Dec. 8, 1959 J. W. MARDEN ET AL 2,916,535

ULTRA-HIGH-TEMPERATURE FURNACE

Filed May 1, 1948 3 Sheets-Sheet 1

Fig. 1.

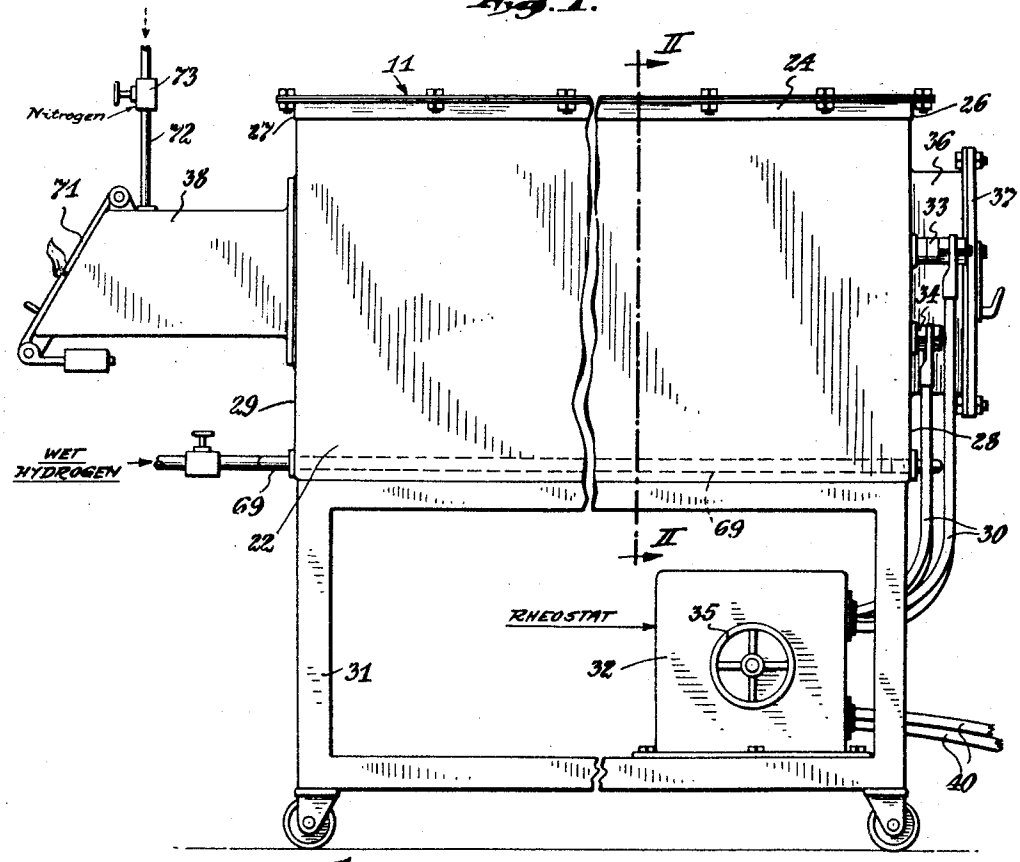


Fig. 2.

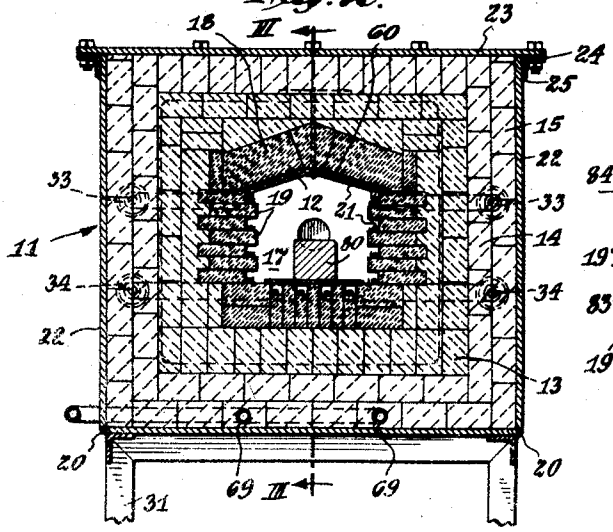
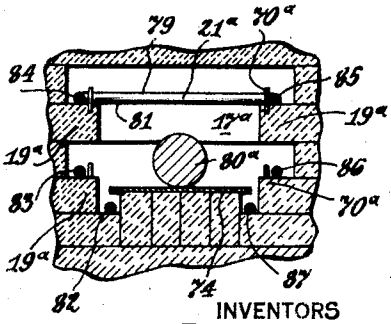


Fig. 9.



INVENTORS
J. W. MARDEN
D. M. WROUGHTON
R. F. BAKER.
BY
ATTORNEY

Dec. 8, 1959 J. W. MARDEN ET AL 2,916,535

ULTRA-HIGH-TEMPERATURE FURNACE

Filed May 1, 1948 3 Sheets-Sheet 2

Fig. 3.

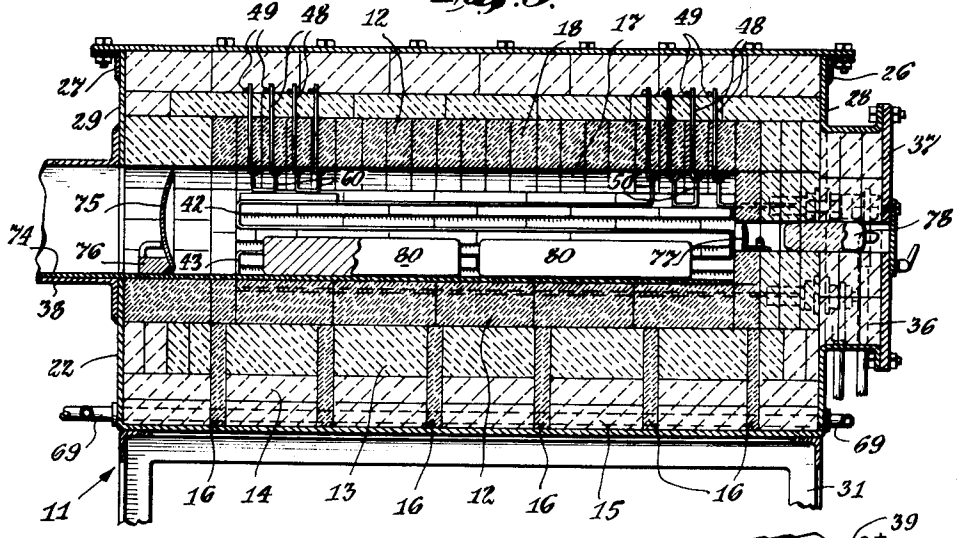


Fig. 4.

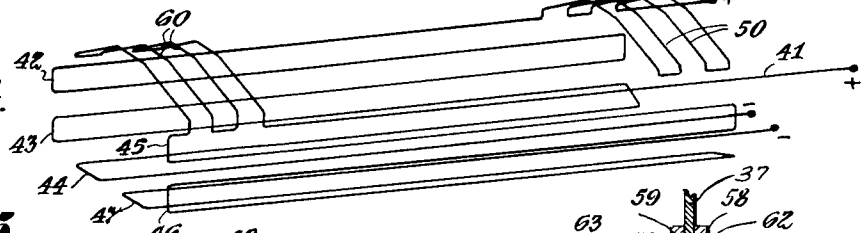


Fig. 5.

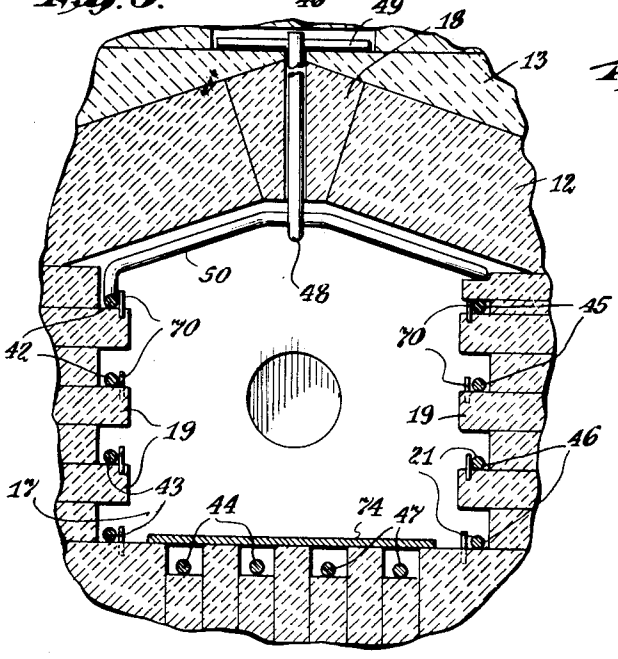


Fig. 6.

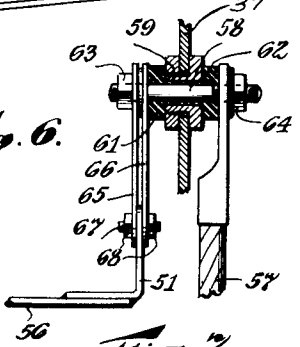
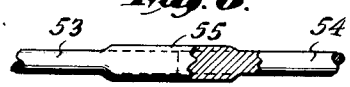


Fig. 7.



Fig. 8.



INVENTORS
J. W. MARDEN
D. M. WROUGHTON
R. F. BAKER.
BY
ATTORNEY

Dec. 8, 1959 J. W. MARDEN ET AL 2,916,535

ULTRA-HIGH-TEMPERATURE FURNACE

Filed May 1, 1948 3 Sheets-Sheet 3

Fig. 10.

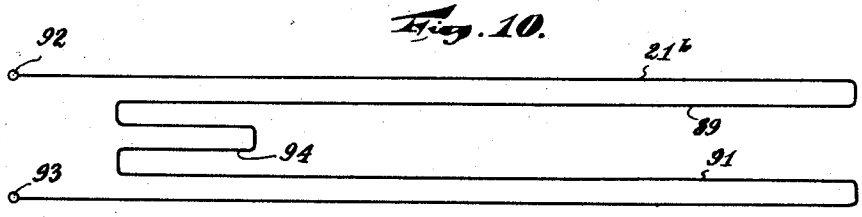


Fig. 11.

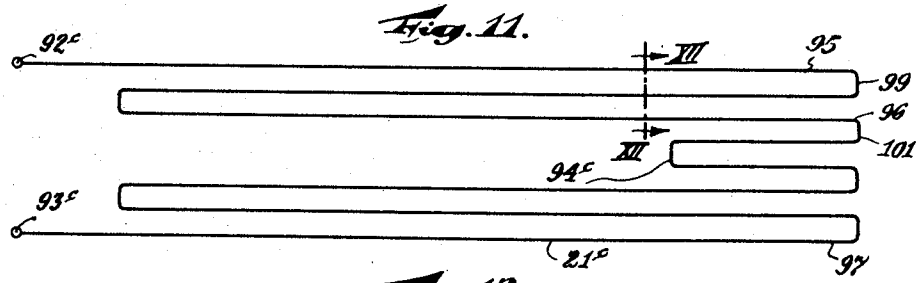


Fig. 13.

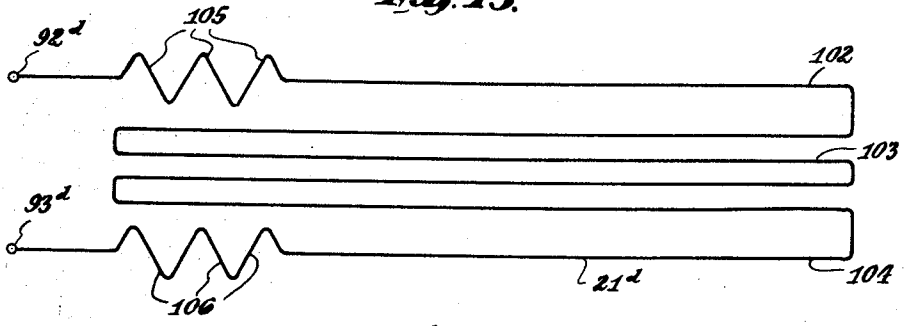


Fig. 14.

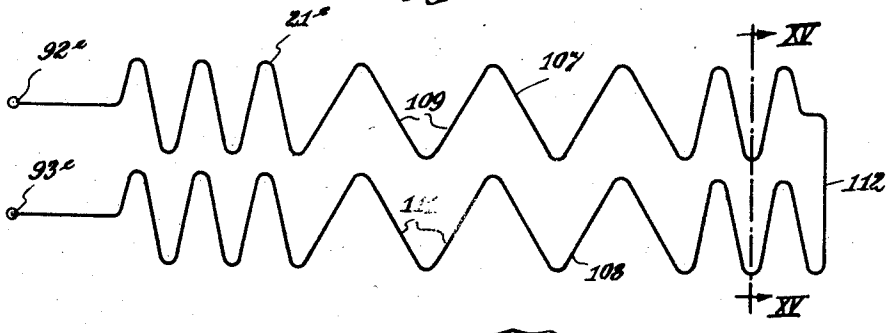


Fig. 12.

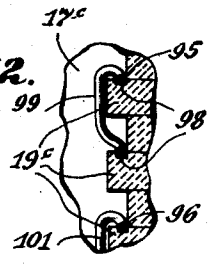
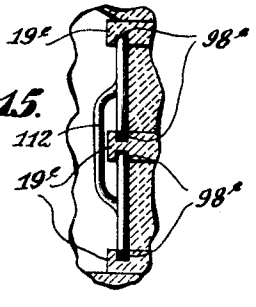


Fig. 15.



INVENTORS
J. W. MARDEN
D. M. WROUGHTON
R. F. BAKER
BY
ATTORNEY

United States Patent Office 2,916,535
Patented Dec. 8, 1959

2,916,535

ULTRA-HIGH-TEMPERATURE FURNACE

John W. Marden, East Orange, Donald M. Wroughton, Livingston, and Robert F. Baker, Newfoundland, N.J., assignors to Westinghouse Electric Corporation, East Pittsburgh, Pa., a corporation of Pennsylvania

Application May 1, 1948, Serial No. 24,466

21 Claims. (Cl. 13—22)

This invention relates to furnaces and, more particularly, to such adapted for temperatures up to about 2300° C.

A principal object of our invention, generally considered, is to produce an electric resistance furnace adapted to efficiently operate at temperatures as high as 2300° C., whereby it may be used for sintering and/or heat-treating refractory metals such as tungsten and molybdenum.

Another object of our invention is the production of a rugged furnace, lined with very refractory material, such as zirconia, beryllia, thoria, or magnesia, of a size and shape depending upon the needs of the operator, and electrically heated by means of a refractory-metal element, whereby very high temperatures are obtainable.

A further object of our invention is the provision of a furnace having a heavy, rugged, electrical-resistance element, supported by high temperature bricks, and replaceable upon removing an end plate.

A still further object of our invention is the provision of an ultra-high-temperature furnace, in which the heating time to full temperature is reduced to a matter of a few hours, rather than days as has been necessary in the past.

An additional object of our invention is the provision of a high-temperature furnace heated by a low voltage resistance element, whereby burn-out due to conduction or arcing through the insulation is avoided.

Another object of our invention is the provision of a furnace heated electrically by a tungsten resistance member or elements, whereby temperatures up to 2300° C. are obtainable, making it possible to treat therein tungsten in wet hydrogen, as disclosed in the Hall et al. patent, No. 2,431,690, dated December 2, 1947.

A further object of our invention is to provide a furnace which is elongated and has an opening at one or each end, overhead, side, or bottom additional straight or zig-zag heating elements being employed adjacent said one or each end to increase the effective length of the hot zone and practically equalize the temperature from end to end.

A still further object of our invention is to improve high temperature furnace construction by interspacing high mechanical strength alumina or other high-melting point brick at intervals in the bottom portion thereof to prevent sagging at high temperatures with heavy loads, using a keyed arch at the top to give structural strength during operation, providing high-temperature material, such as zirconia or "alundum" brick, staggered as the inner lining to provide supporting ledges for the heating elements, and welding or bolting the joints between the outer steel plates of the furnace to make a practically gas tight enclosure, except for the door at the end.

Other objects and advantages of the invention will become apparent as the description proceeds.

Referring to the scale drawing:

Figure 1 is a side elevational view of a furnace embodying our invention.

Figure 2 is a transverse sectional view on the line II—II of Figure 1, in the direction of the arrows.

Figure 3 is a longitudinal sectional view on the line III—III of Figure 2, in the direction of the arrows.

Figure 4 is a perspective diagram of the refractory metal heating elements.

Figure 5 is a view corresponding with the central portion of Figure 2, but on a larger scale.

Figure 6 is a detailed view showing a terminal connection.

Figure 7 is a view showing the initial stage in the connection of abutting ends of two sections of resistance heating elements.

Figure 8 is a view corresponding to Figure 7, but showing the final stage in making a welded joint, after the wire initially wound around the abutting ends has been fused in place.

Figure 9 is a view corresponding to Figure 5 but showing a modification, and looking toward the front opening.

Figure 10 is an elevational diagram of another embodiment of our refractory-metal heating element.

Figure 11 is an elevational diagram of a further embodiment of our refractory-metal heating element.

Figure 12 is a sectional view on the line XII—XII of Figure 11, a portion of the furnace with which the heating element is associated, being also illustrated.

Figure 13 is an elevational diagram view of still further embodiment of our refractory-metal heating element.

Figure 14 is an elevational view of an additional embodiment of our refractory metal heating element.

Figure 15 is a sectional view on the line XV—XV of Figure 14, a portion of the furnace with which the heating element is associated, being also illustrated.

Some of the features of the type of furnace, which will now be described, are: (1) The furnace is of rugged construction for withstanding severe temperature conditions; (2) the furnace may be operated economically; (3) low voltage is used whereby danger to personnel is avoided and the possibility of short circuiting reduced; (4) special construction of heating elements may be provided to increase the effective length of the hot zone and substantially stabilize the temperature along the length of the heating chamber; and (5) provision is made for access to the furnace interior or heating chamber, whereby minor repairs to the heating member or brick work can be made without disturbing said member.

The construction of the ultra-high-temperature furnace **11**, one embodiment of which is illustrated in Figures 1 to 8, inclusive, involves a number of novel details, while at the same time avoiding unnecessary complications. It is built without mortar or other cementing material between the several kinds of bricks, to withstand the stresses caused when an ingot or ingots **80** of molybdenum or tungsten, for example, weighing several hundred pounds is or are pushed in or pulled out at temperatures which may range up to 1750° C. for molybdenum and as high as 2300° C. for tungsten.

In the first embodiment referred to, at least three types of refractory bricks are illustrated. Although a fourth type may be employed as an inner lining, in accordance with the embodiment of Figure 9, the three types illustrated in this form are, first, an alumina brick called "Alundum." A commercial embodiment of this is designated as Norton RA 1139, "Alundum." With such an inner lining, however, temperatures as high as 1750° C. may be withstood.

If it is desired to operate the furnace with an inner temperature of about 2000° to 2300° C., the heating chamber **17** should be completely lined, except at the front end, with a material such as zirconium oxide refractory brick, here designated **12**, using a preferably stabilized zirconia which does not crumble on repeated

heating and cooling. A commercial example of this is that designated Norton stabilized zirconium oxide refractory, Mix L 2090–A–35. Such material should be a minimum of two inches thick at all points, and backed with a minimum of two and one half inches of pure aluminum oxide refractory brick **13**.

The aluminum oxide refractory is, in turn, backed by a layer of high temperature brick **14**, a commercial example of which is Babcock and Wilcox, K–30, which is, in turn, backed by a low temperature insulating brick **15**, a commercial example of which is Babcock and Wilcox, K–23. The K–30 brick will withstand temperatures as high as 1600° C. and has approximately only 1/5 the heat conductivity of the RA 1139 brick. These bricks are so arranged in a furnace as to make the best use of the temperatures they will withstand, as well as their insulating properties.

An exception of this rule is illustrated in Figure 3, where alumina brick **16** are placed at intervals beneath the innerlining, which may be of the same material or of zirconia or the like, as a protective measure against sagging after continual operation at elevated temperatures. Such bricks, however, could be dispensed with if room were provided for an additional layer of alumina brick without sacrificing the outer or insulating bricks.

As shown most clearly in Figures 2 and 3, the upper portion or ceiling of the furnace chamber **17** is defined by a keyed arch **18**, rather than flat brick work covering the span. This is because high temperature material, such as alumina brick, becomes quite brittle after its low temperature binder is baked out. This often causes cracking, which in the case of flat brick construction, would result in brick portions falling into the hot zone. If an arch is used, the brick does not sag or fall out in the case of cracks, since it is firmly held at the sides. For this reason, it is of extreme importance that the arch brick be securely backed up.

In the inner lining is of zirconia, or approximate equivalent such as beryllia, thoria, or magnesia, in order to enable the attaining of temperatures as high as from 2000° to 2300° C., it is necessary to back this up with alumina brick, as well as with the other two insulating bricks above mentioned, examples of which are K–30 and K–23, because the heat conductivity of such high temperature materials is relatively high.

The purpose of staggering the inner-lining bricks, as illustrated most clearly in Figures 2 and 5, is to provide supporting ledges **19** for the molybdenum or tungsten heating member **21** along its entire length, since said member if not so supported will sag under its own weight at elevated temperatures. The inwardly protruding bricks **19** also safeguard the member and minimize the possibility of shorts or damage, by bumping, to said member which is quite brittle when cold. The elements of the heating member are desirably held in place on the ledges **19** by the grooves, studs or pins **70** set thereinto, as illustrated in Figures 2 and 5, and desirably formed of tungsten or molybdenum.

A consideration of Figures 1, 2 and 3 will show that the furnace has an outer cover **22** consisting of steel plates, the side ones of which are welded at their bottom edges to the side edges of the bottom plate, as indicated at **20**, providing gas-tight joints, and the trough so formed is covered by a top plate **23**, the side edges of which are bolted to the outstanding flanges **24** of angle irons which may be welded to the top edge portions of said side plates, as indicated at **25**, as well as corresponding angle irons **26** and **27** at the respective ends of the furnace and correspondingly secured to end plates **28** and **29**, thus making an inclosure in which a reducing or protective gas may be kept pure to thereby protect the heating member from deterioration. The whole furnace may be mounted on a wheeled frame **31**, which carries rheostat **32** from which cables **30** go to the terminal connections **33** and **34** on the one hand, and cables **40** to the transformers (not shown) on the other. A rheostat control wheel **35** is shown provided on the box or housing of rheostat **32**.

At the back end of the furnace there may be provided a reduced section **36** which facilitates taking temperature measurements and permits access to the furnace without disturbing the terminal connections which are therebeyond. Inasmuch as most of the repairs necessary to the heating member are at the back end of the furnace, these repairs can be effected by removing the small pack plate **37**, which is bolted to the furnace as illustrated in Figures 1 and 3. Also this plate can be replaced by one with a nose opening on it, as represented by the access extension **38** on the front end of the furnace, when it is desired to remove the ingots from either end of the furnace. The brick work can be changed to match the other end without much difficulty. In many cases, a broken heating member has been repaired by welding it together without removal from the furnace.

The heating member **21** of the first embodiment is shown as made in two sections **39** and **41**, each supplied by an independent source of power. Each section is shown with three longitudinal loops or hair pins **42**, **43**, and **44** of **39**, and **45**, **46**, and **47** of **41**, two on a wall and one on the floor of the furnace. At either end of the furnace, relatively-small transverse loops **50** and **60** may be passed over the top of the heating chamber directly beneath the arch, those marked **50** from the section **39** being at the back end of the furnace, and those marked **60** from the section **41** being at the front end thereof. These transverse loops provide additional heat if desired at the furnace ends where the heat loss is the greatest, thereby tending to substantially equalize the temperature along the full length of the furnace. Optionally, these additional heating portions may be placed only adjacent the front end or that provided with an access door.

As shown in Figure 5, the overhead loops, those marked **50** being shown, are bent to conform to the shape of the arch. When in place, the central loop portions may be suspended by refractory metal hangers **48**, desirably formed of tungsten or molybdenum, and passing through corresponding apertures in the keystone of the arch, and the upper ends held in place by being welded or otherwise attached to transverse rods **49** of corresponding refractory metal.

The tungsten or molybdenum heating member, or section if formed in two sections as illustrated, may be bent to the desired shape without considerable difficulty by heating the area where a bend is desired, with an oxy-hydrogen torch until soft. The bend should not be too sharp as the material is likely to crack. Such cracking may not be immediately damaging, but it will cause a higher resistance point, and may ultimately result in failure after continued operation.

Because of the difficulty of obtaining molybdenum or tungsten rod of sufficient length for the entire member or section, to facilitate repair, it is desirable to make joints where necessary at the back end of the furnace. The material for the heating member is desirably molybdenum or tungsten rod, .300" or .350" in diameter.

Connections between two loops or hairpins, and between the member and the molybdenum straps **51**, one assembly of which is shown in Figure 6, are welded together by the use of an atomic-hydrogen arc welder. A connection between two loops may be made by making a coiled sleeve **52**, as shown in Figure 7, of .060" molybdenum wire and inserting the two ends, **53** and **54**, of the loops into the ends of the sleeves. The final connection is then made by melting the molybdenum wire and rod together as uniformly as possible to a form as represented in Figure 8. Although the welded portion **55** is apparently firm, it is in reality quite brittle, since

recrystallization has occurred in the entire heated area and extreme care must be taken in handling.

It is not necessary to make a sleeve to connect the heating element **56** to the molybdenum strap. The two surfaces can be made to fuse together by increasing the power of the atomic-hydrogen welder and melting the two surfaces until they flow together, as shown in Figure 6.

Figure 6 also illustrates how the heating member is connected to the power lines on the outside of the furnace. The power passes from the transformers, not shown, through a copper cable **57**, which is desirably 500,000 circular mil in size, to a desirably 1" diameter copper stud **58** which passes through the back of the furnace. Gas leakage around the studs is prevented by use of a bushing **59** and two washers **61** and **62**, backed by two 1" copper nuts **63** and **64** which secure the parts of the assembly. The bushing and washers are formed of refractory fibrous material, preferably such as asbestos board, sometimes called "Transite." The connection between the copper stud and the heating member **21**, through element **56**, is accomplished by the molybdenum strap **51**, which as illustrated is L shape, by means of flat straps **65** and **66**, also of molybdenum because they pass into an area which is too hot for the use of copper straps. These flat straps may be 3/16" thick, 2" wide, and 10" long, and bolted to the L-shaped strap by means of a molybdenum stud **67** and nuts **68**. Such a connection permits removal of the heating member without disturbing the terminal connections, which are not readily accessible.

The hydrogen gas, or other atmosphere such as, for example, nitrogen, argon, cracked ammonia, and cracked or partially combusted illuminating gas, used as atmosphere in the furnace, is introduced through two preferably ½" pipes **69** which run the length of the bottom of the furnace. These pipes have small holes along their entire length to permit even distribution of the gas. The rate of gas flow is measured in cubic feet per hour. In a preferred system, the hydrogen flows through a water bubbler to wet it as desired for heat treating molybdenum or tungsten, in practicing the method described and claimed in the Hall et al., patent, No. 2,431,690, dated December 2, 1947. The hydrogen must pass through the bubbler after passing through the flow meter, as the wet gas moistens the glass and indicator and prevents accurate control. The amount of gas used in one embodiment of our furnace may vary between 40 and 80 cubic feet per hour.

When the furnace door **71** at the front end is opened, it is necessary to increase the rate of flow several times to prevent air from entering the furnace. In the case of a large furnace door, it has been found extremely helpful to use nitrogen or illuminating gas as a curtain. This not only prevents air from entering the furnace, but also decreases the amount of hydrogen, and hence reduces the fire hazard due to the large flame. The nitrogen or other gas for use as a curtain, may be introduced through the pipe **72** passing into the extension **38** near its outer end and controlled by valve **73**. Nitrogen gas may also be used to replace the hydrogen as the furnace-treating gas at lower temperatures where hydrogen is not available. However, such gas should be completely free from oxygen, as otherwise the heating member is likely to be oxidized.

In order to prevent material from sticking in the grooves in the furnace floor, a hearth **74** of molybdenum sheet may be employed to cover the entire area and facilitate sliding in or pulling out of ingots. This hearth may be .1" to .15" thick and when desired 9" to 10" wide. It may be made of two or more pieces laid side by side. The length of the hearth is dependent upon the length of the furnace. The ends of the hearth may be bent at right angles and tucked between the brick and the furnace wall at either end. This will hold the hearth rigid and keep it from sliding during operation.

An additional method of reducing heat loss at the ends, is by the use of baffles of refractory metals such as molybdenum or tungsten. For example, a baffle may be made of two sheets of molybdenum spaced about 2" apart and properly supported to allow it to stand upright in the space between the hot zone and the furnace door. In a reducing atmosphere, the molybdenum sheet reflects the heat and increases the effective length of the furnace. The heavier the molybdenum sheet, the longer the baffle will last. One form of baffle is represented at **75**. In this case, however, it is shown concave toward the inner end of the furnace and supported on a base **76**. A smaller baffle **77** is shown at the other end of the furnace, and back of that is a refractory plug **78** to minimize loss of heat.

The furnace operation is not complicated. Required temperatures are obtained by means of a power-stat which controls the amount of energy supplied to the heating member, or members if in two sections. The output of the power-stat is impressed on the primary of a desirably 36 kva. current transformer, with transformation ratios of approximately 3–1, 4–1, and 5–1. The low voltage power is then tied directly to the terminal posts on the furnace. One power-stat and one transformer are desirably used for each half or section of the heating element, if in two sections. A voltmeter reading to 270 volts and an ammeter reading to 180 amperes may be employed using a supply line of 220 volts.

At a temperature of 1750° C., one embodiment of our furnace, such as represented in Figures 1 to 5, inclusive, consumes about ⅔ kva. per foot of element length, or about 20 kva. total. However, when it is desired to increase the temperature rapidly, it is necessary to use more power than the amount needed to maintain a constant temperature. The rate at which the furnace temperature can be increased is limited by the current capacity of the power-stat. As the temperature increases the current decreases if the voltage is maintained constant. The current decrease allows an added increase in the power-stat control.

A smaller furnace, such as illustrated in Figure 9, may be used on 20 to 30 volts and 450 to 500 amperes when operating at a temperature of about 2000° C. A variable transformer with 0 to 110% regulation and with a 5 to 1 ratio is desirably employed. This wide range of regulation is desirable because of the high temperature coefficient of resistance of tungsten, the resistivity increasing about 10 times as the temperature rises from 0° C. to 2000° C. Cold furnaces must therefore be started at low voltage to prevent drawing excessive current. The features of the furnace, however, are not dependent upon the particular voltage source or type of equipment control used.

A furnace, such as illustrated in Figure 9, has been operated at about 2050° C. as measured optically on the work or ingot **80a** being treated. Safe temperatures are limited by melting or electrical conduction of the high temperature insulating brick. If the thickness of both the zirconia and alumina brick were increased, the safe operating temperature would also be increased. To reduce power requirements more insulating brick may be added. The optimum size of the box would, therefore, be considerably larger, for the same size heating chamber, than that illustrated, although any suitable size may be used.

The furnace in accordance with our invention, will to our knowledge operate at a temperature at least 300° C. higher than any other known similar furnace employing metal resistance elements. Such high temperature is made possible by the combination of rugged tungsten or molybdenum heating elements and zirconia or other highly refractory linings, such as beryllia, thoria, and magnesia.

The rugged heating member provides mechanical strength which prevents breakage while loading or un-

loading the furnace, and which also permits the furnace to be heated very rapidly. The staggered brick work construction provides for free radiation of heat from the member to the work, while at the same time supporting the member and protecting it from contact with the work. The large diameter of the member and consequent low operation voltage, minimize the danger of burnouts caused by electrical conduction through the refractories at or near the maximum operating temperature, or by reaction between the refractories and member. Repairs to the heating member can be effected rapidly by removal of the back plate, permitting access to the terminals or the welded connections. The entire member may be removed through this opening and replaced or repaired without disturbing the major part of the brick work.

Figure 9 shows the smaller embodiment referred to on the same scale as Figure 5, in which the treating compartment is comparatively small, whereby it is not necessary to arch the ceiling as in the form of Figure 5. In this form, the bricks **19a** are staggered, as in the first embodiment, providing supporting ledges for the heating member **21a**. However, as the width of the treating chamber is relatively small, the end of the, in this case, single heating member **21a**, instead of being supported from the top, as in the first embodiment, merely runs across the end of the furnace, as indicated at **79**, being supported on a corresponding back ledge **81**, or not, as desired, in the chamber **17a**.

In this form, it will be seen that the power may pass in at the bottom from the back end, or that opposite the access opening, forward as through part **82**, to a hairpin or loop, returning at **83**, and then pass forward through part **84**, extend across the furnace adjacent the open end through part **79**, unsupported if desired because the distance is small, back through part **85**, forward through part **86**, returning through part **87** to pass out of the furnace. As in the previous embodiment, pins **70a** may if desired serve to hold the member on its ledges. In this embodiment, the inner lining is supposed to be of zirconia, backed by the three linings mentioned in connection with the first embodiment in successive order of decreasing refractoriness, and increasing insulating effectiveness.

Referring now to the embodiment of our invention illustrated in Figure 10, there is shown diagrammatically a heating member **21b**, formed of refractory metal such as tungsten or molybdenum as in the first embodiment.

This member may be a complete heating member for a furnace, or only one section, and formed for permanent location in a furnace, or adapted for sliding into place and withdrawal for repairs when necessary. It comprises two longitudinal loops or hairpins **89** and **91**, which are adapted to extend along a side, bottom or top wall of a furnace or be distributed along a plurality of walls. The electric heating power is supplied to the heating member at its ends **92** and **93**, which make connection with an outside source.

The hairpin portions may be supported on ledges, such as those designated **19** in Figure 5, those designated **19a** in Figure 9, those designated **19c** in Figure 12, or those designated **19e** in Figure 15, the last two figures having not yet been described. In order to provide additional heating portions where most needed, it being assumed that this is the case at the left hand end of the furnace holding the member **21b**, as because of an access opening or for other reason, the member **21b** is provided with a reentrant portion or relatively short loop or hairpin **94** which provides that much additional heating surface at said left hand end. If the member **21b** is a complete heating unit, with the loops **89** and **91** distributed along a plurality of walls, the short hairpin **94** loops across the heating chamber.

Referring now to the embodiment of invention illustrated in Figures 11 and 12, there is shown a heating member **21c** formed with three, rather than two, longitudinal loops or hairpins **95**, **96**, and **97**, electric power being supplied to said heating member at its ends **92c** and **93c** as in the previous embodiment. Said member, as in other embodiments, is formed of a refractory metal, such as tungsten or molybdenum, and the loops or sections thereof may be supported as described in connection with previous embodiments. In this case, it is assumed that more heat is needed in that part of the furnace holding the right hand end portion of the heating member **21c**, and a reentrant portion or short loop or hairpin **94c** is provided at this point.

Figure 12 illustrates how the loops or hairpin portions may be supported in the present embodiment from ledges **19c** projecting into the heating chamber **17c**, like the ledges **19** illustrated in Figure 5. In the present embodiment, however, the ledges **19c**, provided by bricks of refractory material projecting inwardly beyond the neighboring bricks, are provided with grooves **98** in their upper surfaces, respectively receiving the upper and lower elements of hairpin **95** and the upper element of the hairpin **96**, the elements therebelow being supported in a similar manner, but not here illustrated.

The turns or extreme ends of the hairpins are shown inwardly offset into the heating chamber, as indicated at **99** and **101**, thereby clearing the ledges **19c** and making it possible to insert and withdraw the entire heating element from the furnace heating chamber, if supported as illustrated in Figure 12 at a wall thereof, from an access opening of sufficient size.

Referring now to the embodiment of our invention illustrated in Figure 13, there is shown a heating member **21d** of refractory metal such as tungsten or molybdenum, said member receiving electric power from its ends **92d** and **93d**, and usable as in the preceding embodiments, and comprising longitudinally extending loops or hairpins **102**, **103**, and **104**. In the present instance, additional heat is provided for at the left hand end of the member, as for reasons explained in connection with preceding embodiments, by zig-zagging or forming upper elements of a hairpin **102** with corrugations or saw-tooth portions **105**, thereby providing additional heating area at said left hand end, and/or forming the lower element of the hairpin **104** similarly as indicated at **106**.

Referring now to the embodiment of our invention illustrated in Figures 14 and 15, there is shown a heating member **21e** receiving power at its ends **92e** and **93e**, formed of refractory metal and usable as in the preceding embodiments. Said member comprises a single loop or hairpin, consisting of an upper element **107** and a lower element **108**, each element being zig-zagged or formed with saw-tooth portions **109** and **111**, respectively. Said portions **109** and **111**, however, are varied in pitch or distance therebetween, that is, more closely spaced at an end, or at the ends, or at positions where more heat is desired, in order to equalize the heat distribution in the heating chamber in which disposed.

These elements may be held in position along a side wall, bottom, or top wall of a furnace, as by having properly spaced ledges **19e** formed with grooves **98e**, as in Figure 12, only the intermediate ledge **19e** has both upper and lower grooves, while the upper ledge **19e** has a downwardly-opening groove and the bottom ledge **19e** has an upwardly-opening groove, so that the facing grooves may respectively receive the upper and lower ends of the corrugations or saw-tooth portions **109** and **111**, respectively, to thereby hold them in position as illustrated. The extreme end of the hairpin, or that portion **112** joining the sections **107** and **108** is bent outwardly, as illustrated in Figure 15, to clear the intermediate ledge **19e** and thereby permit unimpeded application and removal of the heating member.

Although the members **21b** to **21e**, inclusive, have been described as if they were for application to side walls de-

fining heating chambers, it will be understood that they may, if desired, be applied to the bottoms or floors of such chambers, or to the tops or ceilings thereof, the floors or ceilings, as the case may be, being then correspondingly formed for the reception of said heating members and, if desired, adapted as illustrated in Figures 1 and 15 for the free application or removal thereof, as through an access opening or door.

The following table gives data on two furnaces embodying our invention:

	Furnaces 1 and 8	Furnace 7
Dimensions:		
Heating chamber	9¾" x 10" x 110"	5" x 5" x 24".
Steel furnace shell	40" x 36" x 140"	24" x 24" x 40".
Hearth to bottom of furnace shell	13¼" (actual) 13¾" (preferred)	9½" (act.). 9¼" (pre.).
Approx. element length	330"	110".
Number elements req'd	4	1.
Material of elements	Molybdenum	Tungsten.
Diameter of elements	.300"	.300".
Types of brick used	RA 1139, K-30, K-23.	Zirconium oxide RA 1139, K-30, K-23.
Max. safe temp	1750° C	2,100° C.
Approx. min. time—Max. temp.	12 hours	10 hours.
H requirements—Door closed.	80 cu. ft./hr	40 cu. ft./hr.
H requirements—Door open.	300 cu. ft./hr	150 cu. ft./hr.
N requirements—Door open.	300 cu. ft./hr	200 cu. ft./hr.
Power requirements/element at—		
1,000° C	89 a.—112 v.—10.0 kva.	80 a.—66.3 v.—5.3 kva.
1,350° C	91 a.—130 v.—11.8 kva.	84 a.—85 v.—7.1 kva.
1,700° C	95 a.—156 v.—14.8 kva.	89 a.—107 v.—9.5 kva.
2,000° C		105 a.—128 v.—13.4 kva.
Number of transformers req'd.	4	1.
Type of transformers	Current	Current.
Size of transformers	36 kva.—40, 50, 60 v. sec.	36 kva.—40, 50, 60 v. sec.
Number of powerstats req'd.	4	1.
Size of powerstats	6 gang—270 v. sec.	6 gang—270 v. sec.
Rating of powerstats	45 kva	45 kva.
Dia. of cu. terminals	1"	¾".

From the foregoing, it will be seen that we have provided a very desirable furnace operable at very high temperatures. Although preferred embodiments have been illustrated, it will be understood that modifications may be made within the spirit and scope of the appended claims.

We claim:

1. In an electric furnace, in combination, an insulating housing with an interior wall defining an elongated space to be heated and a bare electrical resistance heating member supported on, and spaced from the inner surface of, said wall, radiating heat directly to said space when energized, with main portions extending longitudinally in said space, elements of said heating member adjacent an end of said space, overlying and disposed laterally of said main portions in order to provide additional heat where heat is most needed for equalizing the temperature of said space.

2. In an electric furnace, in combination, an insulating housing with an interior wall defining an elongated space to be heated, a bare electrical resistance heating member supported on, and spaced from the inner surface of said wall, radiating heat directly to said space when energized, with main portions extending longitudinally in said space, and means for equalizing the temperature of said space comprising elements of said heating member, looping transversely over the top, adjacent an end of said space, overlying and disposed laterally of said main portions, in order to provide additional heat near said ends where heat is most needed.

3. In an electric furnace, in combination, an insulating housing defining an elongated space to be heated and provided with longitudinally extending generally horizontal wall ledges disposed above a floor portion, a

heating member in said space radiating heat directly to said space when energized, and formed of material selected from the group consisting of tungsten and molybdenum, said heating member comprising a lower hair-pin portion which extends from an outside connection through the rear portion of said furnace, passes forwardly along said floor to near the front end, then rearwardly along one side wall while resting on one of said ledges, and then forwardly along an overlying ledge, looping across said space to be heated adjacent the front end to a ledge along the opposite wall of said furnace, passing rearwardly along said ledge, forwardly along a ledge therebeneath, and finally passing rearwardly along said floor to a connection outside of said furnace.

4. In an electric furnace, in combination, an insulating housing defining a heating chamber, a heating member in said chamber and formed of the material selected from the group consisting of tungsten and molybdenum to be heated by the passage of electricity therealong, said member being formed as longitudinally extending loops disposed respectively along the interior surfaces of opposite side walls and along the floor of said chamber, other sections of said member comprising loops extending transversely at the top of said chamber near opposite ends, and refractory supporting members projecting from the portion of said housing defining the upper portion of said heating chamber and engaging intermediate portions of said loops to prevent sagging thereof.

5. In an electric furnace, in combination, an insulating housing defining an elongated space to be heated, a heating member in said space and formed of material, selected from the group consisting of tungsten and molybdenum, to be heated by the passage of electricity therealong, said member comprising elements looping back and forth longitudinally of the furnace and elements, in series therewith, looping back and forth transversely of the furnace adjacent ends thereof, in order to equalize the temperature along the elongated space of said furnace to be heated, said space being defined by refractory brick, some of which project into said space beyond adjacent bricks, defining longitudinally extending ledges, said longitudinal heating element sections resting on said ledges, and support means projecting from above into said space to be heated and engaging said transversely extending sections in order to prevent sagging thereof.

6. In an electric furnace, in combination, an insulating housing defining a heating chamber, an electrical heating member in said chamber, radiating heat directly to the space therein when energized, the portion of said housing immediately adjacent said chamber being constructed of material selected from the group consisting of zirconia, beryllia, thoria, and magnesia, and forming an inner highly- refractory shell adapted to withstand temperature as high as 2300° C., said inner shell being backed and surrounded by a second shell of alumina, in turn backed and surrounded by a third shell of brick which will withstand temperatures as high as 1600° C. and with lower conductivity than said alumina, a fourth shell of low-temperature brick of still higher insulating value, and an outer shell of steel, making the furnace suitable for holding treating atmospheres such as hydrogen.

7. In an electric furnace, in combination, an insulating housing defining an elongated space to be heated, a heating member radiating heat directly to said space when energized, in said space, said member comprising elements looping transversely over the top of said space adjacent each end, in order to equalize the temperature therealong by supplying additional heat where most needed, elements extending longitudinally along both sides and along the bottom of said space, the portion of said housing defining said space disposed, immediately adjacent and engaged by said elements, being constructed of material selected from the group consisting of zirconia, beryllia, thoria, and magnesia, and forming an inner highly-refractory shell adapted to withstand temperatures as high

as 2300° C., said inner shell being backed and surrounded by a second shell of alumina, in turn backed and surrounded by a third shell of brick which will withstand temperatures as high as 1600° C. and with lower heat conductivity than said alumina, a fourth shell of low-temperature brick of still higher insulating value, and an outer shell of welded steel, making the furnace suitable for holding treating atmospheres such as hydrogen.

8. In an electric furnace, in combination, an insulating housing defining an elongated space to be heated, an electrical heating member in said space, radiating heat directly to said space when energized, the portion of said housing immediately adjacent said space being constructed of alumina forming an inner highly-refractory shell adapted to withstand temperatures as high as 1750° C., said inner shell being backed and surrounded by a second shell of brick which will withstand temperatures as high as 1600° C., and with lower conductivity than said alumina, a third shell of low-temperature brick of still higher insulating value, and an outer shell of steel, making the furnace suitable for holding treating atmospheres such as hydrogen, all the elements of said housing being put together in directly abutting relationship, and the portions of the inner shell defining the top of said heating chamber, sloping from a keystone portion, in order to avoid the possibility of material dropping from said housing into said heating chamber.

9. In an electric furnace, in combination, an insulating housing defining an elongated space to be heated, a heating member in said space and formed of material of the group consisting of tungsten and molybdenum, to be heated by the passage of electricity therealong, said member being formed as two independently-controllable sections, one comprising elements looping transversely over the top of said space near one end, extending longitudinally along the interior surface of one side wall defining said space, and along the bottom adjacent said side wall, and the other section comprising elements looping transversely over the top of said space near the other end, extending longitudinally along the interior surface of the other side wall thereof, and along the bottom adjacent said other side.

10. In an electric furnace, in combination, an insulating housing defining a heating chamber, an electrical heating member in said chamber, the material of said housing defining said chamber being formed of material selected from the group consisting of zirconia, beryllia, thoria, and magnesia and forming an inner highly-refractory shell, said inner shell being backed and surrounded by a second shell of alumina, in turn backed and surrounded by a third shell of brick which will withstand temperatures as high as 1600° C. and with lower heat conductivity than said alumina, a fourth shell of low-temperature brick of still higher insulating value, an outer shell of welded steel making a gas-tight furnace portion for holding treating atmosphere such as hydrogen, an extension of reduced section at one end of said furnace, a hinged door at the extreme end of said extension, a pipe for introducing a treating atmosphere into said heating chamber, and a pipe leading directly to said extension, whereby when said door is open a gas such as nitrogen may be admitted through said pipe to form a curtain to prevent undesired contamination of the treating atmosphere in said furnace.

11. In an electric furnace, in combination, an insulating housing defining a heating chamber, an electrical resistance member in said chamber, said member being positioned on generally horizontal ledges in inwardly opening channels along the walls of said chamber, over the top of said chamber at an end, and in upwardly opening grooves in the floor of said chamber, in order to distribute the heat introduced to provide a substantially uniform temperature throughout said chamber, and a plate of metal selected from the group consisting of tungsten and molybdenum closing the floor grooves and adapted to support ingots of material for treatment.

12. In an electric furnace, in combination, an insulating housing defining a heating chamber, an electrical resistance member in said chamber, and means for introducing power to said resistance member comprising copper cables from power supply means, copper studs passing through a wall of said housing, connections between said cables and studs, molybdenum plates connected to the inner end portions of said studs, and welds between the inner end portions of said plates and the ends of said resistance member.

13. In an electric furnace, in combination, and insulating housing defining a horizontally elongated heating chamber open at an end, an electrical resistance member in said chamber, and means for conserving the heat of said chamber comprising a base resting on the floor of said chamber and a inwardly concave imperforate reflector of refractory metal upstanding from said base and approximately closing said open end for directing heat back into said chamber.

14. In combination with an insulating housing defining an elongated space to be heated, a bare electrical resistance heating member radiating heat directly to said space when energized and formed of material of the group consisting of tungsten and molybdenum, said member comprising main portions extending longitudinally along the inner surface of walls of said housing and supplemental portions of said heating member adjacent an end of said space, overlying and disposed laterally of said main portions to provide additional heat where most needed for temperature-equalizing purposes.

15. In combination with an insulating housing defining an elongated space to be heated, a bare electrical resistance heating member radiating heat directly to said space when energized and formed of material of the group consisting of tungsten and molybdenum, said member comprising main portions extending straight horizontally and longitudinally along the inner surface of one side wall of said housing, and along the bottom adjacent said side wall for major portions of their lengths, and elements of said heating member adjacent an end of said space overlying and disposed laterally of said main portions, by being zig-zagged to bunch heating effect where needed for equalizing the temperature in said space.

16. In combination with an insulating housing defining an elongated space to be heated, a bare electrical resistance heating member radiating heat directly to said space when energized and formed of material of the group consisting of tungsten and molybdenum said member comprising main hairpin portions extending straight longitudinally in the elongated space of said housing and lining the floor and opposite side walls thereof, and elements of said heating member looping over the top adjacent an end of said space, overlying and disposed laterally of said main portions, in order to provide additional heat where most needed for temperature-equalizing purposes.

17. In combination with an insulating housing defining an elongated space to be heated, a bare electrical resistance heating member radiating heat directly to said space when energized and formed of material of the group consisting of tungsten and molybdenum, said member comprising elements looping over the top adjacent an end of said space, overlying and disposed laterally of a main portion of said member extending longitudinally along the inner surface of one side wall thereof, and along the bottom adjacent said side wall, to cooperate with a complementary heating member for equalizing the temperature in said space.

18. In combination with an insulating housing defining an elongated space to be heated, a bare electrical resistance heating member radiating heat directly to said space when energized and for an electric furnace, formed of material of the group consisting of tungsten and molybdenum, comprising a lower hairpin portion to extend

from an outside connection into the back of said chamber, pass along the floor to near the entrance end, then bend back and pass along the adjacent side wall to near the back end, and then bend up and pass thereabove toward the furnace entrance end, loop across said chamber, return along the opposite wall to the furnace back end, then turn and pass to the entrance end of said furnace, and finally return along the floor to a back connection outside of said chamber.

19. In an electric furnace in combination, an insulating housing defining a heating chamber, a heating member in said chamber and formed of material selected from the group consisting of tungsten and molybdenum to be heated by the passage of electricity therealong, said member being formed as longitudinally extending loops disposed respectively along the interior surface of opposite side walls and along the floor of said chamber, other sections of said member comprising reentrant relatively short loops disposed transverse of said longitudinally extending loops at the top of said chamber near opposite ends, and refractory supporting members projecting from the portion of said housing defining the upper portion of said chamber and engaging intermediate portions of said loops to prevent sagging thereof.

20. In an electric furnace, in combination, an insulating housing defining a heating chamber, an electrical heating member in said chamber, said member comprising main portions extending longitudinally of said chamber, elements of said heating member adjacent an end of said chamber, overlying and disposed laterally of said main portions for temperature-equalizing purposes, the outer shell of said chamber making a gas-tight furnace portion for holding treating atmosphere such as hydrogen, an extension at one end of said furnace, a door at the extreme end of said extension, a pipe for introducing treating atmosphere into said chamber, and a curtaining gas admitting pipe leading directly to said extension near its outer end whereby when said door is open a gas such as nitrogen may be admitted through said last mentioned pipe to form a curtain to prevent undesired contamination of the treating atmosphere in said furnace.

21. In an electric furnace, in combination, an insulating housing defining a heating chamber, an electrical resistance member in said chamber, and means for introducing power to said resistance member comprising studs insulated from said housing and passing through a wall thereof, connections between power supply means and said studs, molybdenum plates connected to the inner end portions of said studs, and welds between the inner end portions of said plates and the ends of said resistance member.

References Cited in the file of this patent

UNITED STATES PATENTS

787,584	Matteson	Apr. 18, 1905
813,483	Casaday et al.	Feb. 27, 1906
1,413,678	Moffat	Apr. 25, 1922
1,432,442	Collins	Oct. 17, 1922
1,495,503	Armstrong	May 27, 1924
1,515,511	Milner	Nov. 11, 1924
1,545,155	Mehner	July 7, 1925
1,547,002	Ruckstahl	July 21, 1925
1,555,542	Young	Sept. 29, 1925
1,624,217	Cope	Apr. 12, 1927
1,652,200	Hanson	Dec. 13, 1927
1,731,166	Ipsen	Oct. 8, 1929
1,803,282	Morgan	Apr. 28, 1931
1,904,580	Van Nordstrand	Apr. 18, 1933
2,156,608	Schon et al.	May 2, 1939
2,230,141	Heuer	Jan. 28, 1941
2,254,047	Roth	Aug. 26, 1941
2,292,826	Devers	Aug. 11, 1942
2,319,065	Karmanocky	May 11, 1943
2,351,490	Cooper	June 13, 1944
2,404,059	Hall	July 16, 1946
2,404,060	Hall et al.	July 16, 1946
2,465,137	Van Nordstrand	Mar. 22, 1949

FOREIGN PATENTS

323,271	Great Britain	Dec. 23, 1929