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S. D. MARK, JR

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INDUCTION FURNACE

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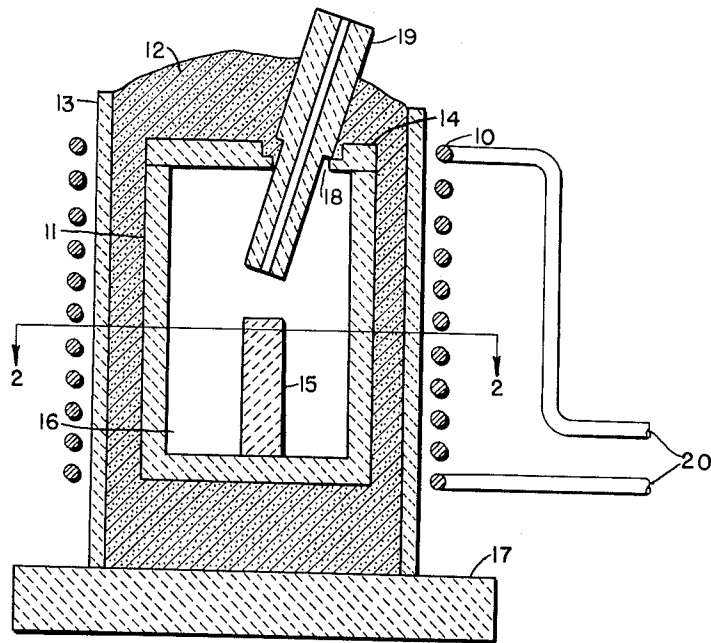


FIG. 1

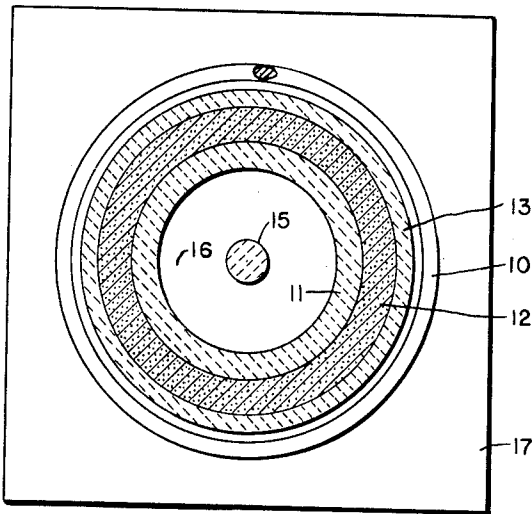


FIG. 2

INVENTOR.
STANLEY D. MARK, JR.
BY *W. J. Foley*

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INDUCTION FURNACE

Stanley D. Mark, Jr., Grand Island, N. Y., assignor to
The Carborundum Company, Niagara Falls, N. Y., a
corporation of Delaware

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The present invention relates to induction furnaces, and in particular to a new insulating material for use in induction furnaces.

A conventional type induction furnace comprises, as essential elements, an inductor, a susceptor, and insulation between the inductor and the susceptor. The inductor, which is an electrical conductor such as copper wire or tubing coiled around the outside of the furnace shell, is connected to a source of fluctuating electric current. The fluctuating current flowing through the inductor sets up a fluctuating magnetic field around the inductor, which causes an electric current to be induced in the susceptor. The susceptor usually is in the form of a cylinder made from electrically conducting refractory material, frequently graphite. In some cases, such as where the material to be heated is itself an electrical conductor, for example a metal, the material to be heated may act as the susceptor. Between the inductor and the susceptor there is a layer of insulating material. Where the susceptor is made of oxidizable material, such as graphite, this material has two main functions, namely to reduce the heat losses from the furnace and to protect the susceptor from oxidation. Between the layer of insulating material and the inductor coil there is usually a refractory insulator tube which has very low heat and electrical conductivity. It is frequently made from fused silica. The main purpose of this tube is to act as a retaining wall for the insulation.

The insulating material used in induction furnaces must have several essential characteristics. First of all, it must be a good heat insulator, so as to prevent excessive heat loss from the furnace. Secondly, the insulating material must be highly refractory so as to withstand high furnace temperatures. Thirdly, the insulating material must be dielectric in nature so that excessive flow of electricity it not induced in the insulation layer, thereby wasting power and heating the insulating layer. Fourthly, the insulating material must be capable of offering substantial protection from oxidation to the susceptor where the susceptor is made of readily oxidizable material, such as graphite. And lastly, the insulating material must not decompose or react at elevated temperatures so as to form materials which have a detrimental effect on the adjacent furnace elements, particularly the susceptor. Besides these five essential characteristics, there are other properties which are highly desirable in induction furnace insulating material, such as ease of handling and ability of the insulation layer to retain its shape when the susceptor is removed from the furnace after furnacing.

Heretofore finely divided carbon, such as carbon black, has been the most commonly used insulation material for induction furnaces. Because of its high pore volume this material is very good heat insulator. It is also highly refractory. It is readily oxidized by atmospheric oxygen and so offers substantial protection against oxidation to graphite susceptors because at elevated temperatures the carbon consumes the atmospheric oxygen before the oxy-

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gen can penetrate the carbon to the graphite susceptors. The oxidation products of carbon are gaseous and have no detrimental effect on other parts of the furnace. Because of its being in a finely divided state, at low power input frequencies very little flow of current is induced in an insulation layer of this material even though carbon has a relatively high electrical conductivity.

However, carbon black is far from an ideal insulation material for use even in low frequency induction furnaces. First of all, carbon black is extremely difficult to handle. Use of carbon black presents a serious house-keeping problem. Secondly, because of its high power of adsorption of gases, extreme care must be taken when heating it, especially for the first time, because expelled gases sometimes burst through the powdered mass, showering the area around the furnace with particles of hot carbon. And thirdly, carbon black does not cake so as to form an insulation layer which will retain its shape when the susceptor is withdrawn. Therefore, every time the susceptor is removed from the furnace removal of most of the carbon black is necessary before the susceptor can be put back in place.

While carbon black, as the insulation layer for low frequency induction furnaces, does perform the essential functions satisfactorily despite the aforementioned disadvantages attendant its use, it has been found that carbon black is highly unsatisfactory for insulation in induction furnaces operating on high power input frequencies, such as over 100 kilocycles per second. Although the carbon black particles are of the magnitude of only a micron or less in diameter, at high frequencies very substantial flow of electricity is induced in an induction furnace insulation layer made of carbon black. This is disadvantageous not only because of the waste in power but also because the flow of current in the insulation heats up the insulation layer. In some cases, the heating of the insulation radically hinders furnace operation. For example, using an induction furnace insulated with carbon black and having an input power frequency of approximately 400 kilocycles per second, it was found that the carbon black acted more like a susceptor than an insulator. During some runs at this frequency so great a flow of electricity was induced in the carbon black that the outside of the fused silica tube surrounding the insulation layer became hotter than the inside of the graphite susceptor. As an area of the insulation became overheated, it appeared to have increased susceptibility to induced flow of current, resulting in a rapid and progressive increase in the temperature of the area causing the formation of a growing hot spot. These hot spots rapidly increased in temperature to the point where there was danger of destroying the surrounding silica refractory tube. To protect the tube it was necessary to cut off the power to the furnace. Also, when areas of the insulation became red hot considerable arcing between the inductor and the silica tube occurred. The high temperature of the insulation of course reduced its effectiveness, resulting in excessive heat loss from the furnace. Furthermore, when the temperature of the carbon black insulation is increased excessive loss of this material through oxidation occurs.

It is an object of the present invention to provide induction furnaces which will perform satisfactorily when operated on very high power input frequencies.

It is a further object to provide induction furnaces having an insulation layer which will cake upon heating so as to maintain its shape.

These and other objects will become evident as the description proceeds.

It has been found that the above-mentioned and other objects may be accomplished by using a layer or loose filling of finely divided silicon carbide as the insulation

between the inductor and susceptor of an induction furnace. While this layer or loose filling is introduced into the space between the inductor and susceptor in the form of an unbonded loose granular or powdered material, the terms "layer" and "loose filling" are to be interpreted as covering not only the initial powdery material, but also a loose material which has become caked during use to the extent that it will substantially retain the form of the space filled so that the susceptor can be withdrawn without general collapse of the material. However, the terms "layer" and "loose filling" are not to be interpreted as covering a bonded body of material originally inserted as a molded shape or rammed or slip cast in situ and fired to bonded form.

For a complete understanding of the induction furnaces of the present invention, reference is made to the drawings in which

Figure 1 is a top view of a present invention induction furnace in operation; and

Figure 2 is a vertical sectional view along line 2—2 of Figure 1.

Referring to the drawings, an inductor 10, which may be copper wire or water cooled copper tubing, surrounds a susceptor 11. Positioned between the inductor 10 and the susceptor 11 is insulating material 12. Between the layer of insulating material 12 and the inductor 10 is a refractory tube 13, which acts as a retaining wall for the insulating material 12. Tube 13 is usually spaced slightly from the inductor 10, as shown in Figures 1 and 2.

In assembling an induction furnace of the type shown in Figures 1 and 2 the refractory tube 13 is placed upon a refractory support 17. The inductor 10 is then placed around the tube 13, spaced evenly therefrom a slight distance, such as one-half inch. Insulating material 12 is then poured into the refractory tube in sufficient amount to position the susceptor 11 the desired distance from the bottom of the refractory tube 13. The susceptor 11 is then placed centrally within the refractory tube 13. Insulating material 12 is then poured into the cavity between the susceptor 11 and the refractory tube 13 to a level approximately even with the top of the susceptor 11. The furnace is then ready to receive the material 15 to be heated. After this material 15 is placed within the susceptor 11, a refractory plate 14 is placed over the susceptor 11 so as to close the susceptor cavity 16. Additional insulating material is then poured over the plate 14. The furnace is then ready for heating.

In operation the inductor 10 is connected through leads 20 to the power supply (not shown) which provides either alternating electric current or pulsating direct electric current. This fluctuating electric current passing through the inductor 10 causes a fluctuating magnetic field to be set up in the surrounding area, which causes an electric current to be induced in the susceptor 11. The flow of electricity in the susceptor 11 causes the susceptor to become heated, thereby heating the material 15 in the cavity 16.

The precise structure of the induction furnaces coming within the scope of the present invention may take many forms. For example, the susceptor may be a cylinder closed at one end so as to form a crucible, as shown in Figure 1, or it may be open at both ends. The susceptor need not be circular in cross section as shown in Figure 2, but may be of square, oval, or other cross section. During operation the susceptor may be completely closed by the refractory plate during firing or, as shown in Figure 1 there may be a hole 18 in the refractory plate 14 which is placed over the top of the susceptor to permit introduction of temperature measuring devices, such as an optical pyrometer sight tube 19, and to allow escape of gases which may be formed during heating of the material to be furnace. Furthermore, the furnace may be positioned horizontally

with both ends of the susceptor completely open to permit continuous passage therethrough of material being treated. Refractory reflecting plates may be positioned within the insulation layer to reflect outflowing heat back toward the susceptor, as is well known in the art. Also, as aforementioned, where the material to be treated is an electric conductor, it may act as the susceptor with no other susceptor in the furnace, means such as an inner refractory cylinder being provided to maintain the cavity within the insulation wherein the material to be heated is placed.

In accordance with the present invention the insulating material 12 is finely divided silicon carbide. This material in the loose granular state is poured into the cavity between the susceptor and the refractory tube forming a layer with a high pore volume. Numerous forms of finely divided silicon carbide have been used as the insulating material, all of which have displayed the hereinafter mentioned desirable properties to varying degrees. For example, insulating layers of hexagonal crystalline structure silicon carbide of varying particle size and purity have been found to be satisfactory. Also, cubic crystalline structure silicon carbide is highly satisfactory.

To determine the effectiveness of these various types of silicon carbide as induction furnace insulating material, a furnace such as that shown in Figure 1 was constructed. The inductor was connected to a source of 400 kilocycles per second alternating or pulsating direct electric current, which power source was provided with means for regulating the power input so as to maintain a constant effective intensity magnetic field surrounding the inductor. With the magnetic field set at a constant effective predetermined value, the furnace, insulated with the type of silicon carbide being tested, was heated. For the types of silicon carbide insulation material tested, the times required to heat the cavity within the susceptor to 2000° C. were recorded, which times are a direct measure of the effectiveness of the different insulating materials. In some cases it was impossible to obtain a temperature of 2000° C. within the susceptor at the set effective magnetic field intensity because of excessive heat losses from the furnace. In these cases the maximum temperature obtainable and the approximate time required to reach this equilibrium temperature were recorded. The results of these tests are shown in Table I. This table also shows the results of an identical test using carbon black as the insulating material.

As shown in Table 1, during Test 8 using carbon black as the insulating material, the maximum temperature reached was only 1750° C. While it did not appear that equilibrium had been reached at this temperature so that a higher temperature could not have been reached at the set effective magnetic field intensity, it was necessary to discontinue this test at this point because high temperature hot spots were rapidly forming in the insulation layer causing the silica refractory tube surrounding the insulating material to become overheated to such a degree that further heating would have destroyed it. During this test with carbon black as the insulating material, while maintaining the constant effective magnetic intensity the power input increased 44%, as shown in Table I, although a temperature of only 1750° C. was reached. It was clearly apparent that the carbon black layer was acting more like a susceptor than an insulator. A highly excessive amount of power was being dissipated by induced currents in the insulation, thereby heating the insulation and so increasing the heat losses from the furnace. Other similar tests at different effective magnetic intensities have shown power input increases during the tests ranging as high as 60%. From these tests it was apparent that the use of carbon black as the insulating material for an induction furnace operating on this high power input frequency is highly unsatisfactory.

TABLE I

Test No.	Material	Particle Size Range in Microns	App. Dens. of Powder in g./cc.	Calculated pore volume of powder in percent	Time required to reach 2,000° C. with a constant effective magnetic field intensity	Power Input to Furnace, in kilowatts		Percent increase in furnace power during test
						at start	at final temperature	
1.....	SiC-Hexagonal Crystalline Structure.	75 to 15.....	1.37	56.8	Equilibrium at 1,810° C. after 100-120 min.	5.75	6.0	4.35
2.....	do.	63 to 12.....	1.39	56.2	Equilibrium at 1,950° C. after 100-120 min.	5.75	6.25	8.70
3.....	do.	40 to 5.....	1.05	66.9	102 minutes.....	5.50	6.0	9.08
4.....	do.	30 to 3.....	0.88	72.4	88 minutes.....	5.75	6.0	4.35
5.....	do.	under 35.....	0.96	69.7	73 minutes.....	5.75	6.0	4.35
6.....	do.	under 5.....	0.69	78.3	62 minutes.....	5.75	6.0	4.35
7.....	SiC-Cubic Crystalline Structure.	under 3.....	0.58	81.7	70-74 minutes.....	5.75	6.25	8.7
8.....	Carbon Black.....	under 1.....	0.44	80.5	52 minutes to 1,750° C. (silica tube overheated).	6.25	9.0	44.0

In contrast to the unsatisfactory results obtained when using carbon black as the insulating material, Table I shows that granular silicon carbide, in a wide range of particle sizes and of both the hexagonal and cubic crystalline types, in highly satisfactory for use as the insulating material for high frequency induction furnaces. As would be expected, the types of silicon carbide having the smaller particle sizes and so the greater pore volumes were the most effective. However, even the silicon carbide having the larger particle sizes was more satisfactory than carbon black. While it was impossible to obtain a temperature of 2000° C. during Tests 1 and 2, the maximum temperatures obtained during these tests were higher than the maximum safe temperature obtained in Test 8, for which test carbon black was used as the insulation.

Furthermore, there was no indication of flow of induced current in the silicon carbide insulation layers during any of these tests. No hot spots formed and there was no overheating of the silica tube. In contrast to the 44% power input increase while heating to only 1750° C. during Test 8 when carbon black was the insulating material, during Tests 1-7 where temperatures ranging to 2000° C. were reached there was an increase of only about 4-9% in the power input to the furnace, as shown in Table I. This is further evidence of the substantial absence of induced currents in the insulation layer. It was also noted that the power input at the start of Test 8 was about 9% higher than the power input at the start of Tests 1-7, indicating that even at room temperature there is substantial power dissipated in induced currents in the insulation layer when this layer is carbon black.

At the completion of each of the above-mentioned tests, the graphite susceptor was removed from the furnace and inspected. There were no noticeable signs of oxidation or other deterioration after any of the tests, thus showing that silicon carbide is highly effective in protecting the graphite susceptor.

Upon removal of the susceptor from the furnace at the completion of Tests 1-7, the insulating layers retained their shape, thereby preserving the cavity formed by the susceptor. The insulation was found to be caked firmly enough to permit handling, but not so firmly as to be unable to be crumbled by hand. In general, the coarser grain insulation layers caked more firmly than the finer grain layers. Because of the silicon carbide insulating layers retaining their shape, it was possible to reinsert the susceptor without removing the insulating material.

In contrast to the ability of the silicon carbide insulating layers of Tests 1-7 to retain their shape after firing, the carbon black insulating layer of Test 8 collapsed upon removal of the susceptor, making it impossible to reinsert the susceptor without first removing most of the insulating material.

All of the forms of silicon carbide used in these tests are extremely easy to handle. They are much easier

to wash from the hands than is carbon black. Furthermore, silicon carbide is not so readily retained in air so as to dust the surrounding area as is carbon black. For these reasons use of silicon carbide instead of carbon black greatly minimizes the housekeeping problems of induction furnace operation.

The hexagonal variety silicon carbide used in Tests 1-6 was made in a resistance furnace by the conventional procedure of passing an electric current through a carbon core to heat a surrounding layer of raw mix comprising silica sand and a source of carbon such as petroleum coke. Hexagonal silicon carbide forms when the raw mix is heated to a temperature of about 2100° C. to 2500° C. The silicon carbide thus formed, after the removal from the furnace in the conventional manner, was crushed and graded for size.

To remove impurities such as carbon and iron, after crushing and grading the silicon carbide used in Tests 1-4 was water washed and then washed with a 15% solution of 95% sulphuric acid. After the acid treatment it was again water washed, dried, the resulting caked mass broken up, and the grain regraded for size.

The silicon carbide used in Test 5 was not acid treated, the only treatment being crushing, grading, and water washing. Because it was not acid treated it is relatively high in impurities.

The silicon carbide used in Test 6 was treated with a hydrofluoric acid solution, followed by a sulphuric acid wash, and then a caustic wash to remove the impurities. The purified product was then water washed, wet graded and dried.

The cubic variety silicon carbide used in Test 7 was made by reacting for two hours in an induction furnace heated to 1800-2000° C. a raw mix of silicon and carbon mixed in stoichiometric proportions for forming silicon carbide. The furnace product was a powdery mass and was used without further treatment. However, cubic silicon carbide made by other methods is equally suitable for this purpose.

The carbon black used in Test 8 was a very high purity grade of carbon black commonly sold and used for induction furnace insulating material.

The chemical analyses of the insulating materials used in Tests 1-8 is given in Table II.

TABLE II

Chemical constituents in per cent

Test No.	SiC	Free C	SiO ₂ +Si	Fe+Al	CaO+MgO
1.....	96.63	0.46	1.93	0.50	nil
2.....	97.45	0.35	1.42	0.53	nil
3.....	93.77	1.36	2.99	0.93	nil
4.....	96.26	0.60	2.19	0.53	nil
5.....	91.47	0.74	2.77	4.22	nil
6.....	97.77	0.93	1.26	0.04	-----
7.....	96.67	1.0	2.33	-----	-----
8.....	-----	99.87	-----	-----	-----

¹ Ash content was 0.13 percent.

As can be seen from the above table, the purity of the silicon carbide used in Tests 1-7 varied substantially. The material used in Tests 2 and 6 was of very high purity. On the other hand the Test 5 material was relatively impure. Nevertheless, as is shown by Table I, Test 5 material was highly satisfactory, the temperature of 2000° C. being obtained almost as quickly in Test 5 as in Test 6, and quicker in Test 5 than in Test 2. In fact from these tests it appears that less pure silicon carbide, such as 91% purity of the Test 5 material, may be equally as effective for induction furnace insulation material as the higher purity grades. The differences in heating time between Tests 2, 5 and 6 can probably be attributed to the difference in particle sizes of the test materials. The only substantial difference noticed in the performance of the Test 5 and Test 6 materials was that the Test 5 material caked harder during the heating than did the Test 6 material. It therefore appears that the degree of purity of the silicon carbide is not an essential factor. It is believed that the desirable properties of silicon carbide as the insulation material for induction furnaces would be present although the purity of the material were much lower than the purity of the Test 5 material. In fact, satisfactory results would probably be obtained although the insulation material contained, besides silicon carbide in predominant proportions, substantial proportions of an inert granular material.

Table I shows that silicon carbide from a wide range of particle sizes is satisfactory insulation material. The smaller particle sizes have superior heat insulating properties, as would be expected because of the greater pore volumes of such material. This is shown by the speed of heating during Tests 4-7 where the temperature of 2000° C. was easily and quickly reached. As the particle size is increased the pore volume decreases, and the heat losses from a furnace lined with such material become relatively greater as demonstrated in Tests 1-3. However, since, as aforementioned, in none of the Tests 1-7 wherein silicon carbide was used as the insulation was there any indication of any current being induced in the insulation layer, it is believed that where the insulating requirements of the insulating material are less drastic, such as where the insulation layer is relatively thick or the desired temperature is relatively low, much larger particles of silicon carbide will function wholly satisfactorily.

While silicon carbide having a large range of particle sizes is satisfactory for use as insulation material for induction furnaces, the results of the above-mentioned tests clearly show that the finer particle sizes which form more porous layers are superior for some uses. For example, when an induction furnace is designed for operating at extremely high temperatures, such as 2000° C. and above, it is desirable that the particle size be relatively small, preferably having a maximum particle size of about 60 microns or less so that the insulation layer has a pore volume of at least 50% and preferably 60% or more. As the desired maximum furnace temperature is reduced, layers of larger particle sizes and lower pore volumes may be used with completely satisfactory results. In general, it is desirable that the pore volume be high enough to give satisfactory thermal insulation. At lower temperatures a pore volume of perhaps slightly less than 50% would be satisfactory.

While finely divided silicon carbide is particularly desirable for use as the insulation material in high frequency induction furnaces, this material may be used to substantial advantage even in low frequency induction furnaces. That is, regardless of the input frequency of the induction furnaces, granular silicon carbide insulating layers not only perform the essential functions of insulating the susceptor and protecting it from oxidation, but also possess the desirable properties of ability to retain their shape after firing and ease of handling, which properties are not possessed by the carbon black commonly used for this purpose. Therefore, it is not intended

to limit the scope of the present invention to the use of silicon carbide in induction furnaces of a specific range of input frequencies.

Furthermore, since the specific form of the induction furnaces of the present invention is not critical, the scope of the present invention is not to be limited to the specific forms of induction furnaces herein disclosed.

While some literature reports silicon carbide as starting to decompose into silicon vapor and carbon at temperatures of about 1700° C., most recent literature reports that the decomposition of silicon carbide does not occur until a temperature of from 2200° C.-2500° C. is reached. Numerous furnace runs of substantial duration have been made where temperatures up to 2300° C. have been reached within the susceptor, after which runs inspection of the silicon carbide insulation layers revealed no signs of decomposition of the insulating material. It is believed that if any decomposition is taking place at these temperatures, it is occurring so slowly that it is unnoticeable. Therefore, the present invention is not limited to induction furnaces designed for operation only at low temperatures.

Having described the invention, it is intended to claim:

1. An electric induction furnace comprising an inductor, a susceptor, and a loose filling comprising finely divided silicon carbide positioned between the inductor and susceptor.
2. An electric induction furnace as in claim 1 in which the silicon carbide is of the hexagonal crystalline form.
3. An electric induction furnace as in claim 1 in which the silicon carbide is of the cubic crystalline form.
4. An electric induction furnace comprising an inductor, a susceptor, a refractory insulator positioned between the inductor and susceptor, and a loose filling comprising granular silicon carbide positioned between the refractory insulator and the susceptor.
5. An electric induction furnace for use with power input frequencies above 100 kilocycles per second comprising an inductor, a susceptor, and a loose filling comprising finely divided silicon carbide positioned between the inductor and the susceptor.
6. An electric induction furnace for use with power input frequencies above 100 kilocycles per second comprising an inductor, a susceptor, a refractory insulator positioned between the inductor and susceptor, and a loose filling comprising finely divided silicon carbide positioned between the refractory insulator and the susceptor.
7. An electric induction furnace for use with high power input frequencies comprising an inductor, a susceptor, and a layer comprising finely divided silicon carbide positioned between the inductor and the susceptor.
8. An electric induction furnace comprising an inductor, a susceptor and a layer comprising finely divided silicon carbide positioned between the inductor and susceptor, said silicon carbide having a maximum particle size of about 60 microns in diameter, said layer having a pore volume of at least 50%.
9. An electric induction furnace comprising an inductor, a susceptor and a layer comprising finely divided silicon carbide positioned between the inductor and susceptor, said layer having a pore volume of at least 50%.
10. An electric induction furnace as in claim 9 in which the silicon carbide is of the cubic crystalline form.
11. An electric induction furnace comprising an inductor, a susceptor and an insulation layer positioned between the susceptor and inductor, said insulation layer comprising a loose filling of finely divided silicon carbide.
12. An electric induction furnace comprising an inductor, a susceptor and an insulation layer positioned between the susceptor and inductor, said insulation layer having a pore volume of at least 60% and comprising finely divided silicon carbide.
13. An electric induction furnace as in claim 12 in which the silicon carbide is of the cubic crystalline form.

14. In an electric induction furnace comprising an inductor and a susceptor, an insulating layer comprising finely divided silicon carbide having a pore volume of at least 50% positioned between said inductor and said susceptor.

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