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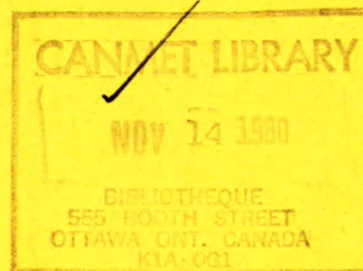
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## REPORT 80-11E

### MINERAL INSULATION – A CRITICAL STUDY

A.A. WINER and S.B. WANG



MINERALS RESEARCH PROGRAM

MINERAL SCIENCES LABORATORIES



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## MINERAL INSULATION - A CRITICAL STUDY

by

A.A. Winer\* and S.B. Wang\*

## ABSTRACT

Mineral insulation, a glass fibre product formed from melting mixtures of inorganic material, is a simple and economical component in energy conservation. Because of expected shortages in energy fuels and subsequent increases in costs, all economic sectors will be effected. The Canada Centre for Mineral and Energy Technology (CANMET) is involved in a project on mineral insulation. As part of this project, a critical study of the literature and field trips to industry have been made and discussions held with experts in insulation technology.

Composition of the inorganic mixture and temperature both influence glass structure, and structure in turn determines glass properties. Important parameters in fiberizing the glass are viscosity, temperature, surface tension and density. Phase equilibria diagrams are very useful in determining optimum composition and correct fiberizing temperature.

Most mineral producers in Canada use the cupola melting furnace and wheel spinning process but the electric furnace is becoming more popular because of its inherent advantages such as the ability to use a finer and therefore more homogeneous charge; it is also more easily controlled and inhibits environmental pollution. In electric melting, electrical conductivity is an important parameter and is related to the degree of ionization.

Tests are performed on mineral insulation products to satisfy standards established for applications in industry, building, and homes. Such standards are not all uniform across the country but may vary according to local requirements.

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\*Research scientists, Mineral Processing Laboratory, Mineral Sciences Laboratories, Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada, Ottawa.

## ISOLATION MINERALE - UNE CRITIQUE

par

A.A. Winer\* et S.B. Wang\*

## RESUME

Les produits isolants minéraux sont fabriqués à partir d'une fibre de verre obtenue en faisant fondre des mélanges de matériaux inorganiques. Ils constituent un élément simple et économique de conservation de l'énergie. La pénurie éventuelle des carburants et l'augmentation des coûts qui en résultera auront un effet sur la plupart des secteurs économiques. Le Centre canadien de la technologie des minéraux et de l'énergie (CANMET) est impliquée dans un projet sur l'isolation minérale. En conséquence, une critique sur la documentation et des visites en industrie ont été effectuées et des discussions en été entamées avec des spécialistes de la technologie de l'isolation. La composition du mélange inorganique et la température influencent la structure du verre et c'est cette structure qui détermine les propriétés du verre. Les paramètres importants pour la mise en fibre du verre sont la viscosité, la température, la tension superficielle et la densité. Les diagrammes d'équilibre de phase sont très utiles pour déterminer la composition optimale et la température adéquate de formation des fibres.

La plupart des producteurs de minéraux au Canada utilisent le cubilot et le procédé de centrifugation mais le four électrique devient de plus en plus populaire à cause de ses avantages intrinsèques notamment la possibilité d'employer une charge plus fine donc plus homogène; celui-ci est aussi plus facile à contrôler et réduit la pollution de l'environnement. Dans la fusion électrique, la conductivité électrique est un important paramètre et est fonction du degré d'ionisation.

Des essais sont effectués sur des produits isolants minéraux afin d'en vérifier leur conformité aux normes établis pour l'industrie, les immeubles et le secteur résidentiel. Ces normes diffèrent à travers le pays selon les exigences locales particulières.

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\*Chercheurs scientifiques, Laboratoire du traitement des minéraux, Laboratoires des sciences minérales, Centre canadien de la technologie des minéraux et de l'énergie, Energie, Mines et Ressources Canada, Ottawa.

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## INTRODUCTION

Mineral thermal insulation is a generic term describing various glass fibre products differentiating one from another by composition of the original furnace charge. Rock wool, slag wool and glass fibre are terms describing particular products. Mineralogically, all insulating fibres made from an inorganic charge are considered to be glass in its final fibrous form. However, conventional "glass fibre insulation", is made from a mixture of industrial minerals similar to those for making glass. The term rock wool includes products made from limestone and silicious materials, and slag wool contains, as its major ingredient, slags from blast furnaces, copper smelters, etc.

Mineral insulation has a vital role to play in energy conservation which has now become very important to the Canadian economy. Because of expected shortages in energy fuels such as gas and oil, there are few sectors of the Canadian economy that will not be affected when shortfalls occur. Energy, Mines and Resources Canada has thus focused on conservation in its energy research programs.

Aware of the imminent need for energy conservation, the Canada Centre for Mineral and Energy Technology initiated a project to produce mineral insulation. This was successfully done on an experimental scale and the project is now continuing on a more intensive basis.

## GLASS AND GLASS FIBRE

### FUNDAMENTAL CONSIDERATIONS

Mineralogically, all mineral insulation fibres are formed as a glass, either in bulk or fibrous form, on cooling from an inorganic melt. Morey defined a glass as an inorganic substance continuous with and analogous to its liquid state, but it can be considered rigid because of a reversible change in viscosity during cooling (1).

The composition of a glass and its thermal history, e.g., temperature of the melt, rate of cooling and fiberization temperature, will govern its properties. The room temperature structure

corresponds to the equilibrium structure which this composition would have in the liquid state at some elevated temperature. This structure equivalence is referred to as the configuration temperature (2).

In the solid oxide structure, metallic cations are surrounded by oxygen ions in a three-dimensional crystalline network. Each cation is surrounded by the maximum number of oxygen anions, referred to as the coordination number which depends only on the size and charge on the ions. During melting the crystalline network is destroyed and, in the liquid phase, the bonds between ions are broken by thermal agitation. The cations are still surrounded by anions but less rigidly, and the coordination number may vary (3). Examples given by Loewenstein are:

1.  $\text{Si}^{4+}$  surrounded by four  $\text{O}^{2-}$  ions form the  $\text{SiO}_4$  group;
2.  $\text{Si}^{4+}$  requires 6 fluoride ions because of smaller radii of  $\text{F}^-$  to form  $\text{SiF}_6$  sufficient for adequate screening of the electrical field (2).

Important in this respect is that the screening required becomes less as the temperature is increased. For example,  $\text{TiO}_6$  at room temperature may exist as  $\text{TiO}_4$  at elevated temperatures.

Ions attempt to screen their electrical field with ions of opposite charge. This competition for different ions is related to polarizing power. The field strength of an ion, a measure of polarizing power, is given by the expression  $Z/r^2$ , where  $Z$  = ion charge and  $r$  = ionic radius (2). From these considerations the following statements can be derived:

- (a) The polarizing power, varying directly as the field strength, requires surrounding ions of opposite charge in numbers related to the field strength.
- (b) From the above formula the highest field strength is when  $Z$  is high and  $r$  is small.

At high field strengths, screening requirements for ions are so strong that a positive ion surrounded by negative ions may share electrons; mobility of the ions may therefore be restricted except at very high temperatures. This type of bonding intermediate between shared elec-

trons (covalent bonding), and donated electrons (ionic bonding), is a characteristic of a glass former of which silica ( $\text{SiO}_2$ ) is a prime example.

An example of bonding and attraction forces is shown in Fig. 1 where silica consists of rings of  $\text{SiO}_4$  groups with  $\text{O}^{2-}$  ions shared between  $\text{Si}^{4+}$  ions.

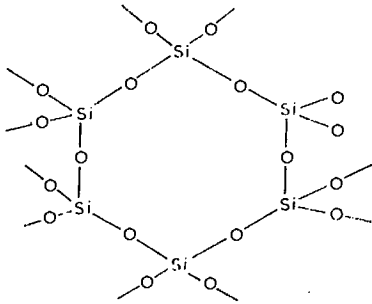
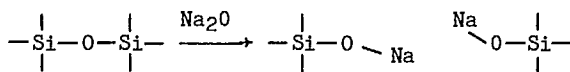


Fig. 1 - Bonding of  $\text{SiO}_4$  groups with shared oxygen ions. (2)

Table 1 shows the types of bonding and attraction forces for mineral oxides in slags which are of interest for mineral insulation production.

Alumina is a special type of network former because it is amphoteric. It forms  $\text{AlO}_4$  groups in glasses and requires positively charged ions for electrical neutrality. Network modifiers, such as the basic oxides, e.g.,  $\text{CaO}$ ,  $\text{BaO}$ ,  $\text{Na}_2\text{O}$ , and  $\text{K}_2\text{O}$ , break  $\text{Si-O-Si}$  bridges and by doing so reduce the temperature for glass-making as shown below:



Each ion has an electric field related to its field strength. The ion which fits into the network is surrounded by a number of oxygen ions. The electrical field of the ion is adequately screened at the configuration temperature.

Intermediate oxides, such as  $\text{MgO}$ ,  $\text{BeO}$ , and  $\text{TiO}_2$  can take up both positions depending on the composition and configuration temperature of the glass.

## GLASSES AND THEIR PROPERTIES

Silica based glasses can be made by heating the mixture to  $1300\text{--}1600^\circ\text{C}$  which results in a modification of the silica network, and other structurally related modifications. Figure 2 depicts the silica structure in both the solid and molten states.

Passage from solid silica to the viscous liquid has no well-defined fusion point and only prolonged heating at about  $1200^\circ\text{C}$  will cause crystallization. Energy levels between glass and crystalline states are small.

The properties of glasses are in general related to their structure (4). Oxides which can also influence the property and structures of a glass fall into distinct groups as shown in the last column of Table 1.

The tensile strength of a glass is much lower than the theoretical due to flaws on its surface. This has been demonstrated by removing the flaws by etching, resulting in a significant increase in strength. The tensile strength of glass also decreases with increasing temperature. Glass fibre strength measured at room temperature and humidity conditions is dependent on glass composition, fibre diameter, and the bulk glass temperature from which it was drawn.

Because of the negative charges on the surface of silica glasses, the surface attracts water molecules to which  $\text{H}^+$  ions are bonded strongly, with the  $\text{O}^{2-}$  ions end away from the surface. A temperature of  $500^\circ\text{C}$  is required to remove this water about 25 molecules thick (2).

Electrical properties are governed by the presence of alkali such as  $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$ . Electrical conduction is generally via the surface of the glass and only at elevated temperatures does conduction through the bulk of the glass become important. When  $\text{Na}^+$  ions are present on the surface of a glass which is covered with absorbed water, these ions would likely provide an electrical path on the surface of the glass.

Density, refractive index and Young's modulus are related to the structure of the glass and, therefore, to the composition and configuration temperatures. When fiberizing the glass, the faster cooling of the melt results in the above



properties being lower than in the bulk glass - density by about 2%, refractive index by 0.15 - 0.4, and Young's modulus by 7-25%. When fibres of the same diameter are drawn at increasing temperature from the same bulk melt, they show a de-

creasing Young's modulus with increasing temperature. Tempering the fibres between 100° and 400°C decreases the difference in these properties.

Table 1 - Types of bonding and attraction forces between cations and  $O^{2-}$  anion (3)

| Oxide     | $z/(R_c + R_a)^*$ | Ionic fraction of bond | Coordination number | Character of the oxide |
|-----------|-------------------|------------------------|---------------------|------------------------|
| $Na_2O$   | 0.18              | 0.65                   | 6 6 to 8            |                        |
| $BaO$     | 0.27              | 0.65                   | 8 8 to 12           |                        |
| $SrO$     | 0.32              | 0.61                   | 8                   |                        |
| $CaO$     | 0.35              | 0.61                   | 6                   | Network breakers       |
| $MnO$     | 0.42              | 0.47                   | 6 6 to 8            | or                     |
| $FeO$     | 0.44              | 0.38                   | 6 6                 | basic oxides           |
| $ZnO$     | 0.44              | 0.44                   | 6                   |                        |
| $MgO$     | 0.48              | 0.54                   | 6                   |                        |
| $BeO$     | 0.69              | 0.44                   | 4                   |                        |
| $Cr_2O_3$ | 0.72              | 0.41                   | 4                   |                        |
| $Fe_2O_3$ | 0.75              | 0.36                   | 4                   | Amphoteric             |
| $Al_2O_3$ | 0.83              | 0.44                   | 6 4 to 6            | oxides                 |
| $TiO_2$   | 0.93              | 0.41                   | 4                   |                        |
| $SiO_2$   | 1.22              | 0.36                   | 4 4                 | Network formers        |
| $P_2O_5$  | 1.66              | 0.28                   | 4 4                 | or acid oxides         |

\* $F = 2ze^2/(R_c + R_a)^2$  proportional to attraction between ions where

F = attraction force between anions and cations

$R_a + R_c$  = distance between ions

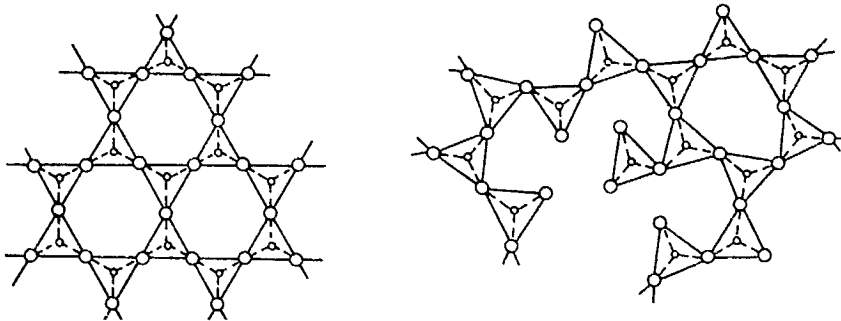


Fig. 2 - Structure of silica: (a) solid; (b) molten. (3)

The physico-chemical properties of the charging mixture play an important role influencing the melt, the process and, therefore, the fibrous insulation product. Some of the more important material parameters are viscosity, temperature, surface tension, density and liquidus temperature. The chemical constituents of the charge obviously will influence the melt.

The standard composition of a mineral insulation melt generally falls within the  $\text{SiO}_2$ - $\text{Al}_2\text{O}_3$ - $\text{MgO}$ - $\text{CaO}$  phase diagrams. However, care must be exercised because small changes in  $\text{SiO}_2$  content are said to cause large changes in viscosity which would require constant changes in temperature (5).

A comprehensive treatment of the science and technology of glass is contained in the proceedings of the XI International Congress on Glass (6).

#### VISCOSITY

The viscosity of a melt is dependent on composition and temperature. The temperature viscosity relationship is shown by the following model (3):

$$\eta = A e^{(E_\eta/RT)}$$

where  $A$  = a constant

$E_\eta$  = activation energy of slag  
viscous flow dependent on  
the composition.

Activation energy of viscous flow of a slag is large, indicated by the small decrease of viscosity with initial temperature rise. With an acid slag, the addition of a basic flux or network modifier such as  $\text{Na}_2\text{O}$  breaks the bonds of the silica tetrahedral structure, decreasing the activation energy and consequently the viscosity.

Predicting the roles of particular metal oxides in silicious melts has been attempted and for this the cationic field strength has been used. Van Der Colf et al. noted a direct relationship for the slags studied between viscosity and electrical resistivity (7). This is not surprising because viscosity is governed by the size of the anions while resistivity depends on the nature of the current-carrying cations. Increasing

the slag temperature thereby loosens the liquid structure and consequently decreasing viscosity and resistivity of the melt.

The slag samples studied at 1500°C by Van Der Colf with results for viscosities and resistivities are shown in Table 2 (7).

A graph of  $\log \rho$  resistivity vs  $\log \eta$  viscosity for the slags is shown in Fig. 3. Although the slopes vary, the general line equation is:

$$\ln \rho = m \ln \eta + \ln C \quad (6)$$

Kozakevitch measured the change of viscosity with temperature and composition, using a rotating cylinder viscometer, for lime-alumina-silicate melt systems (8). The results of the study up to the temperature range of interest for mineral insulation is shown in Table 3.

Carron considered that the viscosity of silicate melts at any particular temperature was influenced by the relative proportions of network modifiers present in the glass (9). Apart from silicon, the other network formers are the ions  $\text{Al}^{3+}$ ,  $\text{Fe}^{3+}$  and  $\text{P}^{5+}$ . The modifiers are taken to be  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Fe}^{2+}$ . The chemical analysis of a silicate material is given in terms of oxides and from this information the following calculations are a mixture or feed material:

- (a) the number of network former cations (T)
- (b) the number of network modifier cations
- (c) the number of oxygen atoms associated with all the cations (O).

The number of active oxygen ions in the melt are then determined. This is defined by:

$$O_A = 2(O - 2T) \quad \text{Eq 1}$$

The parameter related to viscosity is defined by:

$$R = \frac{O_A}{T} \times 100 \quad \text{Eq 2}$$

Log R is then plotted vs log viscosity to give straight lines. These calculations have been used in practice and found to be reasonably accurate (10).

Carron interpreted the results of viscosity measurements to indicate that the viscosity of a glass melt depends on the percentage of broken bonds between the aluminosilicate structure (9). He stated that results of the melt viscosity of "rocks and minerals" could be interpreted by the same model as for binary glasses  $\text{SiO}_2\text{-M}_2\text{O}$ .

Carron stated that the viscosity of any silicate melt can be estimated if the chemical composition, water content, and temperature are known. This estimate comprises the range from  $10^2$  to  $10^{15}$  poises.

Saito and Kawai suggested that molten slags are considered to be ionic solutions and are composed of various networks of  $\text{SiO}_4$  tetra-

Table 2 - Viscosities and resistivities of slags at 1500°C

| Slag | $\eta_{1500}$<br>N.s/m <sup>2</sup> x 10 | $\rho_{1500}$<br>$\Omega.m \times 10^2$ | $\ln \eta_{1500}$ | $\ln \rho_{1500}$ | $\rho_{1500}(\text{calc.})$<br>$\Omega.m \times 10^2$ |
|------|--|---|-------------------|-------------------|---|
| A5   | 0.91                                     | 0.88                                    | -0.094            | -0.128            | 0.79  |
| B14  | 0.72                                     | 0.63                                    | -0.329            | -0.462            | 0.67  |
| B13  | 0.66                                     | 0.66                                    | -0.415            | -0.415            | 0.63  |
| B15  | 1.32                                     | 1.00                                    | -0.278            | -0.000            | 1.02  |
| B11  | 0.80                                     | 0.68                                    | -0.223            | -0.386            | 0.72  |
| B17  | 1.78                                     | 1.00                                    |                   |                   |   |
| C23  | 0.83                                     | 0.57                                    |                   |                   |   |

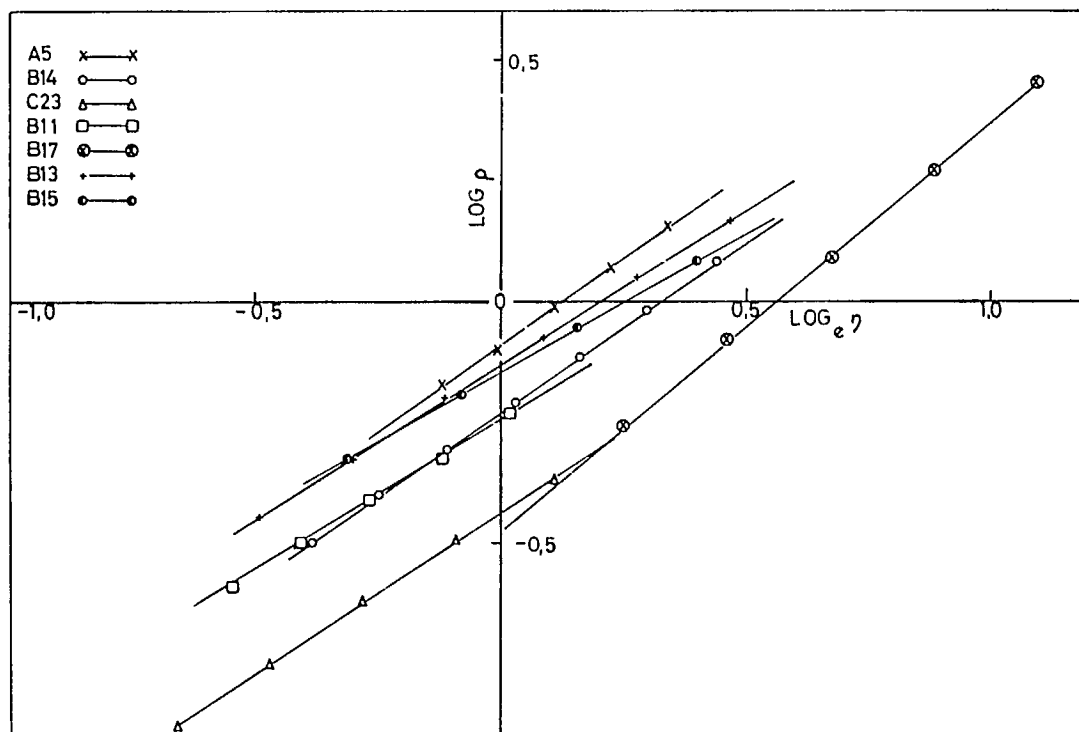


Fig. 3 - Relation between viscosity ( $\eta$ ) and resistivity ( $\rho$ ) of the same slag

Table 3 - Viscosity of CaO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> melts between 1450-1600°C (8)

| SiO <sub>2</sub><br>wt % | Al <sub>2</sub> O <sub>3</sub><br>wt % | CaO<br>wt % | Viscosity in poises at |        |        |        |
|--------------------------|--|-------------|------------------------|--------|--------|--------|
|                          |  |             | 1450°C                 | 1500°C | 1550°C | 1600°C |
| 10                       | 40                                     | 50          | 7.7                    | 5.0    | 3.3    | 2.3    |
| 20                       | 40                                     | 40          | -                      | -      | 6.3    | 4.0    |
| 20                       | 50                                     | 30          | -                      | 11.5   | 7.4    | 4.7    |
| 30                       | 30                                     | 40          | -                      | 9.2    | 6.1    | 4.4    |
| 30                       | 40                                     | 30          | 30.2                   | 18.0   | 11.4   | 7.8    |
| 40                       | 10                                     | 50          | 5.3                    | 3.9    | 2.8    | 2.1    |
| 40                       | 20                                     | 40          | 14.7                   | 9.2    | 6.2    | 4.3    |
| 40                       | 30                                     | 30          | 39.2                   | 25.7   | 16.8   | 11.0   |
| 50                       | 0                                      | 50          | -                      | -      | 2.4    | 1.8    |
| 50                       | 10                                     | 40          | 12.3                   | 8.6    | 6.2    | 4.5    |
| 50                       | 20                                     | 30          | 42.3                   | 32.2   | 22.1   | 15.8   |
| 60                       | 0                                      | 40          | -                      | 9.3    | 6.5    | 4.7    |
| 60                       | 10                                     | 30          | -                      | -      | -      | 17.9   |

hedra (11). Addition of metal oxides destroys the network and finally forms single SiO<sub>4</sub> tetrahedra. Addition of small amounts of Al<sub>2</sub>O<sub>3</sub> to a slag melt does not destroy the SiO<sub>4</sub> network but large amounts of ~ 20% caused formation of AlO<sub>3</sub><sup>3-</sup> ions with consequent large increases in viscosity. Additions of SiO<sub>2</sub> of less than 10 % to the CaO-Al<sub>2</sub>O<sub>3</sub> system resulted in small changes in the slag melt viscosity which implied only minor formation of SiO<sub>4</sub> tetrahedra. The basis for this study was similar to that used by Coudurier (3) and the results could be applied to granite glasses, molten basalts, anhydrous melts, and to hydrated magmas.

Viscosities of some liquids and of rocks and minerals are shown in Table 4. The results show that viscosity of silicate melts appears to be a function of composition. Iron and manganese oxides lower the viscosity of these melts. High magnesium content slags are less viscous than calcium silicate slags but iron is a better flux than magnesium. Alumina, silica, titania and chromium oxide increase viscosity. However, the influence of these oxides is also dependent on temperature of the melt. In general, melts of acid rocks are more viscous than those of basic rocks.

Turkdogan and Bills have critically reviewed the viscosity relationships of the CaO-MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> melt system (13). It is claimed that

inconsistencies of early data for the above systems were partly due to the use of graphite crucibles because alumina-silicate melts react readily with graphite at high temperatures. In other studies from this paper, it was shown that for a given temperature the viscosity and composition relationships of alkaline earth silicates were the same. The effect of the alkali oxides was similar on the viscosity of binary and ternary melts. Also, for any particular silica concentration, the viscosity will increase as more alumina replaces calcia, CaO to a molar ratio of Al<sub>2</sub>O<sub>3</sub>:CaO of about 1:1. Increasing the ratio by increasing Al<sub>2</sub>O<sub>3</sub> results in a viscosity decrease. This is a good example of the amphoteric nature of alumina.

For slags that are neutral or basic, the effects on the viscosity of Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> are similar when Al<sub>2</sub>O<sub>3</sub>:CaO ratios are low. It is therefore assumed that all the network-forming ions are Si + Al. When the Al<sub>2</sub>O<sub>3</sub>:CaO ratios and silica concentrations are both large, the relationship becomes more complex. In this review it is shown that the alkaline earth oxides are interchangeable in their effects on the viscosity of binary melts and this behaviour is assumed to be similar for the quaternary melts. This is shown in Fig. 4.

In the system CaO-MgO-Al<sub>2</sub>O<sub>3</sub>-TiO<sub>2</sub>-SiO<sub>2</sub>,



Table 4 - Viscosities of selected common liquids, rocks and minerals (12)

| Substance        | Temperature | Viscosity ( $\eta$ )                 |
|------------------|-------------|--------------------------------------|
|                  | t°C         | poise                                |
| Water            | 20          | $1 \times 10^{-2}$                   |
| Glycerine        | 20          | 10                                   |
| Gelatine         | 20          | $1 \times 10^6 - 1 \times 10^8$      |
| Diopside         | 1400        | 3.8                                  |
| Anorthite        | 1400        | 38                                   |
| Albite           | 1400        | $4 \times 10^4$                      |
| Orthoclase       | 1400        | $1 \times 10^8$                      |
| Diabase          | 1400        | 60 - 90                              |
| Basalt           | 1400        | 55                                   |
| Nepheline basalt | 1400        | 80                                   |
| Olivine basalt   | 1400        | $1.2 \times 10^2 - 1.36 \times 10^2$ |
| Andesite basalt  | 1400        | $1.38 \times 10^2$                   |
| Vesuvius lava    | 1400        | $2.5 \times 10^2$                    |
| Andesite         | 1400        | $1.17 \times 10^3$                   |
| Obsidian         | 1400        | $1.7 \times 10^5$                    |

the composition variable with the most influence on viscosity as well as resistivity was the basicity expressed as the mass ratio  $(\text{CaO} + \text{MgO}) : \text{SiO}_2$  (7). The ratio  $\text{CaO} : \text{MgO}$  was important only at low basicity.

The variation of viscosity with temperature for the same composition is shown in Fig. 5 and is hypothesized to be due to breakdown of Si-O and Al-O bonds, i.e., structural changes have taken place (13). Below  $1350^\circ\text{C}$ , the relationship between  $\log$  viscosity ( $\eta$ ) and  $\frac{1}{T}$  is linear but deviates from linearity at higher temperatures due to changes in the structure of the melt.

Turkdogan and Bills concluded that the silica equivalence of alumina varied with the  $\text{Al}_2\text{O}_3 : \text{CaO}$  ratio and with the alumina concentration (13). Magnesia and lime, on a molar basis, have the same effect on viscosity.

#### LIQUIDUS TEMPERATURE

The melting point of a charge strongly depends on the composition which can be checked along the liquidus line and this line can be used to determine devitrification zones for a particular slag melt composition.

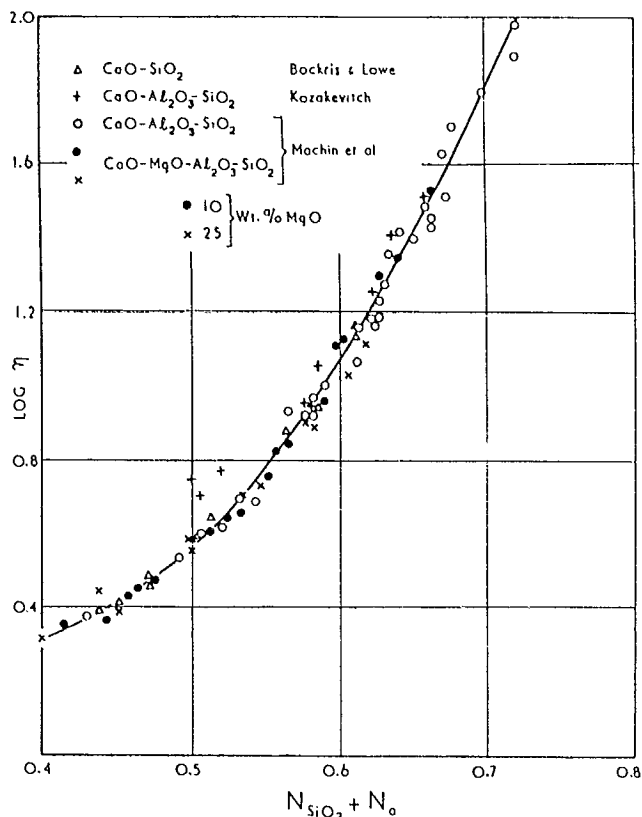


Fig. 4 - Variation of viscosity with composition in the system  $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$  (13)

Note:  $N_a$  is the silica equivalence of alumina.

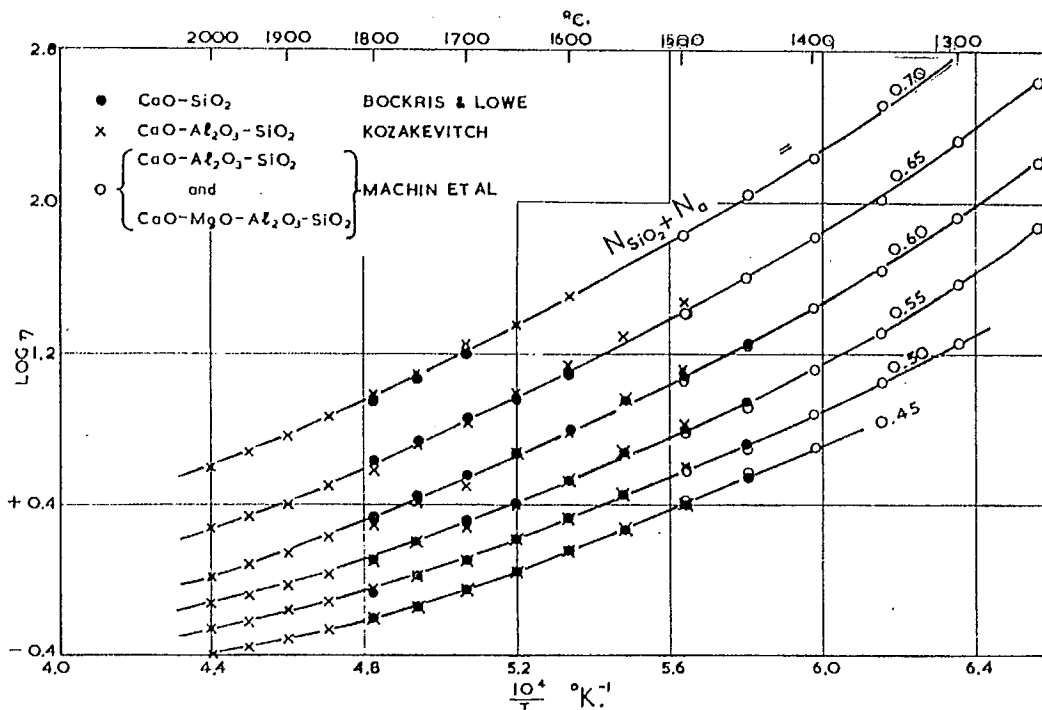


Fig. 5 - Variation of viscosity with temperature and composition of molten silicates and alumina silicates (13)

A phase equilibria diagram for the system  $\text{CaO-SiO}_2\text{-Al}_2\text{O}_3$  is shown in Fig. 6 (14). Components other than  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  can usually be simplified to a  $\text{CaO}$  equivalence. This phase diagram can then be used to determine the slag activity from the individual component activities and the melting temperature of a charge. The slag viscosity and surface tension can also be derived from the individual component data and the composition of the melt system (15,16).

Devitrification or crystallization of a glass is avoided at all times in making glass. All glasses tend to vitrify below a temperature specific to that glass, the liquidus temperature. Rate of crystallization, although increasing below the liquidus temperature, is opposed by viscosity increases of the glass (4).

Crystallization can be calculated by the

following equation: (17)

$$R = \frac{\kappa}{\eta^a} (T_L - T) \quad \text{Eq 3}$$

where

$\eta$  = viscosity of glass  
 $T_L$  = liquidus temperature  
 $\kappa, a$  = glass constants  
 $R$  = rate of crystal growth at temperature  $T$

Observed experimental results agreed closely with predicted data obtained by calculations using this equation.

The phases for a sodium-calcia-silica type glass are shown in Fig. 7 (14). For this particular glass type and working temperature, the area N, O, P, Q, R, represents compositions that have little difficulty with devitrification.

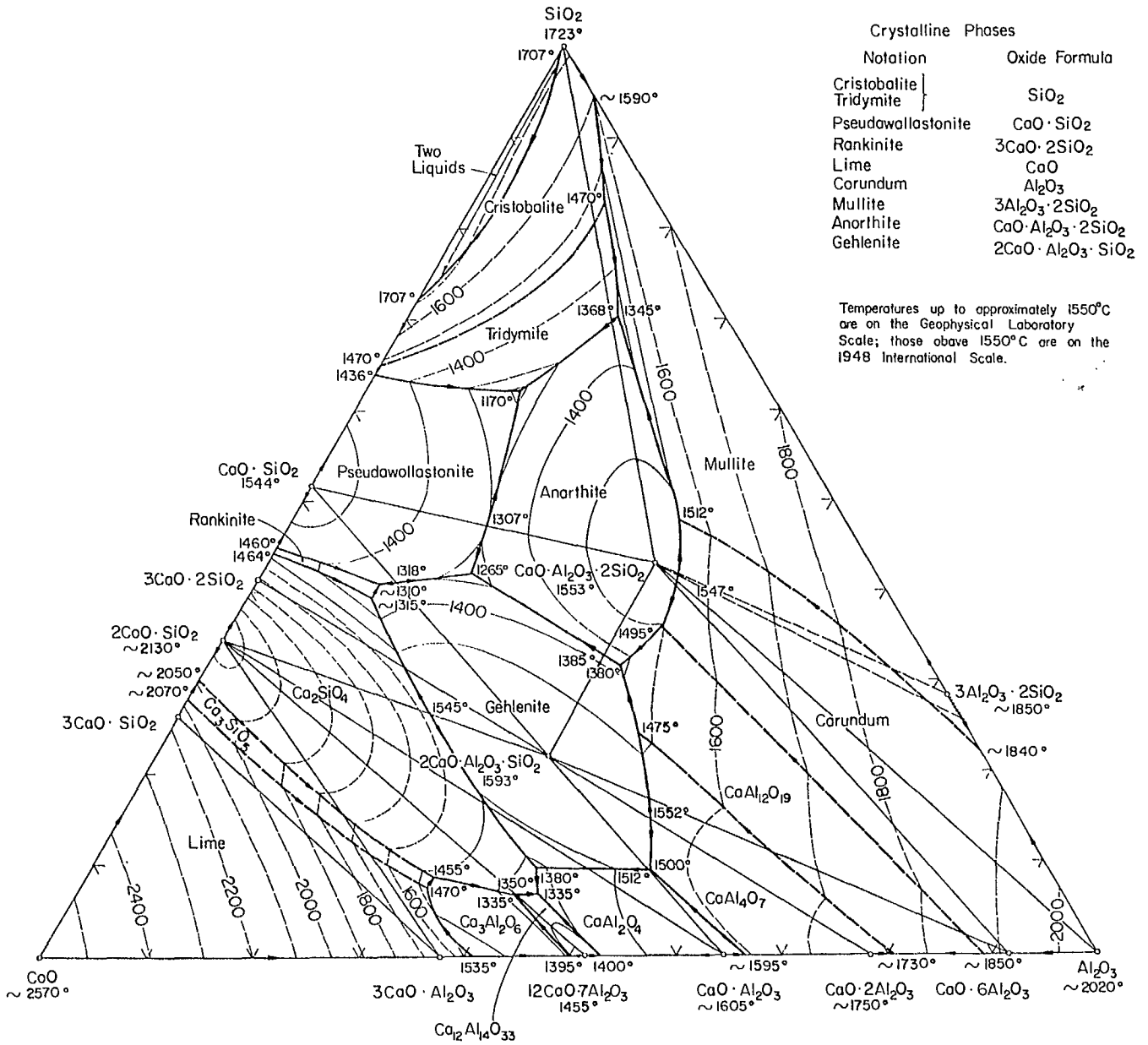


Fig. 6 - Phase equilibrium diagram for the CaO-SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub> ternary system (14)

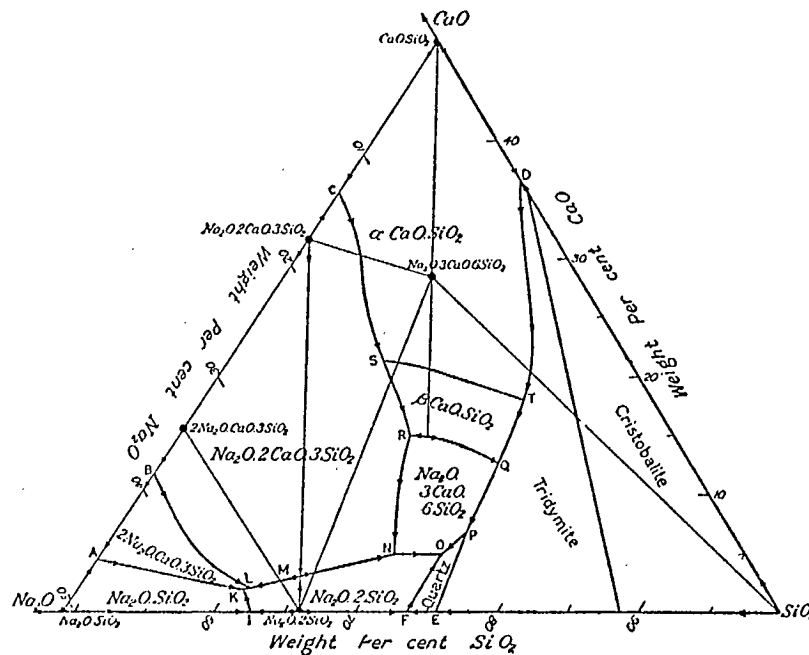


Fig. 7 - Phase equilibrium diagram of the system  $\text{Na}_2\text{O}-\text{CaO}-\text{SiO}_2$   
(14)

#### DENSITY

This property of a glass reflects the structural changes in the melt. Homogeneity of a glass is extremely important as a processing parameter including that for fiberization. Automatic machinery also requires that the composition of the melt be constant. The density of a glass is one of the simpler and more accurate methods for quality control of the above parameters. Compositional differences of glass have been shown to be more accurately determined by density than by chemical analysis (18). Densities of glass melts of varying composition for the system  $\text{CaO}-\text{SiO}_2-\text{Al}_2\text{O}_3$  when plotted against temperature, resulted in straight line relationships for each of the compositions shown in Table 5, Fig. 8.

#### ELECTRICAL AND THERMAL CONDUCTIVITY

Electrical conductivity of slags depends on the number of ions present and their mobility, which in turn is dependent on their size and the slag viscosity. By adding  $\text{CaO}$ ,  $\text{FeO}$  or  $\text{MnO}$  to a silica melt, the slag electrical conductivity is transformed from a low to a much higher value.

Conductivity values are related to the extent of ionization and silica is an ionizing solvent. The conduction of iron and manganese silicates, however, are partly electronic and partly ionic giving large conductivity values. Glass can change dramatically in electrical conductivity values from room to high temperatures (5).

Table 5 - Compositional variations of a glass melt

| Sample No. | CaO | SiO <sub>2</sub> | Al <sub>2</sub> O <sub>3</sub> |
|------------|-----|------------------|--------------------------------|
| 1          | 39  | 42               | 19                             |
| 2          | 35  | 55               | 10                             |
| 3          | 34  | 36               | 30                             |
| 4          | 30  | 45               | 25                             |
| 5          | 30  | 60               | 10                             |
| 6          | 29  | 31               | 40                             |
| 7          | 25  | 55               | 20                             |
| 8          | 25  | 65               | 10                             |
| 9          | 23  | 62               | 15                             |
| 10         | 15  | 65               | 20                             |



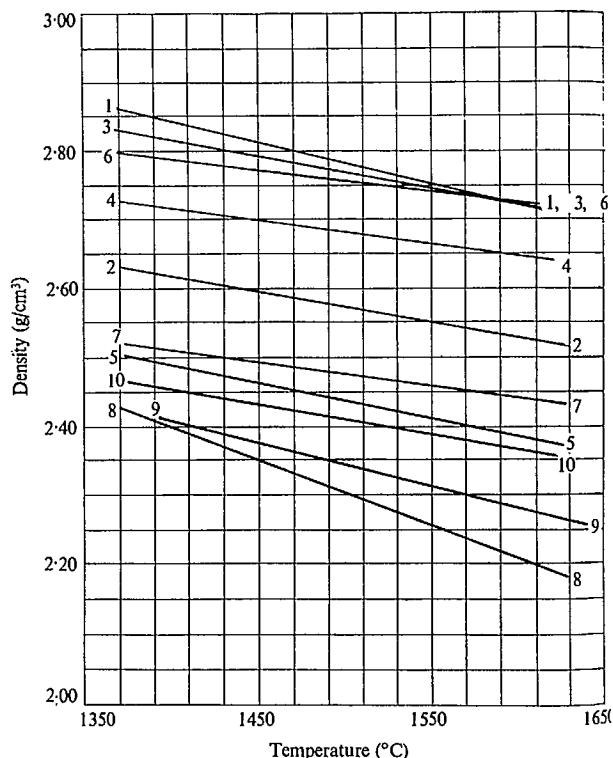


Fig. 8 - Variation of densities with temperature for the  $\text{CaO-SiO}_2\text{-Al}_2\text{O}_3$  system (15)

Generally there is a relationship between the log viscosity and log resistivity; however, a slag with a very high silica or titania content has anomalously low electrical resistance (7).

Thermal conductivity of slags is low and because the major heat transfer in a melt is due to convection, the heat losses are greater than those which could be calculated from thermal conductivity data (3).

#### SURFACE TENSION

This property is important in the fiberization portion of the mineral wool process. Free movement of the melt from the furnace and from the fiberizing equipment is essential. There are methods for obtaining optimum surface tension for silicate melts. Although they are not scientifically rigorous they do serve as a guide to good practice (4,15). Improvements in homogeneity of a glass and the disappearance of cords are closely

related to surface tension. Even small differences of a few dynes/cm have a marked effect on the number of cords in glass (4).

The viscosity/surface tension value in a glass should be greater than 0.01 otherwise the melt flow is said to be reduced to droplets. Generally, the surface tension decreases with increasing temperature. The variation of composition of a melt with surface tension at 1450°C is shown in Table 6 (18).

The calculated surface tension values of selected oxides are shown in Table 7 (19). Reduction of surface tension in the slag system  $\text{CaO-MgO-SiO}_2\text{-Al}_2\text{O}_3$  by additions of  $\text{SiO}_2$  is shown in Fig. 9. Small amounts of sulphur in the slag will slightly alter these values.

Table 6 - Surface tension of melts in the systems  $\text{CaO-SiO}_2\text{-Al}_2\text{O}_3$  and  $\text{CaO-MgO-SiO}_2\text{-Al}_2\text{O}_3$  at 1450°C (18)

| Composition (wt %) |     |                  |                                | Surface tension (dynes/cm) |
|--------------------|-----|------------------|--------------------------------|----------------------------|
| CaO                | MgO | SiO <sub>2</sub> | Al <sub>2</sub> O <sub>3</sub> |                            |
| 30                 | -   | 55               | 15                             | 486                        |
| 47                 | -   | 41               | 12                             | 572                        |
| 40                 | -   | 40               | 20                             | 530                        |
| 48                 | -   | 7                | 45                             | 748                        |
| 47                 | 4   | 35               | 14                             | 591                        |

Table 7 - Calculated surface tension values of metallic oxides (19)

| Oxide                          | Calculated surface tension (dynes/cm) | Temperature (°C) |
|--------------------------------|---------------------------------------|------------------|
| SiO <sub>2</sub>               | 285                                   | 1400             |
| Al <sub>2</sub> O <sub>3</sub> | 640                                   | 1400             |
| CaO                            | 614                                   | 1400             |
| MgO                            | 512                                   | 1400             |
| MnO                            | 653                                   | 1400             |
| Na <sub>2</sub> O              | 297                                   | 1400             |
| K <sub>2</sub> O               | 156                                   | 1400             |
| B <sub>2</sub> O <sub>3</sub>  | 96                                    | 1400             |

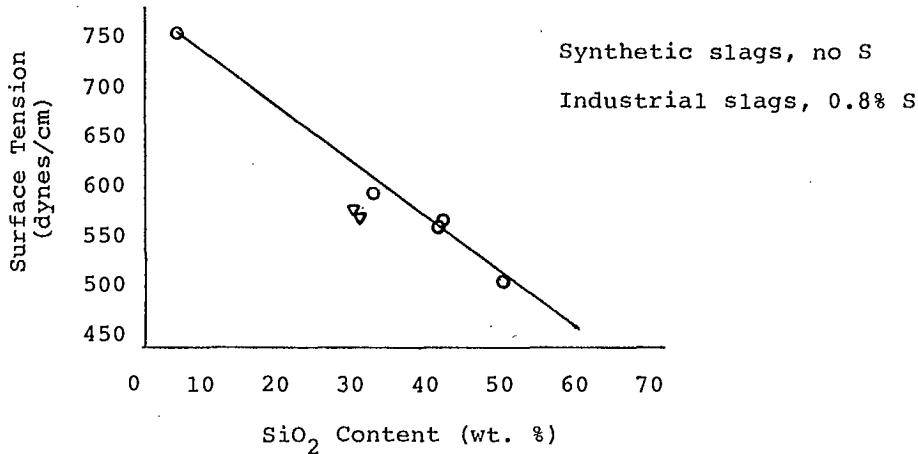


Fig. 9 - Variation of surface tension with SiO<sub>2</sub> content at 1450°C for several synthetic slags in the CaO-MgO-SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub> system and two industrial slags containing sulphur (18)

Optimum surface tension can be derived from the results reported by Ustenko (20) and Zihilin (21). They have stated that at 1400°C a slag melt viscosity is 15 poise and the viscosity/surface tension value is 0.01.

#### RAW MATERIALS

Some of the principal raw materials and oxides supplied for making insulation, including glass and mineral wool, are shown in Table 8.

Mineral wool refers to the insulation product derived from the rocks and minerals in the feed charge. The constituents for making glass wool are similar to those for glass but glass wool requires less alkali.

The melting points of corresponding oxides and of selected compounds are shown in Table 9.

#### MINERAL WOOL PROCESSING

Processes for producing mineral wool are basically simple but there can be many complex variations. All processes attempt to accomplish the following objectives:

1. melting of the feed charge
2. fiberization of the molten stream
3. manufacture of various products such as batts, with and without vapour barrier, of various

densities and R factors\* and granulated, bulk and loose wool.

In Canada and the U.S.A., except for the production of glass wool, the main type of melting furnace used for producing mineral wool is the cupola. For glass fibre insulation, gas or electric melting furnaces are generally used. In Europe, both cupola and electric resistance furnace types are used for mineral insulation manufacture.

#### CUPOLA TYPE FURNACE

A schematic diagram of a typical cupola furnace for the production of mineral wool is shown in Fig. 10.

The furnace is usually water-jacketed to provide cooling and the internal surface may or may not be lined with refractory material.

The cupola furnace is filled with alternate layers of fuel (coke) and raw materials up to the charging door and the air is turned on at the tuyeres. The material is normally in lump form to allow free passage of air and combustion gases, and also because fine material would be

\* R factor - a measure of thermal resistance of the insulation. Its value is obtained from the reciprocal of heat transfer.

Table 8 - Principal raw materials used in glass making (4)

| Material                                | Alternative name                                       | Theoretical formula              | Oxides supplied | Fraction |
|---|--|----------------------------------|-----------------|----------|
| Alumina                                 | Calcined alumina                                       | $Al_2O_3$                        | $Al_2O_3$       | 1.000    |
| Alumina hyd.                            | Hydrated alumina                                       | $Al_2O_3 \cdot 3H_2O$            | $Al_2O_3$       | 0.654    |
| Aplite (typical composition)            | ---  | ---                              | $Al_2O_3$       | 0.240    |
|   | ---  | ---                              | $Na_2(K_2)O$    | 0.100    |
|   | ---  | ---                              | $SiO_2$         | 0.600    |
|   | ---  | ---                              | $CaO$           | 0.060    |
| Feldspar                                | Microcline (composition is of typical commercial spar) | $K_2O \cdot Al_2O_3$             | $Al_2O_3$       | 0.180    |
|   |  | $6SiO_2$                         | $K_2(Na_2)O$    | 0.130    |
|   |  | ---                              | $SiO_2$         | 0.680    |
| Nepheline syenite (typical composition) | ---  | ---                              | $Al_2O_3$       | 0.250    |
|   | ---  | ---                              | $Na_2(K_2)O$    | 0.150    |
|   | ---  | ---                              | $SiO_2$         | 0.600    |
| Calumite                                | Calcium-aluminum Silicate                              | $2CaO \cdot MgO \cdot 2SiO_2$    | $SiO_2$         | 0.380    |
|   |  | $2CaO \cdot Al_2O_3 \cdot SiO_2$ | $Al_2O_3$       | 0.117    |
|   |  | $2(CaO \cdot SiO_2)$             | $CaO$           | 0.400    |
|   |  | ---                              | $MgO$           | 0.080    |
| Kyanite (90% concentrate)               | ---  | $Al_2O_3 \cdot SiO_2$            | $Al_2O_3$       | 0.567    |
|   | ---  | ---                              | $SiO_2$         | 0.433    |
| Kaolin                                  | China clay   | $Al_2O_3 \cdot 2SiO_2$           | $Al_2O_3$       | 0.395    |
|   |  | $2H_2O$                          | $SiO_2$         | 0.465    |
| Cryolite                                | Kryolith   | $Na_2AlF_6$                      | ---             | ---      |
| Antimony oxide                          | ---  | $Sb_2O_3$                        | $Sb_2O_3$       | 1.000    |
| Barium carbonate                        | ---  | $BaCO_3$                         | $BaO$           | 0.777    |
| Barium oxide                            | Baryta   | $BaO$                            | $BaO$           | 1.000    |
| Barium sulphate                         | Barytes  | $BaSO_4$                         | $BaO$           | 0.657    |
| Boric acid                              | Boracic acid   | $B_2O_3 \cdot 3H_2O$             | $B_2O_3$        | 0.563    |
| Borax                                   | ---  | $Na_2O \cdot 2B_2O_3$            | $B_2O_3$        | 0.365    |
|   | ---  | $10H_2O$                         | $Na_2O$         | 0.163    |
| Anhydrous borax ("Pyrobor")             | ---  | $Na_2O \cdot 2B_2O_3$            | $B_2O_3$        | 0.692    |
|   | ---  | ---                              | $Na_2O$         | 0.308    |
| Lime, burnt                             | Quick lime   | $CaO$                            | $CaO$           | 1.000    |
| Lime, hydrated                          | Calcium hydrate  | $CaO \cdot H_2O$                 | $CaO$           | 0.757    |
| Limestone                               | Calcium carb.  | $CaCO_3$                         | $CaO$           | 0.560    |
| Calcium carb                            | Whiting  | $CaCO_3$                         | $CaO$           | 0.560    |
| Lime, dolomitic                         | Burnt dolomite   | $CaO \cdot MgO$                  | $CaO$           | 0.582    |
|   |  | ---                              | $MgO$           | 0.418    |
| Dolomite                                | Raw limestone (dolomitic)                              | $CaO \cdot MgO \cdot 2CO_2$      | $CaO$           | 0.304    |
|   |  | ---                              | $MgO$           | 0.218    |
| Lime, hydrated, Dol.                    | Finishing lime   | $CaO \cdot MgO$                  | $CaO$           | 0.423    |
| Bone ash                                | Calcium phosphate                                      | $2H_2O$                          | $MgO$           | 0.304    |
|   |  | $3CaO \cdot 2P_2O_3 + CaCO_3$    | $CaO$           | 0.372    |
| Potassium carb.                         | Calcined carbonate of potash                           | $CaCO_3$                         | $P_2O_3$        | 0.628    |
|   |  | $K_2CO_3$                        | $K_2O$          | 0.681    |
| Glassmaker's potash                     | Potassium carbonate, hyd.                              | $K_2CO_3 \cdot 1\frac{1}{2}H_2O$ | $K_2O$          | 0.570    |
| Sand                                    | Glass, sand, quartz                                    | $SiO_2$                          | $SiO_2$         | 1.000    |
| Soda ash                                | Sod. carb. coml.                                       | $Na_2CO_3$                       | $Na_2O$         | 0.585    |
| Salt cake                               | Sodium sulphate  | $Na_2SO_4$                       | $Na_2O$         | 0.437    |
| Sodium silicofluoride                   | Sodium fluosilicate                                    | $Na_2SiF_4$                      | ---             | ---      |

Table 9 - Melting points of some compounds of interest in glass making (4)

| Name                        | Formula                 | Melting Point      |           |
|-----------------------------|-------------------------|--------------------|-----------|
|                             |                         | °F                 | °C        |
| Aluminum oxide              | $Al_2O_3$               | 3720               | 2050      |
| Aluminum silicate (Mullite) | $3Al_2O_3 \cdot 2SiO_2$ | 3290               | 1810      |
| Barium carbonate            | $BaCO_3$                | d. 2640            | 1450      |
| Barium sulphate             | $BaSO_4$                | 2875               | 1580      |
| Boric acid                  | $H_2BO_3$<br>185        | d.                 | 365       |
| Boron oxide cryst.          | $B_2O_3$<br>490         | c.                 | 910       |
| Calcia                      | $CaO$                   | 4660               | 2572      |
| Calcium carbonate           | $CaCO_3$                | d. Bright red heat |           |
| Calcium fluoride            | $CaF_2$                 | 2480               | 1360      |
| Calcium pyro-phosphate      | $Ca_2P_2O_7$            | 2245               | 1230      |
| Tricalcium phosphate        | $Ca_3(PO_4)_2$          | 3040               | 1670      |
| Calcium silicate            | $CaSiO_3$               | 2805               | 1540      |
| Calcium sulphate            | $CaSO_4$                | 2640               | 1450      |
| Cryolite                    | $Na_3AlF_6$             | 1830               | 1000      |
| Ferrous silicate            | $FeSiO_4$               | 2200               | 1200      |
| Magnesium carbonate         | $MgCO_3$                | d. Low red heat    |           |
| Magnesium oxide             | $MgO$                   | 5070               | 2800      |
| Magnesium silicate          | $MgSiO_3$               | 2835               | 1555      |
| Magnesium sulphate          | $MgSO_4$                | 2165               | 1185      |
| Phosphorus pentoxide        | $P_2O_5$<br>563         | 1045               |           |
| Potassium carbonate         | $K_2CO_3$               | 1635               | 891       |
| Potassium hydroxide         | $KOH$                   | 716                | 380       |
| Potassium nitrate           | $KNO_3$                 | 635                | 334       |
| Potassium silicate          | $K_2SiO_3$              | 1790               | 976       |
| Potassium sulphate          | $K_2SO_4$               | 1970               | 1076      |
| Silica                      | $SiO_2$                 | 3135               | 1725      |
| Sodium aluminate            | $NaAlO_2$               | 3000               | 1650      |
| Sodium diborate             | $Na_2B_4O_7$            | 1365               | 741       |
| Sodium carbonate            | $Na_2CO_3$              | 1562               | 851       |
| Sodium chloride             | $NaCl$                  | 1480               | 804       |
|                             |                         | Boils              | 2575 1413 |
| Sodium silicate             | $Na_2SiO_3$             | 1990               | 1089      |
| Sodium disilicate           | $Na_2Si_2O_5$           | 1605               | 874       |
| Sodium sulphate             | $Na_2SO_4$              | 1624               | 884       |

d. = decomposes or loses oxygen

c. = approx. soft temp. of glassy form

Sources: Chemical Rubber Co.'s "Handbook of Chemistry and physics",  
International Critical Tables.



lost up the stack. In practice for satisfactory operation, it has been recommended that sized material should be used to prevent excessive channeling (22). The ratio of coke to slag or other feed charge is generally between 1 and 3.5:1 (23).

The rate of burning is usually controlled by a slide gate on the air supply from the blast fan to the tuyeres. Under optimum operating conditions, an average 1.22-m (48-in.)-diameter cupola furnace could melt from about 1361 to 1814 kg (1.5 to 2 t, short) of slag per hour with a coke consumption of approximately 450 kg (0.5 t). The water circulating around the cupola cylinder is maintained at as high a temperature as possible to avoid excessive heat loss (23).

#### REACTIONS WITHIN A CUPOLA FURNACE

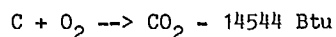
Various temperature zones within the cupola reaction or melting chamber are shown schematically in Fig. 10 (21). Figure 11 shows the principal reactions in the various zones of a

cupola furnace and Fig. 12 shows the temperature in the reaction zone.

It is apparent that the loading of a furnace charge is very important. Generally for best operating characteristics, the coke and charge materials are added in alternate layers so that mixing, melting, fluxing and zone temperature are in proper relation to one another.

The various reactions will now be dealt with in slightly more detail. They are identified as oxidation, or reduction using analogy with cupola operation in iron-steel processing.

Air enters the bottom of the furnace where it is preheated by the hot bottom layer of ash and then passes to the coke where it reacts with the carbon to form  $\text{CO}_2$ :



This major oxidation reaction in the lower coke section is exothermic.

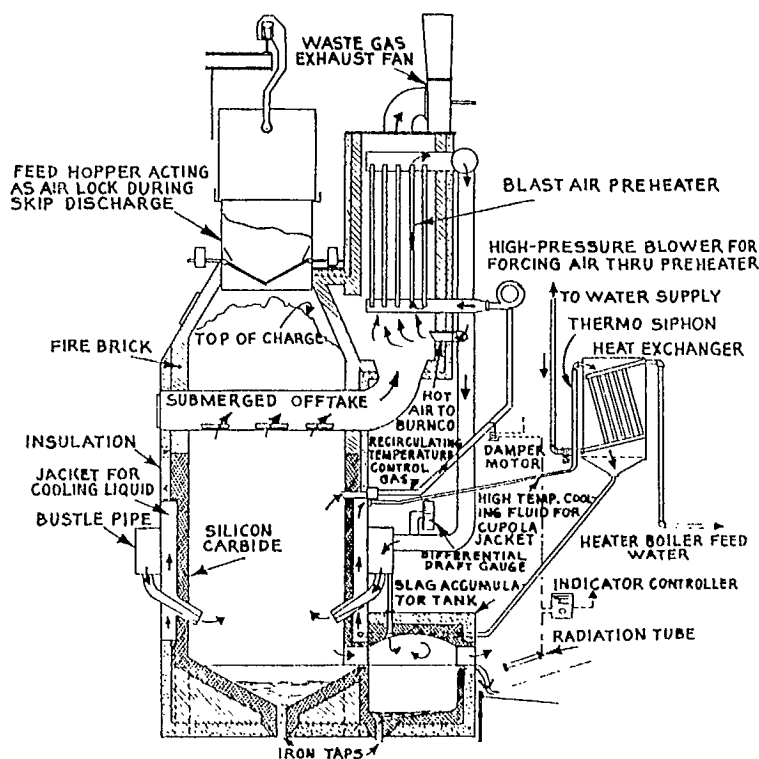


Fig. 10 - Schematic diagram of a cupola furnace used for rock wool fibre production (22)

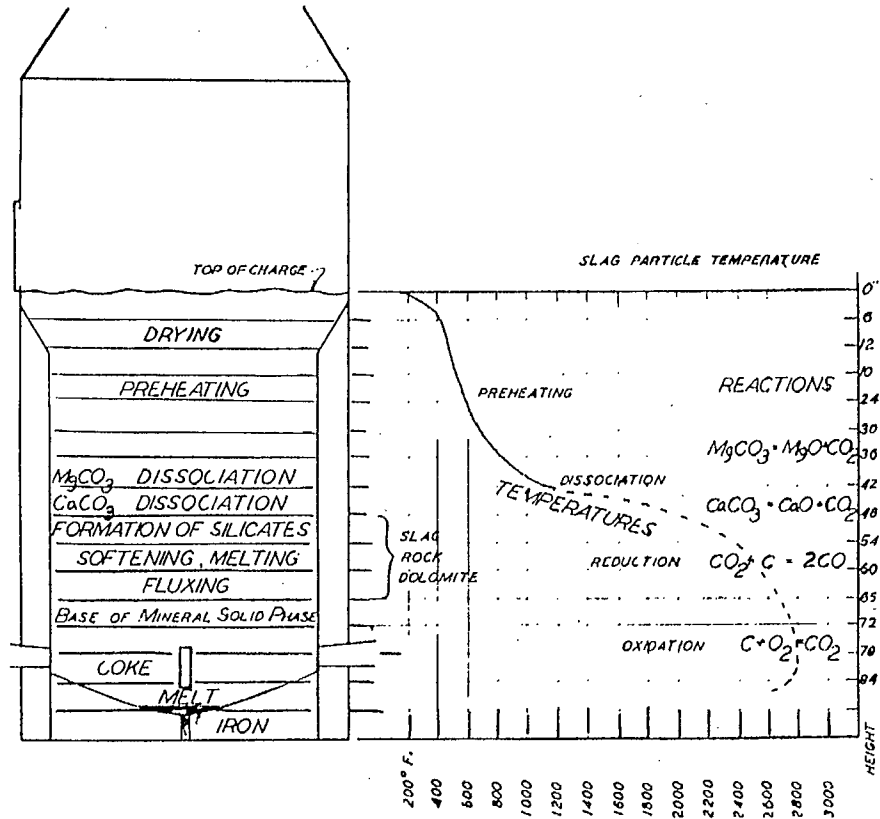


Fig. 11 - Schematic diagram of temperature zones and principal reactions in a cupola furnace (22)

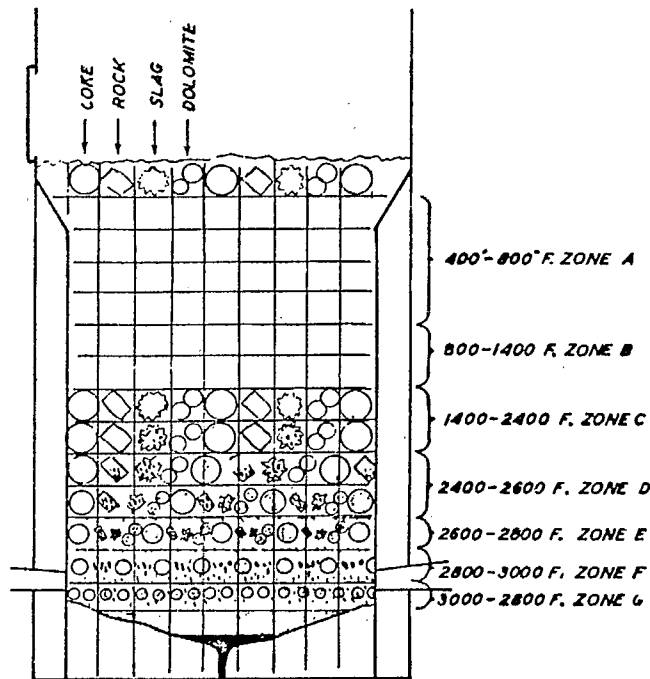
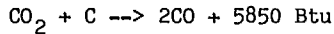


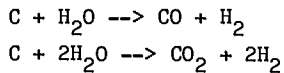
Fig. 12 - Schematic diagram showing the temperatures in the various reaction zones in a cupola furnace (22)

The  $\text{CO}_2$  proceeds upward where it reacts with more carbon to form CO:



This reduction reaction is endothermic.

The following oxidation-reduction water gas reactions also occur in a furnace where coke or carbon is present and are endothermic:



Furnace efficiency is achieved by optimizing the reactions so that as much heat as possible is available for melting the charge rather than being taken up unnecessarily in the endothermic reactions.

#### ELECTRIC SMELTING FURNACES

This type of furnace has recently become more popular. Increased efficiency is possible particularly where relatively small quantities of glass are required (4). Other advantages are that homogeneity and composition of the charge are more quickly and easily controlled, and air pollution is reduced because combustion gases are not swept through the furnace. When volatile components such as fluorides are used in a batch, losses are reduced considerably. Start-up time after a shut-down is relatively simple and quick, and heat loss through the sides can readily be accounted for by increasing the power. Generally, this type of furnace requires much smaller space relative to output, and continuous operation is possible (4).

A few disadvantages are: electric furnaces are restricted to locations where cheap power is available and refractory life is shorter than in other furnace types. However, a shorter down-time results in a refractory cost per rebuild that is lower than for other furnaces. Inorganic materials such as silica and limestone used as charge to the furnace do not conduct electrical current well, therefore, start-up requires a carbon source such as coke or carbon cloth. Conductivity is adequate when a melt is formed.

Figure 13 shows schematically the principles of an arc and submerged electrode type furnace operation. Electrodes are generally of two or three configurations and are operated as single or three phase.

Small furnaces of the all-electric type have more recently been adopted. Continuous operation furnaces of as little capacity as 2722 kg (3 t) per day have been making glass, and mini melters are in operation with a continuous output of as low as 9.1 kg (20 lb) per hour (4).

Electric furnace ratings range from 500 to 5000k VA, the larger type using three phase transformers and voltage taps. Electrodes are generally of the graphite type and erode in time due to oxidation.

The efficiency of a furnace can be influenced by the refractory in the lining. The U.S. Bureau of Mines has studied various types for resistance to erosion (24). The refractory also acts as a resistance to abrasion of the sides of the furnace. The buildup on the refractory by the charge can be calculated by the difference in temperature ( $\Delta T$ ) between the furnace and the outside wall. If all the  $\Delta T$  values are known, e.g., furnace wall, insulation and refractory, then a change of total  $\Delta T$  (inside to outside of furnace wall) is a function of the additional glass or slag refractory formed on the inside of the furnace.

#### INDUCTION OR HIGH FREQUENCY ELECTRIC FURNACE

Simply stated, heat is generated and dissipated in this furnace type by induced currents. Thus the susceptor temperature is raised by transformation of electromagnetic energy to heat energy. To be heated, the material must conduct electricity. Many materials though, such as glass, conduct electricity only when heated and in the liquid state, therefore, they must be started by a conducting material.

The heating circuit can be thought of as a transformer, the primary of which carries the high frequency current. The susceptor, the material within the primary, becomes the secondary.

The relationship of current depth and

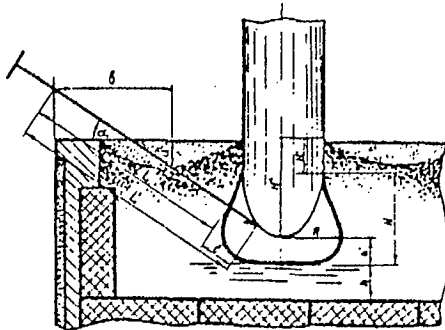
frequency is shown by the following equation (26):

$$T = \frac{1}{2} \pi \sqrt{\frac{P}{\mu f}}$$

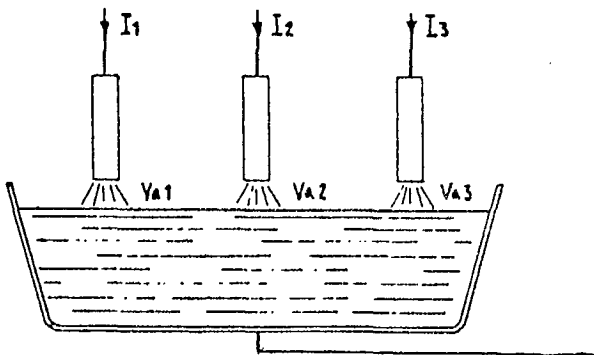
where  $T$  = centimetres  
 $P$  = resistivity of conductor  
 $\mu$  = magnetic permeability  
 $f$  = frequency

A characteristic of high frequency heating is the tendency to concentrate energy on the surface of the susceptor.

Graphite is generally used for the susceptor in atmospheric pressure furnaces and high temperatures can and have been reached. Precautions must be taken so that the graphite and refractory material do not react. Other materials used as susceptors are tungsten, molybdenum and tantalum.



(a) Submerged arc



(b) Open arc

Fig. 13 - Schematic representation of the principles of operation of two types of electric-arc furnaces (24)

A schematic diagram of an induction furnace is shown in Fig. 14 (27).

Because the reaction temperature and the rate of reaction between the graphite and refractory materials are related to their degree of contact, development work had been conducted to decrease the contact (27).

#### OTHER FURNACE TYPES

Some furnaces used for producing glass fibre or glass marbles are similar to those used for ceramic ware such as the regenerative-fired, recuperative-fired, and direct-fired types. The raw materials are crushed, blended and fed into the furnace automatically. They are usually of large size and temperature control is easily maintained (4).

#### FIBERIZATION PARAMETERS

The parameters for melting outlined previously in this report are also important for the fiberization process. In addition, the rate of flow, height of drop of the melt stream before fiberization, thickness of the stream, strand or filament, must all be controlled to provide the proper length, thickness, strength, and flexibility of the fibre product.

Despite the importance of this phase of the mineral insulation process, there is a scarcity of published information. Some experimental work has been done but the results at times have been contradictory. Zaitseva suggested that for centrifugal spinning of fibres the rate of flow of the melt should be 1700-2000 Kg/h at temperatures of between 1360° and 1380°C (28). This reduces the shot to a content of 26 to 21%. Zihilin stated that for the blowing method of fiberizing, the thickness of the molten stream should not exceed 15 to 20 mm in thickness (21). Good quality fibre and diameters up to 3 mm were obtained by Sperantov for melt streams of 15- to 20-mm diameter (29). A uniform flow rate had been determined by others as being necessary to produce good, consistent quality of fibres (30, 31, 32, 33).

It is almost intuitive and one can understand from first principles that temperature vari-



ations from any source, thickness of stream, temperature gradients, and pressure of the gas or air, all have an effect on the fiberization process and consequently on the fibre quality.

The mineral insulation industry uses two main methods of fiberization: (a) spinning, and (b) blowing, but details of the methods and the equipment design are considered by the individual companies to be confidential. Both methods produce some shot which is a small amount of bead material at the end of the formed fibre. Various techniques to reduce or eliminate this undesirable shot have been employed with some success.

### SPINNING

There are many variations of the spinning technique such as horizontal, vertical and cup types. All, however, are based on the centrifugal principle. This may take the form of flat plates or discs placed horizontally, or of spinning

wheels in single or multiple configuration. The wheel is dish shaped and generally water cooled. The wheel is concave in cross section and faced with special metals to minimize wear and erosion.

The molten stream falls onto or into the spinner which, revolving at high speed, causes the melt droplets formed to be thrown out at high speed, elongating the molten glass particle into a comet-like tail with a shot or bead attached. Much of the shot is removed before the fibre product is formed. Rotational speed of the wheel has not been scientifically calculated but is based on operator skill and experience and could benefit from further research. It is easily understood that proper operation, including speed of the wheels, could have an influence on the physical properties of the fibre, e.g., its length and diameter. It could also influence the amount of shot produced. (Fig. 15,16).

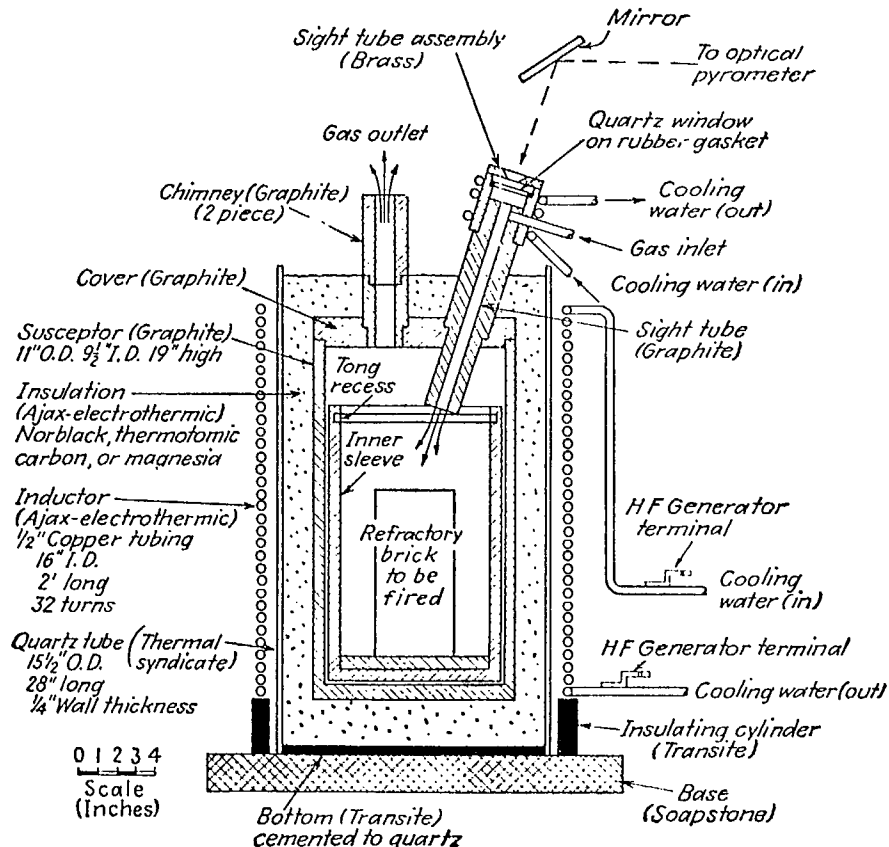


Fig. 14 - Schematic of high frequency furnace for atmospheric pressures (27)



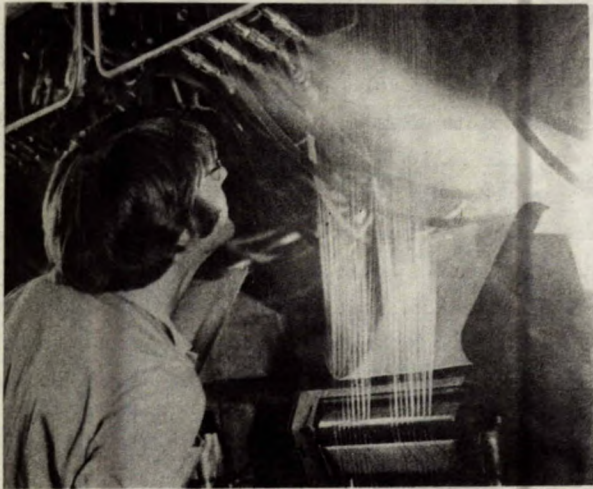


Fig. 15 - Glass fibre manufacture from a melt (34)

#### BLOWING OF THE MOLTEN LIQUID

A molten stream is allowed to fall from the furnace and at the proper distance from it is subjected to a blast or jet of high pressure air at right angles. The liquid forms small droplets which are propelled through the air. The droplets are elongated with a shot adhering to the end of the fibre.

Most commonly, the gas used in blowing is pressurized air but steam was also previously used. Industry has shown that no deleterious effects were experienced in switching from steam to air (35). Other gases have been used experimentally. Pressure of the gas has been said to have an effect on the shot content; it can be seen that it would also have an effect on the fibre length. Conflicting opinions about optimum gas pressure, 345 to 1380 kPa, (50 to 200 psi), indicates the need for further investigation.

Various nozzles are used or have been proposed for blowing mineral wool. Their design should allow a high gas velocity to elongate the particle. Fiberization is more complicated than appears at first glance and also requires further study.

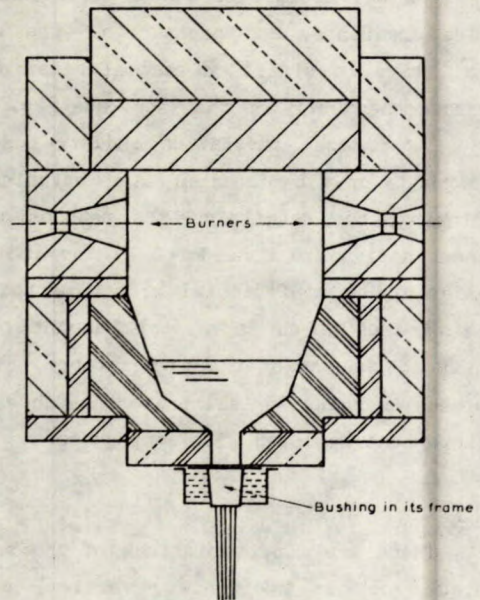


Fig. 16 - Cross section through forehearth showing bushing and glass fibre flow (2)

A simplified schematic diagram of a cupola-blowing process for rock wool is shown in Fig. 17.

An innovative furnace is the Pochet which has the bottom in the form of a water cooled bowl (2). The bowl is lined with a thin refractory layer to inhibit radiation. Molybdenum electrodes at the bottom heat the melt in a three-phase mode. Capacity is 7 t of glass a day and the temperature of the melt can reach 2000°C. Power consumed is 1.2 to 2.0 Kw/kg of glass melted. Additional advantages claimed are lower weight and lower cost per tonne of product. A schematic diagram of this furnace is shown in Fig. 18.

#### ENVIRONMENTAL CONSIDERATIONS

A deteriorating environment has caused public concern in recent years. The regulatory agencies have become firmer in enforcing regulations and require reduced emission from all machines and production processes.

Mineral wool processing plants have been studied in this connection (37, 38, 39, 40).

A flow diagram of the cupola process from

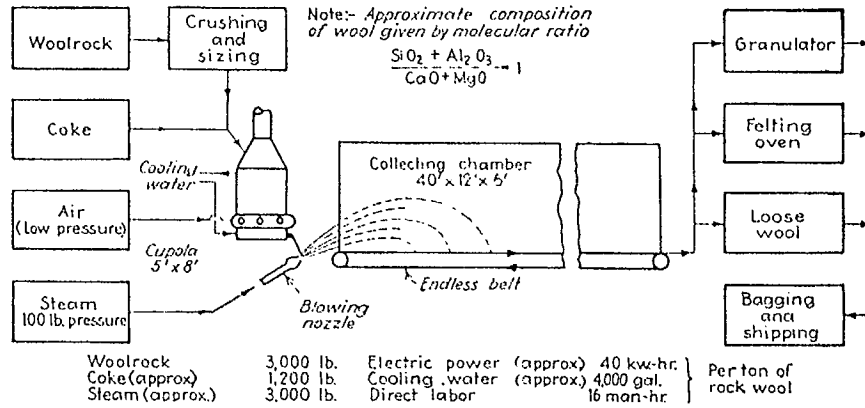
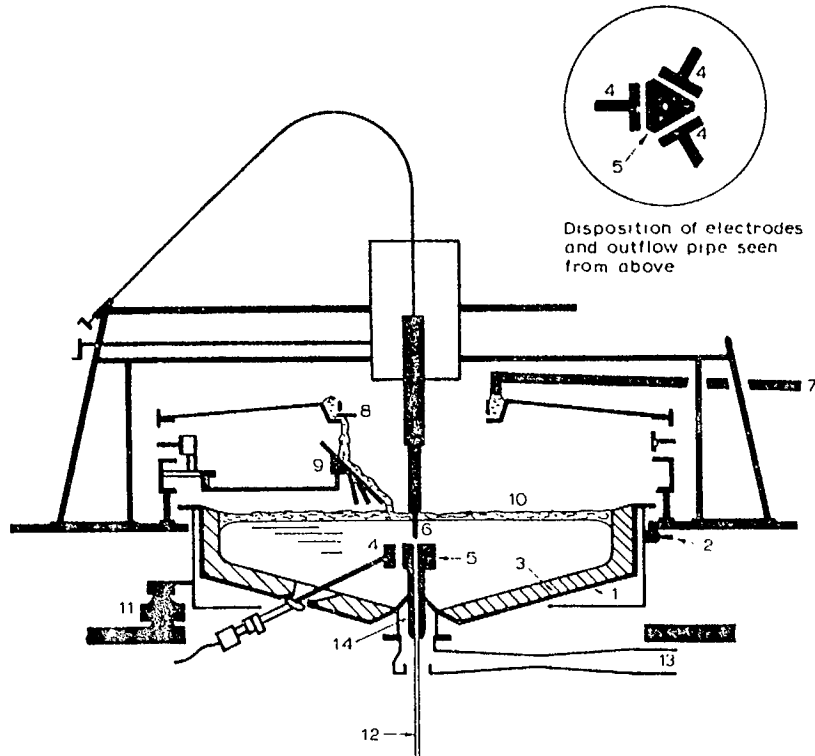


Fig. 17 - A schematic diagram of a rock wool plant (36)



1. Copper bowl surrounded by water-cooled pipes.
2. Cooling-water inlets and outlets.
3. Refractory radiation shield.
4. Electrodes.
5. Glass outflow pipe (see also insert).
6. Glass flow control rod.
7. Batch supply.
8. Rotating batch feeder.
9. Reciprocating batch distributor.
10. Permanent batch blanket.
11. Load cell.
12. Glass stream.
13. Exhaust duct.
14. Hydrogen blanket to shield molybdenum pipe.

Fig. 18 - The Pochet furnace (2)



one of these studies, is shown in Fig. 19. Emissions from the various steps in the process, must be controlled and this requires different techniques. Emissions from the various stages of operation as shown in Table 10 have been analyzed by Danielson of EPA\* (37).

#### EVALUATION OF THERMAL INSULATION

Evaluation tests can be divided into two types:

1. testing during processing and
2. materials testing.

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\*EPA - U.S. Environmental Protection Agency.

Tests during processing are not standard for all insulation material but have been adopted from various sources, generally from the ceramic and glass industries. For glass fibre they may include length, diameter, flexibility, thermal conductivity, density and surface tension of the melt, homogeneity of the melt and glass, and devitrification. These tests are obviously related to both processing and material quality.

Much of the second type of material testing relates to meeting standards for specific localities, and usually for buildings and homes. Most applications are covered by the American Society for Testing and Materials and the tests are generally used by Canadian authorities at

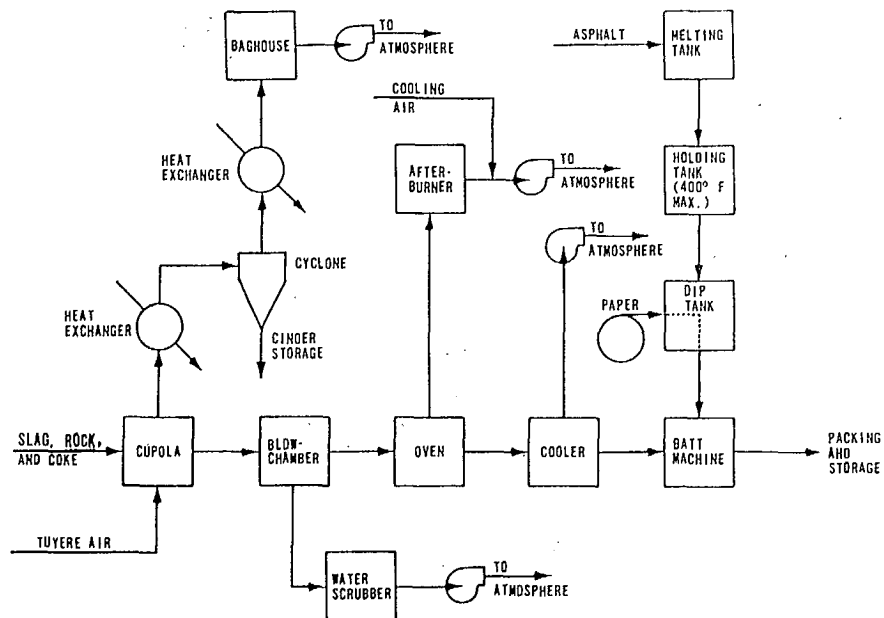


Fig. 19 - Flow diagram of a mineral wool fabrication process showing the stages venting to atmosphere (37)

Table 10 - Types of emissions in mineral insulation plants

| Type of plant | Process stage | Type of emission                              | Remarks |
|---------------|---------------|---|---------|
| Cupola        | Furnace stack | Gases e.g., $\text{CO}_2$ , $\text{SO}_2$ , F | major   |
|               | Blowchamber   | fine fibre, some fumes                        | major   |
|               | Curing oven   | fine fibre, organics                          | medium  |
|               | Cooler        | similar to cooling oven                       | small   |

least as a guide. Standard tests have also been written by the Canadian Standards Association and by the Canadian Government Specifications Board.

These tests include: thermal transmission properties, thermal conductance, specifications for batt insulation, mean specific heat, density of fibrous loose fill insulation and specifications for mineral fibre loose fill insulation. These specifications are included in ASTM C 764-73 which includes the following subject headings:

Classification

Basis of purchase

Materials and manufacture

Physical requirements

Workmanship

Test methods: Thermal resistance

Surface burning characteristics

Moisture absorption

Odour emission

Packaging and marking

For batt insulation the following tests are included:

density

thermal conductivity

handleability

fire resistance

standard sizes

workmanship

Details of testing are included in the Annual Book of ASTM Standards, in ASTM special publications, in publications by the Canadian Standards Association, Toronto, and the Canadian Government Specification Board (41,42,43,44 respectively).

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