experimental quantities of special magnesium base alloys in either tube or billet form. Before forwarding this request to our plant, I would like to obtain further information which would be helpful to them in preparing a quotation.

Unfortunately, we do not have extrusions die equipment for producing standard pipe sizes. We do have die equipment for producing tubing in most fractional dimensions. We are in a position to make a special extrusion die .840" OD x .109" wall at a cost of $85.00.

If you should desire billets rather than extruded tubing, will you please advise us the size and number of billets required of each alloy.

As soon as you furnish us with the above information we will forward your request to our plant for quotation.

Very truly yours,

THE DOW CHEMICAL COMPANY

Guy W. DeKuiper
Production Control
MAGNESIUM DIVISION

GWDK: LA
The Dow Chemical Company
Shoreham Building
Washington 5, D. C.

Attention: Mr. Guy W. DeKuiper

Dear Sir:

Please refer to my letter of February 22, requesting quotations on experimental quantities of special magnesium alloy tubing.

Laboratory equipment has been constructed for use in studying corrosion of magnesium alloy tubing. This equipment was designed for tubing of the same dimensions as 1/2" standard gage iron pipe (0.840" O.D., 0.622" I.D. and 0.109" thick). As the magnesium tubing will be held in place with packing glands, it will be possible to use tubing of smaller outside diameter and the thickness is relatively unimportant. Therefore, I do not feel that it would be necessary to have a special extrusion die made, either for the 1/2" or 1 1/2" tubing.

Please forward price quotations and time required for delivery of the quantities of tubing listed in my previous letter with dimensions as close as possible to those designated.

The time allowed for this research is very limited and your cooperation in handling this order as quickly as possible will be greatly appreciated.

Very truly yours,

Clayton H. Hudson
Virginia Polytechnic Institute  
Department of Chemical Engineering  
Blacksburg, Virginia  
Attention: Mr. Clayton H. Hudson  

Gentlemen:

This is in further regard to your letter of March 4 requesting information on the availability of special magnesium alloys.

We have been advised by our plant that although it is possible to alloy small amounts of tellurium with a magnesium-manganese combination, we have never been successful in obtaining a percentage as high as 1%. Further we are very dubious about our ability to extrude this material even if we were successful in obtaining the alloy. As far as the magnesium-aluminum-chromium alloy is concerned, we would not be able to make this at all.

In view of the above we are sorry to advise that we are unable to quote on your special alloy requirements.

Regarding your request for DOWMETAL J tubing, we wish to advise that we do have small quantities of 7/8" OD tubing in stock and could supply your requirements with a .062" wall tube. We are in a position to furnish you with DOWMETAL M tubing with a .125" wall and DOWMETAL FS-1 with a .134" wall. Our stocks of the above are limited and, of course, the availability of such is subject to prior sale.

Very truly yours,

THE DOW CHEMICAL COMPANY.

Guy W. DeKuiper  
Production Control  
MAGNESIUM DIVISION

GWDK: LA
April 3, 1946

The Dow Chemical Company
Magnesium Division
915 Shoreham Building
Washington 5, D.C.

Attention: Mr. Guy W. DeKuiper

Gentlemen:

This is in reference to your letter of March 26 concerning availability of experimental quantities of magnesium alloy tubing.

Please forward price quotations on the following amount of DOWMETAL FS-1: eight pieces of 7/8" OD tubing with 0.184" wall, seven foot lengths or the nearest equivalent being desired. Also forward price quotations on a like quantity of DOWMETAL M, 7/8" OD with 0.125" wall.

As I mentioned in my letter of February 28, I am interested in obtaining several special magnesium alloys for use in a research problem concerning corrosion of magnesium alloy tubing. Sodium chloride solutions and sulfur bearing fuel oil will be used as the corrosive mediums. In the course of my literature review, I discovered several articles which stated that the addition of chromium greatly increased the corrosion resistance of magnesium. Your letter indicated that you would be unable to produce a magnesium-aluminum-chromium alloy. Would it be possible to produce any magnesium alloy containing chromium?

Please let me know if you are in a position to produce small experimental quantities of special magnesium alloy tubing, other than the regular DOWMETAL products, which would give the best corrosion resistant properties when used under the conditions stated above.

Very truly yours,

Clayton H. Hudson
April 12, 1946

Virginia Polytechnic Institute
Dept. of Chemical Engineering
Blacksburg, Virginia

Attention: Mr. C. H. Hudson

Dear Sir:

We are in a position to furnish from stock the items of magnesium alloy requested in your letter and are pleased to quote on them as follows:

Item: 7/8" O.D. x .134" wall, FS-1 alloy tubing
Quantity: 8 pieces, 7' long
Est. Wt.: 13.5 lbs.
Price: $1.135 per lb. $15.33

Item: 7/8" O.D. x .125" wall, M alloy tubing
Quantity: 8 pieces 7' long
Est. Wt.: 12.7 lb.
Price: $1.065 per lb. $13.53

The above material is Fob Midland, Mich.

In reply to your questions regarding the production of small quantities of extruded special alloys, we wish to advise that at the present time our fabricating facilities are extremely busy in an attempt to fulfill the demand for standard commercial items, and we feel that we would be unable to work with small quantities of special alloys at the moment.

Very truly yours,

THE DOW CHEMICAL CO.

Guy W. DeKuiper
Production Control
Mg. Div1
<table>
<thead>
<tr>
<th>acc.</th>
<th>ot</th>
<th>wn</th>
<th>_w</th>
<th>_r</th>
<th>_f</th>
<th>_s</th>
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<tr>
<td>FS-1</td>
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<td>0.20</td>
<td>0.7-1.5</td>
<td>0.3</td>
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</table>

We refer to section 1.1.2 for details.
The Dow Chemical Company
915 Shoreham Building
Washington 5, D. C.

Attention: Mr. Guy W. DeKuiper:

Gentlemen:

Thank you for your letter of April 12 giving quotations on experimental quantities of magnesium alloy tubing. A requisition for this tubing has been submitted to the college and an order will follow as soon as the requisition has been approved.

I was very disappointed to learn that you are not in a position at the present time to produce the small quantities of extruded special magnesium alloys desired. However, it will be possible to delay the work on these special alloys for several months and I trust that by that time you will be able to fill such an order. Please advise as soon as you are in a position to do so.

Your interest and cooperation in this matter have been greatly appreciated.

Very truly yours,

Clayton H. Hudson

CHH/hh
Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia

Attention: Mr. Clayton H. Hudson

Gentlemen:

This will acknowledge your letter of April 23, and we note with interest that an order for magnesium tubing will be forwarded to us through your Purchasing Department.

We are indeed sorry that we are unable to consider extruding small quantities of experimental alloys at the present time, but we hope that the situation will ease somewhat in the future at which time we will be glad to get in touch with you.

Very truly yours,

THE DOW CHEMICAL COMPANY

Guy W. DeKuiper
Production Control
MAGNESIUM DIVISION

GWDK: LA
June 19, 1946

The Dow Chemical Company
Shoreham Building
Washington 5, D. C.

Attention: Mr. Guy W. DeKuiper

Gentlemen:

Please refer to my letter of April 23 concerning the extrusion of experimental quantities of several special magnesium alloys. You informed me at that time that you were not in a position to produce special alloys but that you might be able to accept an order at a later date.

Please advise if you will be able to produce and deliver special alloys by the middle of August.

Very truly yours,

Clayton H. Hudson

CHH/h
Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia

Attention: Mr. Clayton H. Hudson

Gentlemen:

This is in reply to your letter of June 19 in which you have requested information on our ability to extrude experimental quantities of special alloys.

Our production facilities are still booked to capacity for some months to come but there is a possibility that our Research Department might be able to handle your proposed work. If you will be good enough to advise us, more in detail, as to the project you have in mind we will be pleased to pass this information on to our Research Department for their comments as to their ability to handle your development work at the present time.

Very truly yours,

THE DOW CHEMICAL COMPANY

Guy W. DeKuiper
Magnesium Division
Washington Office

GWDK/aoc
July 9, 1946

The Dow Chemical Company  
915 Shoreham Building  
Washington, 5, D. C.

Att: Mr. Guy W. DeKuiper  

Dear Sir:  

In connection with our previous correspondence concerning experimental quantities of special magnesium alloy tubing, I am interested in knowing if you will be able to fabricate and deliver these alloys by August 15th.

Please forward price quotations on the following amount of Dowmetal "F3-1": seventy pieces of 1/2" OD tubing with 0.109" wall, 21" in length. Also forward price quotations on a like quantity of Dowmetal "M". As the time allotted for the research work on these alloys is very limited, it would be necessary to have a delivery date not later than the first week in August.

Your attention to this matter will be greatly appreciated.

Very truly yours,

Clayton H. Hudson

CHH:JS
Gentlemen:

Thank you for your letter of July 8 advising that there is a possibility of your Research Department handling the extruding of experimental quantities of special magnesium alloys necessary for my research work.

I am working on a research problem concerning corrosion of heat exchanger tubes. Sodium chloride solutions and sulfur bearing fuel oil are being used as corrosive mediums. I am interested in comparing the corrosion resistance offered by regular Dowmetal alloys and by special magnesium alloys. In the course of my literature review, I have found articles stating that small additions of chromium, silver or tin will increase the corrosion resistance and I should like to obtain samples containing about 1% of each of these elements.

The alloys will have to be extruded to form one-half inch tubing of essentially the same dimensions as standard gage iron pipe; namely 0.840" outside diameter, 0.622" inside diameter and 0.109" thick. Five pieces of each special alloy, seven feet in length, will be required.

I have been corresponding for several months with Mr. DeKuiper concerning these alloys. As the time remaining for this work is very limited, it would be necessary to have a delivery date not later than August 15. If you are unable to produce all three of the samples, I should like to have the quantity that you can produce.

I also wrote to Mr. DeKuiper on July 9 concerning experimental quantities of Dowmetal "FS-1" and Dowmetal "M" and have received no answer as yet. Any information that you can furnish concerning these inquiries will be greatly appreciated.

Very truly yours,

Clayton H. Hudson
Virginia Polytechnic Institute  
Department of Chemical Engineering  
Blacksburg, Virginia  

Attention: Mr. Clayton H. Hudson  

Gentlemen:  

This is in reply to your letters of July 9 and July 17. We sincerely regret the delay in replying to these letters as we know you are extremely anxious to obtain the requested material as soon as possible. However, the writer has been on an extended trip and the delay was unavoidable.  

Regarding our ability to furnish quantities of FS-1 and M alloy tubing as well as special alloy tubing, we regret to advise that it would be impossible to furnish any of these items by August 15. In the first place, we do not have extrusion dies for extruding either of the sizes of tubing you have mentioned. Deliveries on extrusion dies at the moment are running about eight weeks due to the tremendous amount of work in the die shops. Further, delivery on standard alloy extrusions is running in the neighborhood of six to ten weeks after receipt of dies. Delivery of special alloys from our Research Department would probably take even longer.  

Even if we supplied material from existing extrusion dies which would approximate the dimensions you have listed it would be quite impossible to make delivery by August 15.  

Should you be able to accept a later delivery we could undoubtedly furnish your requirements of M and FS-1 alloy 1\(\frac{1}{2}\)" OD x .125" wall in approximately eight to ten weeks.
We again regret that we are unable to meet your required delivery date due to the tremendous amount of extrusion business on our books at the present time. We would like to suggest that you might be able to obtain your requirements in M and FS-1 alloy from Revere Copper and Brass, Inc., Baltimore, Maryland.

Yours very truly,

THE DOW CHEMICAL COMPANY

Guy W. DeKuiper
Magnesium Sales
WASHINGTON OFFICE

GWDK:LA
February 13, 1946

The International Nickel Co., Inc.
Development and Research Division
67 Wall Street
New York, New York

Attention: Mr. G. L. Cox

Dear Sir:

Dr. Vilbrandt had suggested that I write to you concerning the research problem that I am working on at the present time. This problem involves the use of magnesium alloy tubing in heat exchangers.

It will be necessary to conduct the corrosive medium from a storage tank to the heat exchanger and back to storage through some material which will not corrode and contaminate the medium. Ten percent hydrochloric and acetic acid will be used at temperatures ranging from 70°F to 150°F. Bronze pipe and fittings could be used but are not available on the market at this time. Can monel, nickel or inconel be used for this purpose? If so, I am interested in obtaining price quotations and time required for delivery of 1/2" pipe, valves and fittings.

Another problem I would like to ask your advice on is the best method of determining corrosion rates. The magnesium tubing used will be 1/8" inside diameter extruded tubing in 6' lengths. It will be impractical to weigh the entire length of tubing and impossible to determine the accurate weight of a small section of the tubing prior to corrosion testing.

I would greatly appreciate any information that you may give concerning the above problems.

Very truly yours,

Clayton H. Hudson
February 15, 1946

Mr. Clayton H. Hudson
Box 120, V. P. I.
Blacksburg, Virginia

Dear Mr. Hudson:

In accordance with your request of February 13th, we are pleased to enclose a copy of our Technical Bulletin T-10, "Corrosion Testing Methods".

We trust that this bulletin will prove to be both interesting and useful to you and if you should have any questions or comments on the information it contains, please do not hesitate to write us.

Very truly yours,

W. Z. FRIEND
Development and Research Division

Enc.
February 25, 1946

The International Nickel Company, Inc.
67 Wall Street
New York, New York

Gentlemen:

I am interested in obtaining a small quantity of monel tubing for use in a research problem concerning corrosion of heat exchanger tubes.

Please furnish price quotations and time required for delivery of the following monel tubing:

Length ------------------ 7'
Outside Diameter ------ 0.840"
Wall Thickness --------- 0.109"
No. Required ---------- 8 each

If you could furnish information concerning composition and metal treatment of the monel, it would be greatly appreciated.

Very truly yours,

Clayton H. Hudson

hh/
March 4, 1946

Mr. Clayton H. Hudson
Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia

Dear Sir:

This will acknowledge receipt of your letter of February 25 in which you request quotation and delivery on a small quantity of Monel tubing.

Since the sale of our products in your vicinity is handled by Whitehead Metal Products Company, Inc., 413-415 West North Avenue, Baltimore 17, Maryland, we have taken the liberty of forwarding them your inquiry. You may expect to hear from Whitehead Metal Products Company promptly.

We are enclosing a copy of our Bulletin T-5, "Engineering Properties of Monel," which we think will be of interest to you. For your convenience in requesting additional literature as you need it, we are also enclosing a copy of our List "B" which summarizes our printed literature.

If we, or the Whitehead Metal Products Company, may be of any further service, please do not hesitate to get in touch with us.

Very truly yours,

Inco Nickel Alloys Department

J. W. Carey

Enclosures
The International Nickel Company, Inc.
67 Wall Street
New York, New York

Gentlemen:

Please refer to my letter of February 25, JQ-2128, in reference to experimental quantities of monel tubing. This tubing was purchased from the Whitehead Metal Products Company, Baltimore, Maryland.

I am interested in knowing the type of monel used in these tubes so that the chemical composition and metal density can be determined. I have your Bulletin T-5, Engineering Properties of Monel and "R" Monel, and note that the density of several monel alloys is given as 8.84 gm/cu. cm. Will I be correct in assuming that the tubes I received are cast monel with the density stated above?

If possible, I would like for you to forward the following bulletins:

How to Recognize and Control Concentration-Cell Corrosion
Corrosion: Processes-Factors-Testing
Monel, Nickel and Inconel in Soap Industry - Bulletin C-1

Your cooperation in furnishing the information requested above and the bulletins would be greatly appreciated.

Very truly yours,

[Signature]

DEPARTMENT OF CHEMICAL ENGINEERING

Virginia Polytechnic Institute
June 25, 1946

Mr. Clayton H. Hudson
Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia

Dear Sir:

This will acknowledge your letter of June 19 in which you raise questions concerning the density and composition of Monel tubes.

The tubes will not be cast but will be in the wrought form, composition being as indicated under Table 3, for wrought products, of Bulletin T-5 attached. You will note that this is only a nominal composition, and there will be slight deviations from the figures as indicated.

"R" Monel is a free machining variety of Monel which is supplied in wrought form only, the composition being essentially the same as that of regular Monel with the exception of its slightly higher sulfur content.

The density will be as indicated in Table 4, of Bulletin T-5, and is the same for regular and for "R" Monel.

The bulletins you requested are enclosed with this letter.

Very truly yours,

Inco Nickel Alloys Department

FRB:FW
Enclosures

F. R. Bailey
Standard Oil Co. of Louisiana
Baton Rouge, Louisiana

Attention: Dr. Cecil L. Brown

Gentlemen:

In connection with a research problem, I propose to study the corrosion resistance offered by several types of heat exchanger tubes when sulfur-bearing fuel oil is used as a corrosive medium. Particular attention will be given to magnesium-alloy tubing and comparative results will be obtained for monel, aluminum, admiralty metal and stainless steel tubing.

Dr. Vilbrandt has suggested that I write to you concerning the availability of sulfur-bearing fuel oil or some other sulfur-bearing distillate fraction. It is necessary that I obtain one hundred gallons of this corrosive medium before I can begin work on the problem. Would it be possible for you to furnish this quantity of oil and also information concerning the composition of the oil?

Your cooperation in furnishing this information would be greatly appreciated.

Very truly yours,

Clayton H. Hudson
Mr. Clayton H. Hudson  
Virginia Polytechnic Institute  
Department of Chemical Engineering  
Blacksburg, Virginia

Dear Sir:

With reference to your letter of April 12, 1946, we shall be pleased to supply you with one hundred gallons of a petroleum stock to be used as a corrosive medium in connection with your research problem on corrosion resistance of heat exchanger tubes made of different alloys. We can send you a reduced Texas crude oil (with 400°F. end point gasoline removed) that will have approximately the following properties:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.P.I. Gravity</td>
<td>16.5</td>
</tr>
<tr>
<td>Flash °F.</td>
<td>280-290</td>
</tr>
<tr>
<td>Sulfur Content, W.%</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Should you feel that this type of oil would be satisfactory for your experimental work, please advise us and we shall ship you the one hundred gallons immediately. We would be pleased if you would accept this sample without cost in view of the many courtesies extended to us by your College in the procurement of men for our organization.

Very truly yours,

C. L. BROWN

Per: C. E. Starr, Jr.

CC: Dr. Frank C. Vilbrandt  
Reply to ELLA 2738
April 23, 1946

Esso Laboratories
Standard Oil Co. of N. J.
Louisiana Division
P. O. Box 551
Baton Rouge 1, La.

Attention: Dr. C. L. Brown

Dear Sir:

Thank you for your letter of April 10 in reference to sulfur bearing petroleum stock to be used in a corrosion research problem.

The Texas crude oil which you advised as being available would be very satisfactory and I would like for you to ship one hundred gallons of this oil at your convenience.

It may be necessary to decrease the sulfur content of the oil after initial tests have been made with the oil bearing 3% sulfur by weight. Could this be done by diluting the reduced crude with commercial fuel oil? Also, could you furnish any information as to the allowable sulfur content of commercial fuel oil?

Your interest in this problem and cooperation in furnishing the sample without cost is greatly appreciated.

Very truly yours,

Clayton H. Hudson

CHH/hh
May 23, 1946

Shipments of 100 Gallons of Petroleum Stock

Mr. Clayton H. Hudson
Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia

Dear Sir:

Please be informed that we are shipping you today 100 gallons of reduced Texas crude oil having a sulfur content of 2.69%. This oil is being sent to you by motor freight contained in two iron drums. Inspections of the material as shipped are given in the following tabulation.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity, API</td>
<td>16.5</td>
</tr>
<tr>
<td>Furol Viscosity at 122°F.</td>
<td>106</td>
</tr>
<tr>
<td>Pensky-Martin Flash °F.</td>
<td>above 200</td>
</tr>
<tr>
<td>ASTM Bomb Sulfur, w. %</td>
<td>2.69</td>
</tr>
<tr>
<td>Bottom Sediment by Centrifuge,</td>
<td>v. %</td>
</tr>
<tr>
<td></td>
<td>0.02</td>
</tr>
<tr>
<td>Sediment by Extraction* w. %</td>
<td>0.01</td>
</tr>
<tr>
<td>Sediment by Hot Filtration w%</td>
<td>0.01</td>
</tr>
<tr>
<td>Ash, w. %</td>
<td>0.013</td>
</tr>
</tbody>
</table>

*Benzene used as solvent.

We trust that you find this oil satisfactory for your corrosion research studies and if we can be of any further assistance to you, please inform us.

Very truly yours,

C. L. BROWN

Per C. E. Starr, Jr.

JATilton;ma

CC: Dr. Frank C. Vilbrandt
VIRGINIA POLYTECHNIC INSTITUTE
Department of Chemical Engineering
Blacksburg, Virginia

July 5, 1946

Standard Oil Co. of N. J.
Louisiana Division
P. O. Box 551
Baton Rouge 1, Louisiana

Attention: Mr. C. E. Starr, Jr.

Dear Sir:

The two drums of Texas crude oil which you forwarded by motor freight have not arrived and I should like to request that you initiate a tracer.

I received a mimeographed form dated June 7 and signed by Mr. M. B. Amis, informing me that two drums of reduced Buckner Crude, sample #46-506 had been shipped by the Herrin Motor Lines and the Nola Cook Truck Lines. The drums must have been delayed in route as I have received no further information concerning the shipment.

Thank you for your interest and cooperation in furnishing this sample of crude oil.

Very truly yours,

Clayton H. Hudson
AIR MAIL

Mr. Clayton H. Hudson
Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia

Dear Sir:

With reference to your letter of July 5, 1946, please be informed that we have traced the shipment of the two drums of oil and our results have ended in a most unfortunate finding. As you were aware, the sample had been shipped by the Herrin Motor Lines and the Hola Cook Trunk Lines. We were able to trace the shipment to New Orleans, Louisiana, and beyond this point no one seems to know what happened to the drums.

We have assumed the shipment to be lost and are proceeding with the preparation of a second sample. According to our schedule the second sample of high sulfur reduced crude will be ready for shipment on July 26, 1946. It will be made from the same stock as the first sample and should have approximately the same inspections as given in our letter to you of May 23, 1946.

We trust that this delay will not inconvenience you too much.

Very truly yours,

C. E. STARR, JR.

JATilton:org
Reply to ELIA #5543
July 26, 1946

Standard Oil Co. of N. J.
Louisiana Division
P. O. Box 551
Baton Rouge 1, Louisiana

Attention: Mr. C. E. Starr, Jr.

Dear Sir:

Thank you for your letter of July 19 in reference to the shipment of two drums of high sulfur crude oil.

I am sorry that the first shipment was lost in route and I greatly appreciate your forwarding another sample. The delay caused no inconvenience on my part.

Thank you for your interest and cooperation in this matter.

Very truly yours,

Clayton H. Hudson
Mr. Clayton H. Hudson  
Virginia Polytechnic Institute  
Blacksburg, Virginia

Dear Sir:

We are shipping to you today 100 gallons of reduced Hawkins-Buckner Crude having a sulfur content of 2.78%. This material is being sent by rail freight in two drums labeled "Sample No. 46-769". Inspections of the material as shipped are given in the tabulation below:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity, °API</td>
<td>16.3</td>
</tr>
<tr>
<td>Furol Viscosity at 122°F.</td>
<td>133</td>
</tr>
<tr>
<td>Saybolt Viscosity at 100°F.</td>
<td>2943</td>
</tr>
<tr>
<td>Flash, Cleveland Open Cup, °F.</td>
<td>300</td>
</tr>
<tr>
<td>ASTM Bomb Sulfur, W.%</td>
<td>2.78</td>
</tr>
<tr>
<td>Pour, °F.</td>
<td>0</td>
</tr>
<tr>
<td>B S &amp; W, Vol. %</td>
<td>0.1</td>
</tr>
</tbody>
</table>

We received your letter concerning the oil which was lost in shipment and were glad to hear that you had not been inconvenienced by this unfortunate delay.

If we can be of any further assistance to you, do not hesitate to let us know.

Very truly yours,

C. E. STARR, JR.

JSAnderson/ma
August 22, 1946

Standard Oil Co. of N. J.
Louisiana Division
P. O. Box 551
Baton Rouge 1, Louisiana

Attention: Mr. C. E. Starr, Jr.

Dear Sir:

Thank you for your letter of July 30 concerning the shipment of two drums of Hawkins-Buckner Crude Oil for use in a corrosion research problem.

This shipment arrived safely and corrosion tests have been made using aluminum-alloy, monel and stainless steel as heat exchanger tubes.

The following table lists the results obtained from these tests:

<table>
<thead>
<tr>
<th></th>
<th>Aluminum, 35</th>
<th>Monel</th>
<th>S-Steel, 316</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av. Vel. (gal/min)</td>
<td>3.42</td>
<td>3.42</td>
<td>3.42</td>
</tr>
<tr>
<td>Av. Inlet Temp. (°C)</td>
<td>88.10</td>
<td>86.9</td>
<td>84.20</td>
</tr>
<tr>
<td>Av. Outlet Temp. (°C)</td>
<td>93.00</td>
<td>95.40</td>
<td>100.50</td>
</tr>
<tr>
<td>Area (sq. in.)</td>
<td>177.73</td>
<td>180.8</td>
<td>179.70</td>
</tr>
<tr>
<td>Time of Test (hrs.)</td>
<td>72.00</td>
<td>72.00</td>
<td>72.00</td>
</tr>
<tr>
<td>Wt. Loss (gms.)</td>
<td>2.35</td>
<td>2.05</td>
<td>0.57</td>
</tr>
<tr>
<td>Penetration (in/yr)</td>
<td>0.0361</td>
<td>0.0095</td>
<td>0.0029</td>
</tr>
<tr>
<td>Life (yrs.)</td>
<td>3.02</td>
<td>11.50</td>
<td>37.60</td>
</tr>
</tbody>
</table>

I was most anxious to make a corrosion test using admiralty metal but was unable to secure the tubing at this time. Dr. Vilbranit has suggested that I ask if you possibly have the following tubing available: three pieces, seven feet in length, 0.840" O.D., 0.623" I.D.
Thank you for furnishing the oil free of charge. Your interest and cooperation in this matter has been greatly appreciated.

Very truly yours,

Clayton H. Hudson, Jr.
Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia
Att: Mr. Clayton H. Hudson

CONTRACTS SUBJECT TO STRIKES, ACCIDENTS, DELAYS OF CARRIERS, OR OTHER CAUSES BEYOND OUR CONTROL. ALL QUOTATIONS ARE F.O.B. BROOKLYN AND ARE SUBJECT TO ACCEPTANCE BY RETURN MAIL UNLESS OTHERWISE SPECIFIED. STENOGRAPHICAL AND CLERICAL ERRORS SUBJECT TO CORRECTION. NO CLAIM FOR LARGER OR DAMAGES ALLOWED. MATERIAL PROVEN DEFECTIVE WILL BE REPLACED, BUT ONLY IF IN ORIGINAL FORM. NO GOODS TO BE RETURNED WITHOUT OUR PERMISSION. CANCELLATION OF CONTRACTS OR ORDERS NOT PERMITTED. QUOTATIONS ARE NOT BINDING UNLESS ACCEPTED BY US IN WRITING. QUOTATIONS ARE SUBJECT TO CHANGE WITHOUT NOTICE.

Gentlemen:

We have your letter of February 13th with reference to Magnesium Alloy Tubing.

We note you mention the White Metal Rolling and Stamping Corporation who are in a position to roll and extrude this alloy for you. We believe this organization could also produce the base alloy for you.

In our operations, we are not producing Magnesium base alloys but using Magnesium as a minor alloying agent with other elements.

We hope that you will be able to obtain your requirements from this source.

While writing we do call your attention to our many products and invite you to call upon us should you again have requirements for our products.

Yours very truly,

George Henning

BELMONT SMELTING & REFINING WKS., Inc.

Robert V. Henning
Vice Pres. & Secy.
Ruth K. Henning
Asst. Treas.

Cable Address: Belsmel, New York

General Office
330 BELMONT AVENUE
BROOKLYN 7, NEW YORK

Telephone: Dickens 2-4000

In Reply Please Refer to
February 15th,
1 9 4 6
GH PL
**INVOICE**

**CORNING GLASS WORKS**  
CORNING, N.Y., U.S.A.

<table>
<thead>
<tr>
<th>Customer's Name and Date</th>
</tr>
</thead>
</table>
| VIRGINIA POLYTECHNIC INSTITUTE  
CLAYTON HUDSON, DEPT OF CHEM. ENGINEERING  
BLACKSBURG, VIRGINIA |

<table>
<thead>
<tr>
<th>SOLD TO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SHIPPED TO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Salesman</th>
</tr>
</thead>
<tbody>
<tr>
<td>32700</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fact. Ord.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PZ-1261</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date Entered</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/14/46</td>
</tr>
</tbody>
</table>

**TERMS:** Bills 1st TO 15th payable on 25 of month. Bills 16th to 31st payable on 10th following month with 1% allowance for cash or 30 days net from date of bill.

**TERMS:** THIS MERCHANDISE IS SOLD ONLY UPON CONDITION THAT TITLE AND POSSESSION PASS TO THE BUYER UPON DELIVERY TO CARRIER AT POINT OF SHIPMENT. OUR (SELLER'S) RESPONSIBILITY THEN CEASES.

**ITEMS NOT EXTENDED, OR EXTENDED FOR PARTIAL QUANTITIES HAVE BEEN BACK ORDERED OR PREVIOUSLY SHIPPED.**

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>QUANTITY SHIPPED</th>
<th>UNIT PRICE</th>
<th>AMOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 PC A 727230 PIPE FLANGED 2&quot; BY 60&quot; H R CLEAR GLASS 774(X)</td>
<td>1</td>
<td>6.80 EA. NET</td>
<td>6.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 CTN.</td>
<td>.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7.75</td>
</tr>
</tbody>
</table>

**Paid: July 4, 1946**

**Routing:** EXP.

**No. MFG. Copies**

**Priced Copies**

**Memo. Copies**

**NOTES:**

- Invoice Date: 6-24-46
- Inv. No.: 1819
- Date: 6-24-46
- Shipped: EXP.
- Partial Shipment: X
- Terms: 1st TO 15th payable on 25 of month. Bills 16th to 31st payable on 10th following month with 1% allowance for cash or 30 days net from date of bill.

**Routing:**
- EXP.
Corning Glass Works  
Corning, New York

Gentlemen:

Please forward price quotations and time required for delivery of two "Pyrex" glass tubes, each with the following dimensions: 5 feet long, 2 inches inside diameter with flanged ends. These glass tubes will be used as heat exchangers in a research problem concerning corrosion of heat exchanger tubes.

Your cooperation in furnishing the above information will be greatly appreciated.

Very truly yours,

Clayton H. Hudson
Virginia Polytechnic Institute  
Department of Chemical Engineering  
Blacksburg, Virginia  

Attention: Mr. Clayton H. Hudson  

Gentlemen:  

We are in receipt of your letter dated February 13th but regret our inability to be of service to you, inasmuch as the alloys we fabricate are additive and intermediate for use in the non-ferrous foundries.  

Thanking you, however, for thinking of us in this connection, we are  

Very truly yours,  

ELECTRO REFRACTORIES & ALLOYS CORP.  

Paul J. Buchheit  
Assistant Sales Manager
May 28, 1946

Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia

Attention of Mr. Clayton H. Hudson

Gentlemen:

This will acknowledge your letter of May 16 concerning special magnesium alloys.

We do not offer magnesium alloys, so we are unable to quote you on heat exchanger tubes. The Dow Chemical Company at Midland, Michigan may be able to assist you.

Thanking you for your inquiry, we are,

Very truly yours,

FANSTEEL METALLURGICAL CORPORATION

Sales Engineer - Tantalum

J Evard
MLB
Fansteel Metallurgical Corp.
North Chicago
Illinois

Gentlemen:

I am interested in obtaining several special magnesium alloys for use in a research problem concerning corrosion of heat exchanger tubes. A study will be made of the corrosion resistance offered by several types of heat exchanger tubes when sulfur bearing fuel oil and sodium chloride solutions are used as corrosive mediums.

The alloys would have to be extruded to form 1/2" tubing of the same dimensions as standard gage iron pipe, namely 0.840" outside diameter, 0.622" inside diameter and 0.109" thick; or made into billets of suitable size so that I might have the extruding accomplished elsewhere.

If you are in a position to produce these special alloys, please forward price quotations and time required for delivery of the following extruded tubing:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5% Cr, Bal. Mg.</td>
<td>610&quot;</td>
<td>0.840&quot;</td>
<td>0.622&quot;</td>
<td>8</td>
</tr>
<tr>
<td>1.5% Ag, Bal. Mg.</td>
<td>6'0&quot;</td>
<td>0.840&quot;</td>
<td>0.622&quot;</td>
<td>8</td>
</tr>
<tr>
<td>2% Sn, Bal. Mg.</td>
<td>6'0&quot;</td>
<td>0.840&quot;</td>
<td>0.622&quot;</td>
<td>8</td>
</tr>
<tr>
<td>1.5% Cr, Bal. Mg.</td>
<td>1'9&quot;</td>
<td>1.5&quot;</td>
<td>1.232&quot;</td>
<td>64</td>
</tr>
</tbody>
</table>

Please list separately the price of the last alloy.

Your cooperation in furnishing the above information will be greatly appreciated.

Very truly yours,

Clayton H. Hudson
July 26, 1946

Phipps and Bird Co.
P. O. Box 2-V
Richmond 5, Virginia

Gentlemen:

Please refer to V. P. I. Requisition 138 dated June 27, 1946, which was an order for ten pounds of chromic acid.

This chromic acid is needed urgently and it would be appreciated if you would expedite the shipment. If you are not able to ship immediately, please advise.

Very truly yours,

Clayton H. Hudson
Gentlemen:

I am interested in obtaining a small quantity of chromic acid to be used in connection with a corrosion research problem. This acid will be used to clean corrosion products from magnesium test specimens and I believe that the technical grade product would be satisfactory.

Please forward price quotations and time required for delivery of ten pounds of technical grade chromic acid. Your cooperation in furnishing this information will be greatly appreciated.

Very truly yours,

Clayton H. Hudson

Copy to: Phipps and Bird, Richmond, Va.
The B. F. Goodrich Company  
21st and Mippincott Streets  
Philadelphia 22, Pa.

Attention: Mr. Walter M. Bowen

Dear Sir:

Thank you for your letter of April 22 regarding quotations on Vulcalock barrels.

Tentative changes in my plan of research have altered the purpose for which I planned to use a Vulcalock barrel and I cannot place an order with you at the present time.

Your cooperation in furnishing the information requested is greatly appreciated.

Very truly yours,

Clayton H. Hudson
Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia

Attention: Clayton H. Hudson
Subject: Vulcalock Barrels

Dear Mr. Hudson:

On March 5th, 1946 we quoted you on Vulcalock barrels.

As we have not heard further from you in this connection we are wondering what disposition has been made of the matter.

Will you kindly advise?

Yours truly,

THE B. F. GOODRICH COMPANY

Industrial Products Sales Division

Walter M. Bowen
hd
Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia

Attention: Mr. Clayton H. Hudson
Subject: Vulcalock Barrels

Dear Mr. Hudson:

Your letter of February 25, 1946, concerning rubber lined barrels, has been received by us, and we quote as follows:

Vulcalock Barrels 50 gal. capacity @ $46.00 ea. Net

Concerning delivery, we will not be able to give you very much in the way of definite information, because of the fact that we are so dependent on the steel industry as a source of supply.

We can say, however, that it usually takes six (6) to eight (8) weeks after receipt of the steel to make delivery on material of this sort.

The regular industrial terms of 2-10-30 apply, FOB Akron, Ohio.

Thank you very much for your inquiry and we hope we may have the pleasure of handling your order.

Yours truly,

THE B. F. GOODRICH COMPANY

Walter M. Bowen
Industrial Products Sales Division

PLEASE READ — THE FOLLOWING IS A PART OF OUR QUOTATION

Unless otherwise stated, all quotations and promises of shipment are subject to change without notice prior to acceptance and all orders are subject to acceptance by our Akron Office. Furthermore, because of present conditions, all orders accepted shall be subject to the condition that deliveries thereunder may be deferred by us (or if the merchandise covered thereby is subject to allocation by a Governmental agency deliveries will be made only in accordance with its permission) and, when made, will be made at the price or prices in effect on the date of shipment.

In the event of any price increase other than due to any tax, excise, duty or levy, or in the event deliveries are unreasonably deferred, any unshipped portion may be cancelled at the purchaser's option, provided, however, that if an order covers an item of special manufacture and the purchaser has been notified of a price increase prior to commencement of manufacture it shall not, thereafter, be subject to cancellation except with our written consent.

Quoted prices do not include, and if we are required to pay or collect, any tax, excise, duty or levy now or hereafter enacted or imposed by any governmental authority on the manufacture, sale, delivery and/or use of any item delivered, an additional charge will be made therefore unless we are furnished with a proper exemption certificate in those cases where its use is legally authorized.

Merchandise manufactured by us is warranted to be free from defect in material and workmanship. Our liability is limited, however, to the purchase price of any merchandise proved defective or, at our option, to the replacement of such merchandise upon its return to us, transportation charges prepaid, after making a pro rata charge for the service rendered.
February 25, 1946

The B. F. Goodrich Company
21st & Lippincott Streets

Gentlemen:

In connection with a research problem on which I am working, it will be necessary to store 15% hydrochloric and acetic acid at a temperature of 100°F. The acid will be pumped from the storage through 3/4" bronze pipe to a heat exchanger and back to the storage tank.

Your catalog section 9030, 2-38, lists rubber-lined barrels with removable heads suitable for shipping hydrochloric acid which I believe could be used for the purpose stated above. However, a 3/4" inlet, 3/4" outlet and a vent will have to be inserted in the barrel. These fittings could not be welded to the barrel without damaging the rubber lining, but I believe that I could insert the fittings through drilled holes and hold them in place with gaskets and lock nuts.

If you think that a barrel will be suitable for such use, please forward price quotations and time required for delivery of one 50-gallon rubber-lined barrel.

Very truly yours,

Clayton H. Hudson

hh/
Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia

Attention: Clayton H. Hudson
Subject: Hard Rubber Pipe and Fittings

Dear Mr. Hudson:

Referring to your letter of January 15, 1946, sent directly to our main office in Akron, Ohio.

We are enclosing Catalog Section No. 9400 covering Hard Rubber Pipe and Fittings, and Catalog Section No. 9405 covering Hard Rubber Products, which we hope will be of benefit to you. You will find that the information contained is very complete and concerning the list of prices that you desired we will be unable to quote or give Catalog Sections on the last three items namely valves, pumps and Venturi meters.

If you will look through these catalog sections and give us an idea of the specific items on which you desire price quotations, we will be very glad to submit them to you.

Thank you very much for your interest in these items.

Very truly yours,

THE B. F. GOODRICH COMPANY

Industrial Products Sales Division

Walter M. Bowen
January 24, 1946

The Goodyear Tire & Rubber Co., Inc.
Akron 16, Ohio

Gentlemen:

I am working on a research problem concerning corrosion in heat exchangers. Hydrochloric acid and acetic acid will be used as corrosive mediums at temperatures up to 200°F.

Please forward information regarding available sizes and price quotations on the following rubber-lined items:

1. Pipe, 1/4" to 1"
2. Fittings, 1/4" to 1"
3. Valves, 1/4" to 1"
4. Venturi meter, 1/2"

Your cooperation in furnishing the above information will be greatly appreciated.

Very truly yours,

Clayton H. Hudson

Copies sent to:  
\(\checkmark\) Goodall Rubber Co., Inc. 11 S. 36th St. "Philly, Pa  
\(\checkmark\) The Manhattan Rubber Mfg. Division, Raybestos-Man., Inc. 91-Townsend St., Passaic, N. J.  
\(\checkmark\) U. S. Stoneware, Tower Rubber Div., Ravenna, Ohio

--Bronze & Rubber-lined--
\(\checkmark\) Crane Co., 836 S. Michigan Ave., Chicago 5, Ill.  
\(\checkmark\) Maurice A. Knight, Kelly Ave., Akron, Ohio  
March 4, 1946

Mr. Clayton H. Hudson

Gentlemen;

We have at hand your letter of Jan 24, 1946 and note with interest your problem in the handling of hydrochloric and acetic acids at temperatures up to 200°F.

Flexible hard rubber is quite capable of doing a good job for you in this connection but we note that you are interested in pipe sizes which are below our usual procedure.

Inasmuch as we actually place a rubber tube 1/8" thick inside the steel pipe, you can readily appreciate that if we work with pipe much less than 1-1/2" in diameter, there isn't much room left for the liquid when you reduce the diameter at least 1/4".

Furthermore, our construction is such that nothing but flanged pipe can be used with the rubber tube coming out of the inside of the pipe and up over the flange face in order to make everything acid tight.

We are attaching herewith our sales folder on the general subject of Plioweld linings, so that you may see what we do for corrosion problems and if there is anything in the line of larger piping, fittings, valves and tanks, we would like very much to have the opportunity of quoting you on this problem.

Yours very truly,

Mgr-Tank Lining Sales
Mechanical Goods Division

N. E. Kimball
ghs
February 20, 1946

Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia

Attention: Mr. Clayton H. Hudson

Gentlemen:

We wish to acknowledge and thank you for your inquiry of January 24th, regarding corrosion in heat exchangers.

We have investigated this inquiry and find that we are not in a position at the present time to quote on the items mentioned. We expect to be in a position to supply these fittings in the near future, and if you are still interested at that time, should be pleased to quote.

Very truly yours,

GOODALL RUBBER COMPANY

W. J. Toshk Office Manager
January 29, 1946

Virginia Polytechnic Institute
Dept. of Chemical Engineering
Blacksburg, Virginia

Attention: Mr. Clayton H. Hudson

Gentlemen:

Thank you for your letter of January 24th.

Unfortunately, none of our standard products will meet the specifications set forth and, therefore, we regret that we cannot submit a proposal at this time.

Nevertheless, your courtesy in calling upon us is appreciated.

Yours very truly,

THE U. S. STONEWARE COMPANY

W. B. Carroll
Process Equipment Division

WBC: bk
Enclosure
Dear Mr. Hudson:

Your letter of January 24th has been referred to me but I am afraid that I am not going to be very helpful.

Referring first to Item 4 in your list, the Venturi meter, that is a piece of equipment which we do not make and which we cannot supply.

Referring to the other items, rubber lined valves, pipe and fittings are not available in sizes below 2 inches. So you are probably faced with the necessity of using metal or ceramic materials. The temperature of 200°F is probably too high for such materials as Saran and hard rubber which might be available in the smaller sizes. Presumably your installation can use plastic, glass, stoneware or porcelain if the thermal shocks are not too severe and where rapid heat transfer is not an absolute requirement. Again, however, we do not make these materials and cannot supply them.

Since you have failed to include any information about the acid concentrations which you propose to use, I cannot make any definite recommendations, but since hydrochloric acid will be one of the acids going through this heat exchanger there does not appear to be much choice among metallic materials. As far as I know, the hastelloys are the only commonly available alloys which possess anything like good resistance to hydrochloric acid. I suggest, therefore, that you write to the Haynes Stellite Company of Kokomo, giving them the quantities you will require in the various sizes and specifying acid concentrations and temperatures. With that information they should be able to determine which of their alloys to use and to indicate a suitable source of supply for the meter and other items which they do not make themselves.

Yours very truly,

CRANE CO.

L.G. Vande Bogart, Research Engineer
\textbf{High Nickel Bronze}  

- Number: 1
- Location: 62 mi
- Grade: 30
- Size: 5

\textbf{Monel Metal}  

- Number: 2

\textbf{Fluximite}  

- Number: 3
- Location: 14.5 mi
- Grade: 3
- Size: 2.50
- Size: 82.5% Fe

\textbf{Retacon A}
Virginia Polytechnic Institute
Blacksburg, Virginia

Attn: Mr. Clayton H. Hudson

Gentlemen:

We have your letter of January 24th in which you advise that you are working on a research problem concerning corrosion heat exchangers in which hydrochloric acid and acetic acid will be used as corrosive mediums at temperatures up to 200°F. We do not manufacture rubber-lined equipment nor do we handle bronze items unless they are in connection with some of our unit heat exchangers.

We are pleased to enclose a copy of our Drawing No. 3197 showing the type of heat exchangers that we have recently developed. This unit is built of stoneware with an interior tube of Pyrex glass or Karbate or copper or any other type of tubing material. The cooling water passes through the annular space between the steel pipe and the Pyrex or Karbate or similar heat transfer tube. The liquid to be cooled travels in the annular space between the stoneware pipe and the Pyrex, Karbate or other type of cooling pipe. This type of installation has the advantages usually found in small units compared to two bundles. If one tube in the tube bundle goes bad, the whole bundle is bad and one tube cannot be replaced without taking the whole unit apart, whereas in our unit heat exchangers, the tube can be replaced from the exterior in any unit or any unit can be by-passed and the remainder of the system operated while the defective unit is being repaired. Replacement of the tube, if necessary, is a matter of minutes instead of hours or days as would be the case with a bundle operating in a tube and shell system.

For the purpose of cooling or heating muriatic or acetic acid, we would recommend units similar to our Drawing No. 3197 except that the heat transfer tube would be of Karbate. The tube would be 2" bore, 2-5/8" O.D. x 6' long. The surface area for heat transfer would be 3.6 square feet per unit and the rate of heat transfer through Karbate would be between 150 and 600 B.T.U.'s per square foot per degree Fahrenheit depending somewhat on the velocity of the cooling water and also on the velocity of the hot acid. We are pleased to quote $100.00 each for these units f.o.b. our plant.
1. QUOTATIONS: All prices quoted shall be for immediate acceptance only, and are subject to change without notice. Stock pieces are offered subject to prior sale.

2. TERMS: Unless otherwise expressly agreed, all shipments are made strictly F.O.B. Akron, Ohio, transportation charges collect. Invoices shall be dated on the day of shipment and are due and payable Net Cash.

3. C.O.D.: In cases where credit relations have not been established, prepayment will be required or C.O.D. shipment will be made.

4. DELIVERY: Delivery upon all orders and contracts accepted by us shall be contingent upon strikes, fires, accidents, delays of carriers and all other causes unavoidable or beyond our control.

5. BREAKAGE: We do not assume responsibility for loss, damage or breakage in transit. Carriers are responsible for goods lost or damaged in transit; therefore, as required in Rule 3 of Uniform Bill of Lading, in case of loss or damage en route, consignee must immediately notify the railroad agent at destination, in writing, in order to substantiate formal claim when presented.

6. CANCELLATION: After acceptance by us, orders cannot be cancelled except with our consent and upon terms that will indemnify us against loss. Requests for cancellation of orders calling for special equipment, or equipment of standard design made up to order, will not be considered if the manufacture of the material has been commenced when such request is received.

7. REPLACEMENT: Every piece of apparatus of our manufacture is carefully inspected and tested before shipment, but as it is impossible to always detect imperfections, the only guarantee that is given by us is to replace such goods as prove defective or allow credit for such goods at our option.

8. LIABILITY: Under no circumstances are we responsible for any damages beyond the price of the goods. If our goods appear defective, discontinue their use and notify us promptly so the matter may be investigated without delay. No charge for labor or expense required to repair defective goods or occasioned by them will be allowed. If the goods are defective, the measure of damages is the price of the defective pieces.

9. CORRECTIONS: In all cases clerical errors are subject to correction.

10. TAX: The amount of any sales, processing, or other tax, federal or state, now in effect or hereafter imposed, which the manufacturer (seller) is or shall become obligated to pay, either on his own behalf or on behalf of the purchaser, or otherwise, with respect to the material covered by this quotation (order) (contract) and any increase in the manufacturer’s (seller’s) cost attributable to compliance with any code; agreement; or license approved, shall (unless such prices are expressly stated to be inclusive of such tax or increased costs) be added to the prices contained herein and paid by the purchaser in the same manner and with the same effects as if originally added hereto.
MAURICE A. KNIGHT

TO Virginia Polytechnic
DATE January 26, 1946

Under separate cover we are sending you our PYROFLEX Construction Catalog together with some general literature on KNIGHT-WARE Plant Equipment, Acid Proof Cement and BERL Saddles.

We would be very happy to cooperate with you in any way possible in connection with this research work.

Very truly yours,

MAURICE A. KNIGHT COMPANY

C. A. Rauh, Manager
PYROFLEX Department

CAR/cm1
This job is pending. You may expect our order on date
This job has been delayed until. Job placed elsewhere?
Reason

Without obligation to us please send your representative to discuss.

Remarks:

January 26, 1946

By

Virginia Polytechnic Institute
 Blacksburg, Virginia

Attn: Mr. Clayton H. Hudson

Gentlemen:

We have your letter of January 24th in which you advise that you are working on a research problem concerning corrosion heat exchangers in which hydrochloric acid and acetic acid will be used as corrosive mediums at temperatures up to 200°F. We do not manufacture rubber-lined equipment nor do we handle bronze items unless they are in connection with some of our unit heat exchangers.

We are pleased to enclose a copy of our Drawing No. 3197 showing the type of heat exchangers that we have recently developed. This unit is built of stoneware with an interior tube of Pyrex glass or Kurbate or copper or any other type of tubing material. The cooling water passes through the annular space between the steel pipe and the Pyrex or Kurbate or similar heat transfer tube. The liquid to be cooled travels in the annular space between the stoneware pipe and the Pyrex, Kurbate or other type of cooling pipe. This type of installation has the advantages usually found in small units compared to bundles. If one tube in the tube bundle goes bad, the whole bundle is bad and one tube cannot be replaced without taking the whole unit apart; whereas in our unit heat exchangers, the tube can be replaced from the exterior in any unit or any unit can be by-passed and the remainder of the system operated while the defective unit is being repaired. Replacement of the tube, if necessary, is a matter of minutes instead of hours or days as would be the case with a bundle operating in a tube and shell system.

For the purpose of cooling or heating muriatic or acetic acid, we would recommend units similar to our Drawing No. 3197 except that the heat transfer tube would be of Kurbate. The tube would be 2\" bore, 2-5/8\" O.D. x 6\' long. The surface area for heat transfer would be 3,6 square feet per unit and the rate of heat transfer through Kurbate would be between 150 and 600 B.T.U.'s per square foot per degree Fahrenheit depending somewhat on the velocity of the cooling water and also on the velocity of the hot acid. We are pleased to quote \$100.00 each for these units f.o.b. our plant.
Virginia Polytechnic

January 26, 1946

Under separate cover we are sending you our PYROFLEX Construction Catalog together with some general literature on KNIGHT-WARE Plant Equipment, Acid Proof Cement and BERL Saddles.

We would be very happy to cooperate with you in any way possible in connection with this research work.

Very truly yours,

MAURICE A. KNIGHT COMPANY

C. A. Rauh, Manager
PYROFLEX Department
January 29, 1946

Virginia Polytechnic Institute  
Department of Chemical Engineering  
Blacksburg, Virginia  

Attention: Mr. Clayton H. Hudson  

Gentlemen:  

In reference to your letter of January 24, we are pleased to furnish some information regarding piping for hydrochloric acid and acetic acid.  

Rubber lined piping is usually not obtainable in the 1" or smaller size piping. May we suggest that you consider the use of glass? Corning Glass Works at Corning, New York supplies standard glass pipe and fittings 1" and larger in size while Fischer and Porter at Hatboro, Pennsylvania, supplies these items in 1/4" to 3/4" sizes.  

Very truly yours,  

STRUTHERS WELLS CORPORATION  

C. Prichard  
Process Equipment Department  

CP/im
TO: Virginia Polytechnic Institute  
Department of Chemical Engineering  
Blacksburg, Virginia  

Attention: Mr. C. H. Hudson  

Gentlemen:  

Answering your inquiry of Feb. 20, we take pleasure in quoting you as follows:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Hastelloy Alloy</th>
<th>DESCRIPTION</th>
<th>Estimated Wt.</th>
<th>Price</th>
<th>Extra</th>
</tr>
</thead>
<tbody>
<tr>
<td>less than 10 Lbs.</td>
<td>B</td>
<td>3/4&quot; pipe - extra heavy cast</td>
<td></td>
<td>$4.40 per ft.</td>
<td></td>
</tr>
<tr>
<td>less than 30 ft.</td>
<td>B</td>
<td>3/4&quot; tubing 16 Ga.</td>
<td></td>
<td>2.20</td>
<td></td>
</tr>
<tr>
<td>less than 30 ft.</td>
<td>B</td>
<td>3/4&quot; tubing 12 Ga.</td>
<td></td>
<td>3.14</td>
<td></td>
</tr>
<tr>
<td>1 B</td>
<td></td>
<td>3/4&quot; Union</td>
<td></td>
<td>18.65 Ea.</td>
<td></td>
</tr>
<tr>
<td>1 B</td>
<td></td>
<td>3/4&quot; - 90° Elbow - threaded</td>
<td></td>
<td>4.40</td>
<td></td>
</tr>
<tr>
<td>1 B</td>
<td></td>
<td>3/4&quot; Tee - threaded</td>
<td></td>
<td>6.25</td>
<td></td>
</tr>
<tr>
<td>1 B</td>
<td></td>
<td>3/4&quot; Coupling - threaded</td>
<td></td>
<td>4.15</td>
<td></td>
</tr>
<tr>
<td>1 B</td>
<td></td>
<td>3/4&quot; Nipple 6&quot; long E.H. cast</td>
<td></td>
<td>4.80</td>
<td></td>
</tr>
</tbody>
</table>

Delivery promises are made in good faith, but are subject to delays resulting from conditions beyond our control. All quotations are subject to change without notice. Sales tax, if any, in effect at date of invoice to be added to above prices.

Very truly yours,

HAYNES STELLITE COMPANY
February 20, 1946

Haynes Stellite Company
Kokomo, Indiana

Gentlemen:

Please refer to my letter of February 13, 1946, which requested price quotations and time required for delivery of 1/4" and 1/2" Hastelloy Alloy B pipe, fittings and valves.

Request that you also furnish information on 3/4" Hastelloy Alloy B pipe, fittings and valves.

Very truly yours,

Clayton H. Hudson
TO: Virginia Polytechnic Institute  
Department of Chemical Engineering  
Blacksburg, Va.

HAYNES STELLITE COMPANY  
Unit of Union Carbide and Carbon Corporation  
KOKOMO, INDIANA

Date: Feb. 19, 1946
Terms: ½ of 1% 10 days  
Net 30 days  
F. O. B. Kokomo, Indiana  
Delivery 6 to 8 weeks

Gentlemen:

Answering your inquiry of 2/13/45, we take pleasure in quoting you as follows:

<table>
<thead>
<tr>
<th>Quality</th>
<th>Hastelloy</th>
<th>DESCRIPTION</th>
<th>Estimated Wt.</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 100 lbs.</td>
<td>B</td>
<td>1/2&quot; pipe - extra heavy cast</td>
<td>$3.60 ft.</td>
<td></td>
</tr>
<tr>
<td>Less than 50 ft.</td>
<td>B</td>
<td>1/2&quot; 16 Ga. tubing</td>
<td>1.60 ft.</td>
<td></td>
</tr>
<tr>
<td>Less than 50 ft.</td>
<td>B</td>
<td>1/2&quot; 12 Ga. tubing</td>
<td>2.38 ft.</td>
<td></td>
</tr>
<tr>
<td>Less than 100 lbs.</td>
<td>B</td>
<td>1/4&quot; pipe - extra heavy cast</td>
<td>2.25 ft.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>1/2&quot; union</td>
<td>15.60 lbs.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>1/2&quot; 90° elbow - threaded</td>
<td>3.80 ft.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>1/2&quot; tee - threaded</td>
<td>5.25 ft.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>1/2&quot; coupling threaded</td>
<td>3.75 ft.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>1/2&quot; - 1/4&quot; reducing coupling threaded</td>
<td>3.75 ft.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>1/2&quot; nipple 6&quot; long E.H. cast</td>
<td>4.10 ft.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>1-1/2&quot; coupling threaded</td>
<td>11.00 ft.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>1-1/2&quot; - 1&quot; Reducing coupling threaded</td>
<td>11.00 ft.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>1&quot; - 3/4&quot; reducing coupling threaded</td>
<td>5.00 ft.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>3/4&quot; - 1/2&quot; Reducing coupling threaded</td>
<td>4.15 ft.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>1/4&quot; nipple 6&quot; long E.H. cast</td>
<td>3.15 ft.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>1/4&quot; 90° elbow threaded</td>
<td>3.25 ft.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>1/4&quot; Union</td>
<td>13.50 ft.</td>
<td></td>
</tr>
</tbody>
</table>

Note: We do not manufacture the gate, globe, and needle valves, for which you requested quotation. We refer you to Crane Company and The William Powell Company for these items.

Delivery promises are made in good faith, but are subject to delays resulting from conditions beyond our control. All quotations are subject to change without notice. Sales tax, if any, in effect at date of invoice to be added to above prices.

Very truly yours,

HAYNES STELLITE COMPANY
February 13, 1946

Haynes Stellite Company
Kokomo, Indiana

Gentlemen:

Please forward price quotations and time required for delivery of the following listed items:

1. Hastelloy Alloy B, 1/2" pipe
2. Hastelloy Alloy B, 1/4" pipe
3. Hastelloy Alloy B valves:
   a. Gate valves, 1/2"
   b. Globe valves, 1/2"
   c. Needle valves, 1/2"
4. Hastelloy Alloy B fittings:
   1/2"
   a. Unions
   b. 90° Elbows
   c. Tees
   d. Couplings
   e. Reducer, 1 1/2 x 1/2
   f. Reducer, 1 1/2 x 1/2
   g. Nipples, 1/4"
   h. 90° Elbows, 1 1/2"
   i. Unions, 1 1/2"

Your cooperation in furnishing the above information will be greatly appreciated.

Very truly yours,

Clayton H. Hudson

hh/
January 18, 1946

Virginia Polytechnic Institute
Blacksburg, Va.

Gentlemen: Att. Mr. Clayton H. Hudson

We have your letter of January 15 in reference to material for the handling of hydrochloric and acetic acid at 200° F.

We regret to advise that we do not recommend hard rubber for the handling of solution at this heat.

We do make a special stock which will withstand up to 180° F.

We are sending you under separate cover, marked to your attention, a copy of our catalog describing hard rubber for the Chemical Process Industries and enclose price list covering same. We allow some discounts from this sheet, depending upon whether stocks are standard or special and the quantities involved.

We would be very glad to quote on your specific requirements. We do not manufacture venturi meters.

All prices are f.o.b. Trenton, New Jersey, terms 1½ 10, net 30 days.

Yours very truly,

THE LUZERNE RUBBER COMPANY
## THE LUZERNE RUBBER CO. TRENTON N.J.

**LIST PRICES - CHEMICAL EQUIPMENT.**

**STANDARD THREADED PIPE AND FITTINGS.**

<table>
<thead>
<tr>
<th>Nominal Size</th>
<th>1/4</th>
<th>3/8</th>
<th>1/2</th>
<th>3/4</th>
<th>1</th>
<th>1 1/4</th>
<th>2</th>
<th>2 1/2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe</td>
<td>1/4</td>
<td>3/8</td>
<td>1/2</td>
<td>3/4</td>
<td>1</td>
<td>1 1/4</td>
<td>2</td>
<td>2 1/2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Dimensions</td>
<td>1/4 x 1/2</td>
<td>3/8 x 1/2</td>
<td>1/2 x 1/2</td>
<td>3/4 x 1/2</td>
<td>1 x 1/2</td>
<td>1 1/4 x 1 1/4</td>
<td>2 x 2</td>
<td>2 1/2 x 2 1/2</td>
<td>3 x 3</td>
<td>4 x 4</td>
</tr>
<tr>
<td>Pipe Flow No Thds.</td>
<td>.25</td>
<td>.32</td>
<td>.35</td>
<td>.47</td>
<td>.63</td>
<td>.95</td>
<td>1.17</td>
<td>1.65</td>
<td>2.22</td>
<td>3.15</td>
</tr>
<tr>
<td>Threaded Nipples 3&quot; or Less</td>
<td>.40</td>
<td>.47</td>
<td>.52</td>
<td>.70</td>
<td>.80</td>
<td>1.00</td>
<td>1.00</td>
<td>1.50</td>
<td>1.50</td>
<td>1.50</td>
</tr>
<tr>
<td>&quot; 4&quot; Long</td>
<td>.46</td>
<td>.48</td>
<td>.56</td>
<td>.78</td>
<td>.88</td>
<td>1.14</td>
<td>1.38</td>
<td>1.76</td>
<td>2.34</td>
<td>3.00</td>
</tr>
<tr>
<td>&quot; 6&quot; Long</td>
<td>.55</td>
<td>.58</td>
<td>.65</td>
<td>.94</td>
<td>1.10</td>
<td>1.44</td>
<td>1.77</td>
<td>2.28</td>
<td>3.02</td>
<td>4.04</td>
</tr>
<tr>
<td>&quot; 7&quot; to 12&quot;</td>
<td>.55</td>
<td>.62</td>
<td>.65</td>
<td>.97</td>
<td>1.13</td>
<td>1.45</td>
<td>1.77</td>
<td>2.35</td>
<td>3.02</td>
<td>4.05</td>
</tr>
<tr>
<td>Tees</td>
<td>1.17</td>
<td>1.65</td>
<td>1.75</td>
<td>2.00</td>
<td>2.25</td>
<td>2.60</td>
<td>2.95</td>
<td>4.10</td>
<td>5.25</td>
<td>7.60</td>
</tr>
<tr>
<td>Eells - 90°</td>
<td>.95</td>
<td>1.05</td>
<td>1.30</td>
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<td>1.75</td>
<td>2.10</td>
<td>2.45</td>
<td>3.30</td>
<td>4.00</td>
<td>5.30</td>
</tr>
<tr>
<td>Eells - 45°</td>
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<td>.95</td>
<td>1.20</td>
<td>1.40</td>
<td>1.65</td>
<td>2.00</td>
<td>2.35</td>
<td>3.05</td>
<td>3.75</td>
<td>4.70</td>
</tr>
<tr>
<td>Plug Cocks</td>
<td>2.50</td>
<td>3.50</td>
<td>3.75</td>
<td>4.70</td>
<td>5.85</td>
<td>7.50</td>
<td>9.35</td>
<td>12.85</td>
<td>16.40</td>
<td>19.90</td>
</tr>
<tr>
<td>St'Way Cocks</td>
<td>3.00</td>
<td>3.15</td>
<td>4.70</td>
<td>5.85</td>
<td>10.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screwed Unions</td>
<td>2.95</td>
<td>2.95</td>
<td>3.05</td>
<td>3.75</td>
<td>4.45</td>
<td>5.05</td>
<td>5.85</td>
<td>7.00</td>
<td>9.35</td>
<td>11.70</td>
</tr>
<tr>
<td>Crosses</td>
<td>.80</td>
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<td>1.55</td>
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<td>3.65</td>
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<td>18.75</td>
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<td>Pet Cocks Male Pipe Thd. 1-End</td>
<td>1.75</td>
<td>1.75</td>
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<td>&quot; Hose Conn. 1-End</td>
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<td>Return Bends</td>
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<td>3.25</td>
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<tr>
<td>Threading Pipe Fem</td>
<td>.15</td>
<td>.15</td>
<td>.15</td>
<td>.25</td>
<td>.25</td>
<td>.25</td>
<td>.30</td>
<td>.35</td>
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</tbody>
</table>

Reducing Fittings - Use price for largest size indicated and add 1-Reducing Bushing of this size for each reduction.

Reducing and Blind Flanges - Add 25% to price of flange of same diameter.

**PUMPS**

<table>
<thead>
<tr>
<th>Type A</th>
<th>Heavy Duty - Belt or Motor Driven - Roller Bearings - Open Impeller - Less Motor</th>
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</thead>
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<tr>
<td></td>
<td>$250.00 NET</td>
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<tr>
<td>Type B</td>
<td>Light Duty - Motor Driven Only - Ball Bearings - Closed Impeller - Less Motor</td>
</tr>
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<td></td>
<td>$250.00 NET</td>
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</tbody>
</table>

Rubber Covering Base and Bearing Stand - either pump

Price for Motor Assembled on Pump depends on current characteristics.

5' Gallon Bottle - with lid - $10.00 each NET.
January 15, 1946

Luzerne Rubber Company
11 So. Des Plaines St.
Chicago, Illinois

Gentlemen:

I am working on a research problem concerning corrosion in heat exchangers. Hydrochloric acid and acetic acid will be used as corrosive mediums at temperatures up to 200° F.

Please forward information regarding available sizes and price quotations on the following hard-rubber items:

1. Pipe, 1/4" to 1"
2. Fittings, 1/4" to 1"
3. Valves, 1/4" to 1"
4. Pumps, small
5. Venturi meter, 1/2"

Your cooperation in furnishing the above information will be greatly appreciated.

Very truly yours,

Chayton H. Hudson

cc to: Luzerne Rubber Co.
Trenton, N. J.

and

The B. F. Goodrich Company
Akron, Ohio
February 18, 1946

Virginia Polytechnic Institute
Dept. of Chemical Engineering
Blacksburgh, Virginia

Att: Clayton H. Hudson

Gentlemen:

Please refer to your letter of February 13, 1946.

We are producers of magnesium base alloys in ingot form only and cannot supply tubing; nor do we have molds to produce billets.

Should White Metal Rolling and Stamping Corporation be unable to produce the alloys you require in their own melting department, it may be possible that The Dow Chemical Company, The American Magnesium Corporation, or Revere Copper and Brass could assist you.

Very truly yours

THE NATIONAL SMELTING COMPANY

R. L. Crist

HLC: 1z
Virginia Polytechnic Institute  
Department of Chemical Engineering  
Blacksburg, Virginia

Attention: Mr. Clayton H. Hudson

Gentlemen:

At present, due to market conditions, our schedule on Admiralty metal in the standard pipe size is closed. However, we do make this pipe in the condenser tube sizes. I have listed below two sizes, one of which would come closest to the O.D. and the other closest to the I.D. of the 1/2" pipe size that you ordered:

<table>
<thead>
<tr>
<th>O.D.</th>
<th>I.D.</th>
<th>Gauge</th>
</tr>
</thead>
<tbody>
<tr>
<td>.875&quot;</td>
<td>.709&quot;</td>
<td>.083&quot;</td>
</tr>
<tr>
<td>.750&quot;</td>
<td>.620&quot;</td>
<td>.065&quot;</td>
</tr>
</tbody>
</table>

The composition of our Admiralty Metal is as follows:

- Copper 70 - 72%
- Lead .075% Max.
- Iron .06% Max.
- Tin .90 - 1.20%
- Arsenic .02 - .05%
- Zinc Balance

The physical properties of this metal are as follows:

- Density 308 pounds per cubic inch
- Young's Modulus of Elasticity 15,000,000 p.s.i.
- Melting Point 1715° F.
- Coefficient of Thermal Expansion .0000112 per degree @ 68° F.
- Tensile Strength 50,000 p.s.i. Soft
- Elongation Percent in 2" 55 Soft
- Rockwell Hardness B-20 Soft

- continued -
I hope this information is sufficient and if you are interested in the above sizes we would be glad to forward price quotation upon receipt of your request.

Very truly yours,

REVERE COPPER AND BRASS INCORPORATED

J. A. Rhodes
Technical Advisory Service
Baltimore Division

JAR:CK
Virginia Polytechnic Institute  
Department of Chemical Engineering  
Blacksburg, Virginia

Attention: Mr. Clayton H. Hudson

Gentlemen:

This is to thank you for your letter of February 22 in which you request price and delivery on bronze fittings and valves. We do not handle this line of merchandise at the present time and it is unknown when we will again make this item available to our customers.

We manufacture magnesium tubing in M and FS-1 alloys and would not be interested in making magnesium tubing in any other alloy.

It is regretted that we are unable to help you in this instance and we wish to thank you for keeping us in mind when you have requirements of copper and brass, aluminum and magnesium.

Very truly yours,

REVERE COPPER AND BRASS INCORPORATED

Franklin F. Younger - Sales Department  
Magnesium-Aluminum Division Products

FFY:EAF
Revere Copper & Brass, Inc.
230 Park Avenue
New York 17, New York

Gentlemen:

Please forward price quotations and time required for delivery of the following listed items:

- 3/4" Bronze Unions
- 3/4" Bronze Elbows 90°
- 3/4" Bronze Tees
- 3/4" Bronze Crosses
- 3/4" x Short Bronze Nipples
- 3/4" x 3" Bronze Nipples
- 3/4" Bronze Couplings
- 1" x 1/2" Bronze Couplings
- 1 1/2" x 1" Bronze Reducers
- 1" x 3/4" Bronze Reducers
- 3/4" Bronze Gate Valves
- 3/4" Bronze Globe Valves
- 3/4" Bronze Needle Valves

The above listed items would be required in very small quantities for use in research work.

I am also interested in knowing if your company will produce special magnesium alloy tubing if specifications are given.

Your cooperation in furnishing the above information will be greatly appreciated.

Very truly yours,

Clayton H. Hudson
Schutte & Koerting Company
12th and Thompson Streets
Philadelphia 22, Pa.

Gentlemen:

This is in answer to your letter of March 21. I have found that it will be possible to use an orifice and manometer to measure the required flow of liquids and have therefore decided not to purchase a rotameter at this time.

Thank you for your interest in the problem.

Very truly yours,

Clayton H. Hudson
March 21, 1946

Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia

Attention: Mr. Clayton H. Hudson

Gentlemen:

On February 27 we wrote you as shown on the attached copy of our letter.

Is there some additional information that you desire regarding the problem outlined in our letter? Please be assured of our desire to help you in your Rotameter problem.

Yours very truly,

SCHUTTE & KOERTING COMPANY

H. W. Gripton
Manager, Meter Department

HWG: dif
Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia

Attention: Mr. Clayton H. Hudson

Gentlemen:

Thank you for your interesting letter of February 20 regarding the corrosion experiments which you propose to set up in your laboratory.

It occurs to us that we should inquire regarding the material from which the Rotameter should be made. Naturally, if you expect to have corrosive conditions which will attack Hastelloy B then certainly the Rotameter should be made of something superior to this material. Otherwise, there would be no Rotameter left when the experiments were completed and the results would continue to be erroneous because of corrosion taking place, especially around the metering rotor.

We therefore suggest that the Fig. 1827 Rotameter be used for these experiments. First, because it can be made with principal parts of hard rubber and glass, and secondly because it is low in cost. This Rotameter is illustrated on page 13 of the enclosed bulletin 18-27. Our quotation on this Rotameter is enclosed. We shall be very glad to receive your order and cooperate with you on this experiment.

Yours very truly,

SCHUTTE & KOERTING COMPANY

H. W. Gripton
Manager, Meter Department
Virginia Polytechnic Institute
Dept. of Chemical Engineering
Blacksburg, Virginia

February 27, 1946

Attn: Mr. Clayton H. Hudson

1. #6LA 1" slip joint rubber tube connections
   Fig. 1327-R 8&K Rotameter having rotor stops made of hard rubber and rotor of
   hard rubber but weighted to give
   maximum capacity of 7 gpm of liquid
   specific gravity 1.0. Millimeter scale
to be etched on glass tube and calibrat-
   ion chart supplied.

NET PRICE EACH FOR PHILADELPHIA
INCLUDING SPECIAL EDUCATIONAL DISCOUNT
TO V. P. I. ........................................ $37.79
Virginia Polytechnic Institute  
Department of Chemical Engineering  
Blacksburg, Virginia

Attention: Mr. Clayton H. Hudson

Gentlemen:

Thank you for your interesting letter of February 20 regarding the corrosion experiments which you propose to set up in your laboratory.

It occurs to us that we should inquire regarding the material from which the Rotameter should be made. Naturally, if you expect to have corrosive conditions which will attack Hastelloy B then certainly the Rotameter should be made of something superior to this material. Otherwise, there would be no Rotameter left when the experiments were completed and the results would continue to be erroneous because of corrosion taking place, especially around the metering rotor.

We therefore suggest that the Fig. 1827 Rotameter be used for these experiments. First, because it can be made with principal parts of hard rubber and glass, and secondly because it is low in cost. This Rotameter is illustrated on page 18 of the enclosed bulletin 18-R. Our quotation on this Rotameter is enclosed. We shall be very glad to receive your order and cooperate with you on this experiment.

Yours very truly,

SCHUTTE & KOERTING COMPANY

H. W. Gripton
Manager, Meter Department

HWG: dif
Virginia Polytechnic Institute  
Dept. of Chemical Engineering  
Blacksburg, Virginia  
Att: Mr. Clayton H. Hudson

Dear Sirs: Referring to yours of ___________ we quote as follows:

<table>
<thead>
<tr>
<th>QUANTITY</th>
<th>SIZE</th>
<th>ARTICLE</th>
<th>LIST EACH</th>
<th>DISCOUNT</th>
<th>NET PRICE EACH</th>
<th>TOTAL</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>#6LA</td>
<td>1&quot; slip joint rubber tube connections Fig. 1827-R S&amp;K Rotameter having rotor stops made of hard rubber and rotor of hard rubber but weighted to give maximum capacity of 7 gpm of liquid specific gravity 1.0. Millimeter scale to be etched on glass tube and calibration chart supplied.</td>
<td></td>
<td></td>
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<td>$37.79</td>
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NET PRICE EACH FOB PHILADELPHIA
INCLUDING SPECIAL EDUCATIONAL DISCOUNT TO V. P. I.

PLEASE NOTE THAT ANY FEDERAL SALES TAX IMPOSED BY THE U. S. GOVERNMENT OR STATE SALES TAX SHALL BE ADDED TO THE PRICES QUOTED HEREIN

Yours Respectfully

SCHUTTE & KOERTING CO.

PER__.  

SEE REVERSE SIDE FOR "TERMS OF SALE"
Virginia Polytechnic Institute  
Department of Chemical Engineering  
Blacksburg, Virginia

Attention: Mr. Clayton H. Hudson

Gentlemen:

Thank you very much for your letter of 20 February in which you requested information regarding a Rotameter for measuring the rate of flow of 10% hydrochloric and acetic acids.

There are several different types of instruments which we could offer you for this service as Fischer & Porter Rotameters are ideally suited for handling such highly corrosive liquids as you encounter.

You will find our quotation enclosed covering our Figure 28 all-glass Rotameter. This instrument will be complete with Corning type flanges and cast iron back-up flanges and will be similar to illustrations #7 and #8 on page 3205 of catalog section 32-E. A float of Hastelloy "B" will be provided and it is believed that this combination of materials will give you an instrument which will give you long, trouble-free service.

In case this Rotameter is to be installed in a location where an unprotected all-glass meter would not be suitable, we have shown a price for the meter with porcelain end fittings similar to that illustrated on the face of catalog section 32-E. Both of these instruments would have the same range and would be equipped with our "Bead-Guide" metering tube. In this construction, the tube has three glass ribs which extend its length to guide the float throughout its travel and eliminate the necessity of any guide wire. This construction of tube is illustrated on the back page of bulletin 45-A.

A kit consisting of three Rotameters which comprise a very wide range set of instruments has been developed particularly for the benefit of laboratory users to take care of the many varied flow rate measuring problems which you encounter. We are enclosing catalog section 33 which describes the two types of kits which we manufacture in considerable detail and includes...
capacities and prices. From the prices shown on this catalog section, you are entitled to a discount of 10% which we allow to educational institutions.

All prices quoted are for acceptance before 1 April 1946.

We are always anxious to assist you in working out your flow rate measuring problems and therefore request that you feel free to contact us at any time.

Yours very truly,

FISCHER & PORTER COMPANY

George D. Keller

Encls: Quotation
32-E, 33, 45-A
Data sheets

CC: Marvin C. Care
F&P Divisional Field Engineer
TO: Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia

DATE: 26 February 1946

ATTENTION: Mr. Clayton H. Hudson

REFERENCE:

PRODUCT & QUANTITY: One (1) - Size #6, 1" Figure 28 Fischer & Porter all
glass Rotameter

METERING INSTRUMENT:

Figure Number: 28
Meter Size: #6
Connection Size: 1"
Connection Type & Rating: Corning type flanges
Material of Fittings: Glass with cast iron backup flanges
Float Guide: Patented "Bea-Guide" Tube with three glass
ribs to guide and to center the float
Packing: None
Connections to Face: Inlet - vertical, outlet - vertical
Panel Mounting Fittings: None
Metering Tube: BGA25A exclusive F&P heavy-walled, precision bore,
tapered beaded Pyrex metering tube with 250 MM
Type of Scale & Units: Direct reading in GPM
Float Specification: BL-60 of Hastelloy "B"

FLUID SPECIFICATIONS:

Fluid: 10% Hydrochloric acid and acetic acid
clear
Color and Transparency: transparent
Specific Gravity: 1.05

Operating Density: 65.5
Operating Viscosity: Please specify when ordering
Operating Pressure: Maximum 125°F

FLOW RANGE:

Maximum Flow: 8.2 GPM
Minimum Flow: 0.4 GPM

Note: All gas volumes represent free gas
at 14.7 p.s.i. absolute and 70°F.

Remarks: Porcelain meter with Hastelloy "B" float as per illustration #1
in catalog section 32-E. Price - $111.74.

PRICE: $61.20 each net

TERMS: Net 30 days
F. O. B. Hatboro, Pa.
DELIVERY: 4 weeks

By ____________________________

George D. Keller
February 20, 1948

Schutte & Koerting Co.
1261 No. 13th St.
Philadelphia 22, Pa.

Gentlemen:

In connection with a corrosion research problem, it is necessary that I measure flow of corrosive liquids through 1/2" or 3/4" Hastelloy-B pipe. Ten percent hydrochloric and acetic acids at temperatures up to 125°F will be pumped through the pipe at a rate of 7 gallons per minute.

Can you furnish a standard rotameter or a throttle rotameter that can be used for this purpose? If so, please forward price quotations and time required for delivery of both the 1/2" and 3/4" connection sizes.

Your cooperation in furnishing the above information will be greatly appreciated.

Very truly yours,

Clayton H. Hudson

copies sent to: Cochrane Corporation
3135 N. 17th St.

Fischer & Porter Co.
Warminster Rd.
Hatboro, Pa.
February 18, 1946

Mr. Clayton H. Hudson  
Dept. of Chemical Engineering  
V. P. I.  
Blacksburg, Virginia

Dear Sir:

I am today in receipt of a letter from The William Powell Company, concerning Bronze valves for your Acid Service.

They advise that all of their Bronze valves are made from Bronze with the exception of some which are made from a very high zinc content Bronze, however they state that a Nickel Bronze composition disc and seat will prolong the life of the valves for your service. These valves are slightly higher in price than valves with a composition disc.

As to the fittings I have not developed a delivery as yet as our Norfolk stock is entirely depleted of Bronze Fittings. I have contacted the factory and will advise you concerning this delivery within the next few days.

Very truly yours,

TIDEWATER SUPPLY COMPANY, INC.

R. L. GAINES, Sales Dept.'t.
March 1, 1946

Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg
Virginia

Attention: Mr. Clayton H. Hudson

Gentlemen:

We wish to acknowledge receipt of your inquiry of February 22 regarding the material for use in 10% Hydrochloric and Acetic Acid Service.

We regret that we are unable to offer our products for this service since the Acids mentioned would severely attack the Brass Fittings and Valves we are in a position to furnish.

Yours very truly,

WALWORTH COMPANY

GWD:MMG
AAA

G. W. Dunn
Walworth Company, Inc.  
Eastern Division  
1st and 0 Streets  
South Boston, Mass.

Gentlemen:

I am working on a research problem involving the corrosion of heat exchanger tubes. It will be necessary to conduct a corrosive liquid from a storage tank to the heat exchanger and back to storage through some material which will not corrode and contaminate the liquid. Ten percent hydrochloric and acetic acid will be used at temperatures ranging from 70°F to 125°F. Can a copper-tin bronze alloy be used for this purpose? If so, I am interested in obtaining price quotations and time required for delivery of the following listed items:

- 3/4" Bronze Unions
- 3/4" Bronze Elbows 90°
- 3/4" Bronze Tees
- 3/4" Bronze Crosses
- 3/4" x Short Bronze Nipples
- 3/4" x 3" Bronze Nipples
- 3/4" Bronze Couplings

- 1 1/2" Bronze Couplings
- 1 1/2" x 1" Bronze Reducers
- 1" x 3/4" Bronze Reducers
- 3/4" Bronze Gate Valves
- 3/4" Bronze Globe Valves
- 3/4" Bronze Needle Valves

The above listed items would be required in very small quantities and your cooperation in expediting an order would be greatly appreciated.

If bronze cannot be used for the above stated purpose, do you manufacture valves and fittings of any other material that will be suitable? Please advise as to where I might obtain 3/4" bronze pipe.

Very truly yours,

Clayton H. Hudson

nh/
Virginia Polytechnic Institute  
Department of Chemical Engineering  
Blacksburg, Virginia

**Attention: Mr. Clayton H. Hudson**

Gentlemen:

In reply to your inquiry of February 4, we are pleased to quote you as follows:

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Net Price</th>
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<tbody>
<tr>
<td>1/2&quot; 200# Brass Octa Unions, Fig. 3477</td>
<td>$ .473</td>
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<tr>
<td>1/2&quot; Brass 90 deg. Ells, F.B.</td>
<td>$ .091</td>
</tr>
<tr>
<td>1/2&quot; x 1/4&quot; Brass Tees, F.B.</td>
<td>$ .17</td>
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<tr>
<td>1/2&quot; Brass Tees, F.B.</td>
<td>$ .14</td>
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<tr>
<td>1/2&quot; x short Brass Nipples (85% Copper)</td>
<td>$ .074</td>
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<tr>
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<td>$ .089</td>
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<tr>
<td>1/2&quot; x 6&quot; ditto</td>
<td>$ .207</td>
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<tr>
<td>1/2&quot; Brass Couplings, F.B.</td>
<td>$ .091</td>
</tr>
<tr>
<td>1/2&quot; Brass Crosses, F.B. with</td>
<td>$ .274</td>
</tr>
<tr>
<td>1/2&quot; x 1/4&quot; Brass Hex Bushings</td>
<td>$ .065</td>
</tr>
<tr>
<td>1/2&quot; x 1/4&quot; Brass Couplings, F.B.</td>
<td>$ .104</td>
</tr>
<tr>
<td>1/4&quot; 200# Brass Octa Unions, Fig. 3477</td>
<td>$ .368</td>
</tr>
<tr>
<td>1/8&quot; x short Brass Nipples (85% Copper)</td>
<td>$ .047</td>
</tr>
<tr>
<td>1/8&quot; x 2&quot; ditto</td>
<td>$ .056</td>
</tr>
<tr>
<td>1/8&quot; x 2-1/2&quot; ditto</td>
<td>$ .065</td>
</tr>
<tr>
<td>1/8&quot; x 3&quot; ditto</td>
<td>$ .074</td>
</tr>
<tr>
<td>1/8&quot; x 3-1/2&quot; ditto</td>
<td>$ .083</td>
</tr>
<tr>
<td>1/8&quot; x 4&quot; ditto</td>
<td>$ .092</td>
</tr>
<tr>
<td>1/8&quot; x 4-1/2&quot; ditto</td>
<td>$ .10</td>
</tr>
<tr>
<td>1/8&quot; x 5&quot; ditto</td>
<td>$ .109</td>
</tr>
<tr>
<td>1/8&quot; x 5-1/2&quot; ditto</td>
<td>$ .118</td>
</tr>
<tr>
<td>1/8&quot; x 6&quot; ditto</td>
<td>$ .127</td>
</tr>
<tr>
<td>1/8&quot; x 1/8&quot; Brass Couplings, F.B.</td>
<td>$ .078</td>
</tr>
<tr>
<td>1/2&quot; Fig. 4 Std. Brass Gate Valves</td>
<td>1.27</td>
</tr>
<tr>
<td>1/2&quot; Fig. 95 150# Brass Globe Valves</td>
<td>1.79</td>
</tr>
<tr>
<td>1/2&quot; Fig. 120 Brass Needle Point Globe Valves</td>
<td>1.41</td>
</tr>
</tbody>
</table>

This Quotation is subject to terms and conditions printed on reverse side of this sheet, and is subject to change without notice.
F. O. B. Factories with freight allowed on 500# or more of Fittings and 500# or more of Valves.

The five items we have checked are in stock, subject to prior sale, and can be shipped immediately upon resumption of plant operations.

In the absence of definite quantities, we can only offer approximate deliveries on an order covering nominal quantities and these would be as follows:

- Balance of Fittings
- $\text{1/2" Unions}$
- $\text{1/2" Gate Valves}$
- $\text{1/2" Globe Valves}$

We are unable to quote on the items of Brass Pipe you require since we do not manufacture.

The item of $\text{1/2" x 1/4" x 1/4" Brass Tees}$ is discontinued so we can only offer $\text{1/2" x 1/4" Brass Tees with 1/2" x 1/4" Brass Hex Bushings}$, and you will find prices for these in the schedule.

This will also apply to the item of $\text{1/2" x 1/2" x 1/4" x 1/4" Brass Crosses}$ since reducing Crosses are also discontinued.

Terms and conditions as per the attached apply.

Yours very truly,

WALWORTH COMPANY

GWD: MDG
ENC.

S/M. Dunn

AAA
Terms are 2% 10th and 25th of the month.

This quotation is effective for a period of 30 days from this date. If not accepted within this 30-day period, this quotation is cancelled.

Prices on all orders accepted by us are firm until the O.P.A. authorizes or orders a change in price or ceases to exist, at which time any un-shipped balances will take our prices in effect at time of shipment.

The delivery information given is based on conditions existing at the time this quotation was prepared, and is, of course, subject to immediate change.

To the prices and terms quoted there will be added any manufacturers or sales tax payable on the transaction under any effective statute.

Cancellation, suspension or deferring deliveries of merchandise called for under this quotation or order will not be accepted unless such cancellation or deferred delivery is authorized by us in writing.
February 4, 1946

Walworth Company, Inc.
810 - 16th Street, N. W.
Washington, D. C.

Gentlemen:

Please forward price quotations and time required for delivery of the following listed items:

1. Bronze pipe, rough finish, $\frac{3}{4}$
   2. Bronze pipe, rough finish, $\frac{1}{2}$
   3. Bronze fittings, Rough finish --

   $\frac{3}{4}$
   (1) Unions
   (2) Elbows, 90°
   (3) Reducing tees, $\frac{3}{4}$ to $\frac{1}{2}$, both runs
   (4) Tees
   (5) Short nipples
   (6) Long Nipples, $\frac{3}{8}$
   (7) Couplings
   (8) Reducing crosses, $\frac{3}{4} x \frac{1}{8} x \frac{3}{4} x \frac{1}{4}$
   (9) Reducing couplings, $\frac{3}{4} x \frac{1}{4}$

4. Bronze valves --

   (1) Gate valves, $\frac{3}{4}$
   (2) Globe valves, $\frac{3}{4}$
   (3) Needle valves, $\frac{3}{4}$

Your cooperation in furnishing the above information will be greatly appreciated.

Very truly yours,

Clayton H. Hudson
February 9, 1946
(Dist. 2/8/46)

Mr. Clayton H. Hudson
Virginia Polytechnic Institute
Dept. of Chemical Engineering
Blacksburg, Va.

Dear Mr. Hudson:

Your letter of January 29, 1946 has been referred to me and while we are glad to furnish you with the 1/2" O.D. x .050" wall tubing you request in Item 1, this would have to be in J5-1 as we do not produce J-1 in wall thicknesses under .081". The attached folder describes the difference.

We are not in position at the present time to undertake the manufacture of the special alloys which you request in Items 2, 3 and 4, but should you make arrangements to have billets of these alloys cast for us between 6-1/2" and 7-3/8" in diameter by 32" maximum length, we will be glad to extrude the tubing sizes which you need. Perhaps one of the magnesium foundries could cast these billets for you and they could be made sufficiently larger to allow for scalping the exterior surface.

Trusting that this will provide a solution to your problem and with every good wish.

Cordially,

C. Z. Larson
General Manager

encl. WHITE METAL ROLLING & STAMPING CORP.
January 29, 1946

White Metal Rolling & Stamping Corp.
60 Moultrie Street
Brooklyn 22, New York

Gentlemen:

Please forward price quotations and time required for delivery of the following listed items:

1. Whitelight Alloy, J-1
   Length ---- 6 ft.
   Outside Diam. ½ in.
   Wall Thickness 0.05 in.
   No. Required 6 each

2. Special Mg. Alloy, 2% Mn, 1% Te, Bal. Mg.
   Length -------- 6 ft.
   Outside Diam. --- ½ in.
   Wall Thickness -- 0.05 in.
   No. Required ---- 6 each

3. Special Mg. Alloy, 4% Al, 2% Cr, Bal. Mg.
   Length -------- 6 ft.
   Outside Diam. --- ½ in.
   Wall Thickness -- 0.05 in.
   No. Required ---- 12 each

4. Special Alloy (Same as No. 3 above)
   Length -------- 21 in.
   Outside Diam. --- 1½ in.
   Wall Thickness -- 0.109 in.
   No. Required ---- 22 each

It is desired that impurities be kept at an absolute minimum as the above tubing will be used in research work. Please refer to previous letter dated January 9, 1946.

Your cooperation in furnishing the above information will be greatly appreciated.

Very truly yours,

Clayton H. Hudson
January 23, 1946

Mr. Clayton H. Hudson
Virginia Polytechnic Institute
Department of Chemical Engineering
Blacksburg, Virginia

Dear Mr. Hudson:

Kindly refer to your letter dated January 9, 1946 in which you requested information regarding the use of magnesium alloys in heat exchangers and absorption towers. We are attaching a descriptive booklet of magnesium alloys, which will contain data on all points mentioned in your letter.

We are in a position to produce special magnesium alloy tubing if specification are given, and will be glad to quote on your requirements.

As for shapes that may be suitable absorption tower packing material, it is possible for us to extrude lengths of various shapes, which can be cut in short lengths and used for packing material. An excellent application along this line would be the use of short pieces of tubing as "Raschig Rings".

If we can be of any further assistance in your problem, please do not hesitate to get in touch with us.

Very truly yours,

WHITE METAL ROLLING & STAMPING CORP.

VL/eh
Enc.

A. Vernon Lorch
Chief Metallurgist
January 9, 1946

White Metal Rolling & Stamping Corp.
Moultrie, Colyer & Humboldt Streets
Brooklyn 22, New York

Gentlemen:

I am working on a research problem to determine the practicability of using magnesium-alloy tubing in heat exchangers. Heat transfer and corrosion resistance data are to be determined. At present, I have not definitely decided upon the magnesium-alloy that will be used. Information is needed concerning the composition of magnesium-alloy tubing available, sizes, purity, metal treatment, mechanical properties, corrosion-resistant properties, etc. I am also interested in knowing if your Company will produce special magnesium-alloy tubing if specifications are given.

Your letterhead lists special shapes of magnesium castings. Do you have any shapes that would be suitable for absorption tower packing material?

Your cooperation in furnishing the above information will be greatly appreciated.

Very truly yours,

Clayton H. Hudson