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Studies Of Parametric Analysis Of High Temperature Resistance Furnace

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ABSTRACT:

High temperature resistance furnace, so far in the conventional systems regarding manufacturing, temperature controlling and heating to the desired temperature, cause tremendous thermal losses, very bulky and costly affairs in resistance heating operating up to 1600 degree C. Though the concept of 'high temperature resistance furnace' is quite old, but, recent development of material science has created a radical change in the aspects of manufacturing process, like, in the concept of insulation, concept of control systems and in the design of heating system astonishingly. Considering all the new-age developments, **present proposed work is outlined specifically to meet the requirements of** followings :

" high and low temperature furnace with compound heating system (using two different types of heating elements up to 1600 degree C), to achieve optimum thermal efficiency (minimum thermal losses)".

A new design of compound heating using two different elements, viz. silicon carbide (SiC) and molybdenum di sillicide (MoSi2) elements simultaneously to attain required temperature (1600 degree C), with minimum consumption of current, arresting thermal losses using improved insulation to improve thermal efficiency, and with latest control systems (PID programmable type). The goal of this experiments is to achieve optimum thermal efficiency with skin temperature equal to the room temperature, to achieve accurate results in terms of resolution and sensitivity, and for continuous operations in multiple programmable cycles etc set for various heating processes requiring temperature from ambient temperature up to 1600 degree C in multiple ranges to be programmed before to be followed continuously one after another, for wide range of applications as laboratory furnaces, testing the equipments within the temperature 1600 degree C (maximum), as high temperature 'sintering production' furnaces etc. The present experiment will be a great mileage ushering new era for research, and tap so many untapped factors to achieve most satisfactory results in the field of "thermal engineering" in coming years.

KEY WORDS: Resistance furnace, thermal efficiency, zirconium insulation, KANTHAL SUPER, programmable PID controller.

INTRODUCTION

Resistance heating furnace is a device where heat energy is available by electric arc to heat the charged materials, up to a temperature as high as 1600 C. Arc heating is one of the many ways of heating methods applied in an environment of air, inert gas, vacuum etc with no pollution. Thus the heating process is carried out using qualitative heating elements made up of Sic, MoSi2 etc meant for "higher temperature application" in multiple programmable cycles set before the operation and controlled by PID programmable controller to 100% resolution to achieve desired results. The heat transfer takes place by mode of conduction and radiation, with homogeneous heating inside the working chamber through out the cycles of operations continuously. High temperature resistance furnace with temperature range up to 1600C has large scope of applications, such as laboratory furnaces for testing the equipments within the temperature 1600C (max.), as high temperature 'sintering production furnaces, many more.

The Literature survey carried out has revealed that various studies have done for analysis of high temperature furnace for different processes within temperature ranges below 1500C. Like, Wilson S.R.et al (4) conducted an analysis of high temperature furnace annealing of buried oxide wafers formed by ion implantation. Silicon-on-insulator films were formed by ion implantation of oxygen and were treated with various annealing cycles at peak temperatures of 1150 °C, 1200 °C, and 1250 °C in a conventional diffusion furnace. Evans MN et al (5) did study high-temperature pyrolysis and oxygen isotopic analysis of cellulose via induction heating. Yamada H.et al (6) studied the spectral Interference in Antimony Analysis with High Temperature Furnace Atomic Absorption. A. Hasan et al (7)studied 'high temperature vacuum tube furnace, widely used for processing materials, developing new materials and sintering various types of materials under vacuum or gaseous conditions'. R.D. Schueller et al (8) carried out 'tensile and shear tests were carried out on these materials at various temperatures to develop a better understanding of the failure mechanisms involved at high temperatures'. C. Feist et al (9) studied 'the undesired behavior like irreversible deformations of refractory metals. S.T. Misture (10) did 'analysis of thermal expansion of alumina in a fully automated powder diffraction furnace that operates from 20 to 1600°C under controlled atmosphere or vacuum .' H.M.Kerch et al (11) did to study of thermal processing of materials, such as the sintering behavior in ceramics. A. J .Martin et al (12)studied ' thermal analysis of beryllium and its alloys, at extremely rapid heating and cooling rates when required, or, with slow heating and cooling rates. Longtsong Ju et al (13)' did study the effects of the carbide precipitation on the mechanical properties and strain shape of type 18-8 within the sensitizing temperatures (475-850°C).

The study presented herein, different from all the above concepts, would be "an analysis of high temperature resistance furnace with working temperature as high as 1600C", and with the following objectives to achieve from the experiments conducted based on various parameters described as below:

A) High and low temperature furnace using two different types of heating elements (SiC and $MoSi_2$) for 1600C.

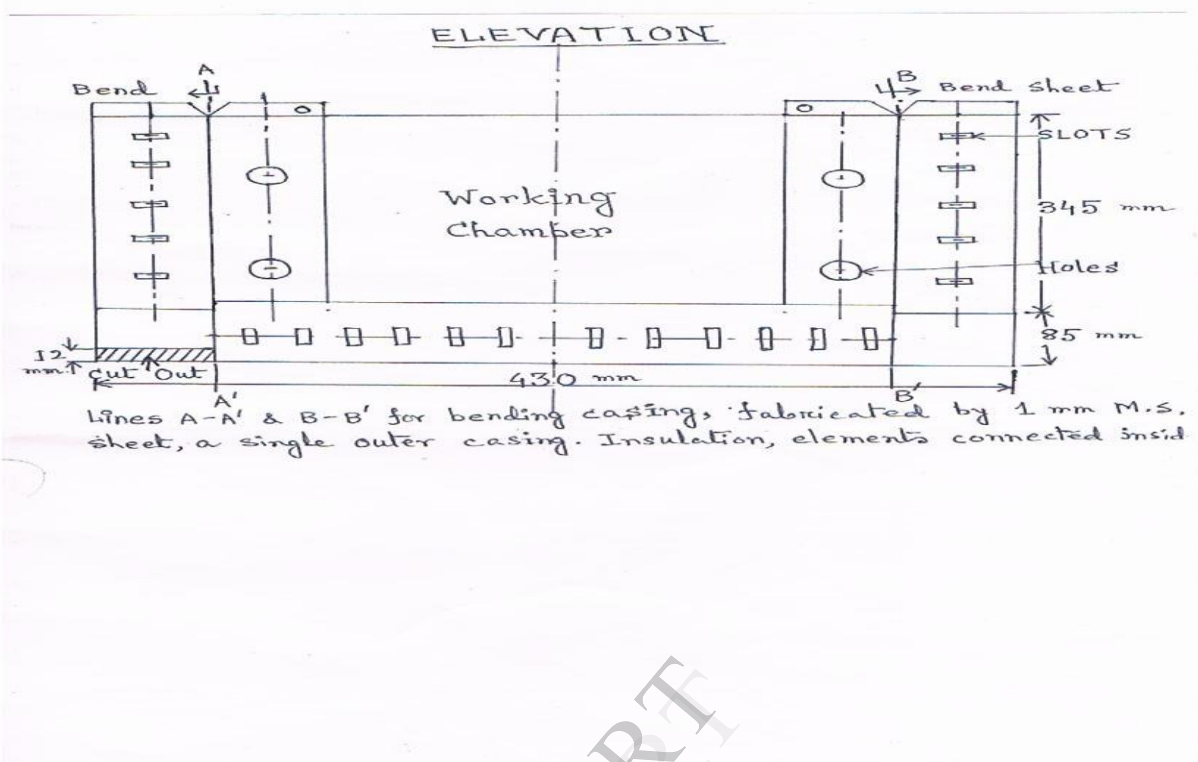
B) New design on insulation to attain optimum thermal efficiency, with skin temperature as the room temperature.

C) Perfect control system to monitor on-going processes with 100% accuracy.

EXPERIMENTAL details:

EXPERIMENTAL SET UP: Experimental set up signifies the regularly periodic testing of different important parameters, viz. temperatures, current (consumed), inter-locking system efficiency and effectiveness of insulating materials used. Measuring the temperatures is very vital, as first-of all, measuring the temperature inside the working chamber, followed by that of interfacing surfaces (between two insulating materials, e.g., interface temperature between zirconium based plates facing the chamber and muilite tiles, and that between muilite tiles and zirconium ceramic fibers), and, finally checking up the skin temperature outside the outer casing; secondly, checking up the uniformity and homogeneousness of heating inside every where of the working chamber done by measuring the temperature nearest to the heating elements (from central line of chamber) as also measuring the temperature at the farthest points (from heating elements) in distant corners of the chamber during working hours.

In this regard, to note that the modes of heat transfer take place by all three ways, viz. conduction, convection (as inside working chamber atmosphere is air every where) and radiation, as also by combination of all three modes. Hence, measuring the temperatures at the abovementioned points time-to-time during working hours to test the uniform heating is of utmost important task unfailingly.



To not here, that, the moment SiC is stopped working by inter-locking system, voltage drops from 220 V (full when using SiC) to zero voltage (for starting heating MoSi2 elememt) what gradually then rises to a value 50 V (maximum) when temperature rises from 1400 C to 1600 C (voltage changes happen by step-down transformer with change of elements from SiC to MoSi2 automatically), but, current value increases (from 18 amps while using SiC) to a maximum value (40 amps) with increase of temperature (from 1400 C to 1600 C) without much resistance in heating for using MoSi2 during complete working cycles uninterruptedly.

Experimental details for :

A) Compound heating system:-- High and low temperature furnace using two different types of heating elements (SiC and MoSi2) for 1600C :

Materials: SiC heating element is branded as 'KANTHAL GLOBAR SD', (make : KANTHAL, SWEDEN), molybdenum disilicate (MoSi2)' heating elements are branded as "KANTHAL SUPER" (make : KANTHAL, SWEDEN).

Basically, the heating elements consist of a set of silicon carbide (SiC, having re-crystallization temperature over 2500C). and a set of molybdenum di- silicide (MoSi2 elements are soft and ductile above 13C and below it becomes hard and brittle- after 10—12 operations, to reaching 1600C.).

Methodology of compound heating system (Figures-1 to 3 shows all design aspects):

Depending upon the area of the furnace, element length are to be selected and spacing of the element mostly advised vertically from the top in "U"-format at a distance of 50 mm between two consecutive heat elements.

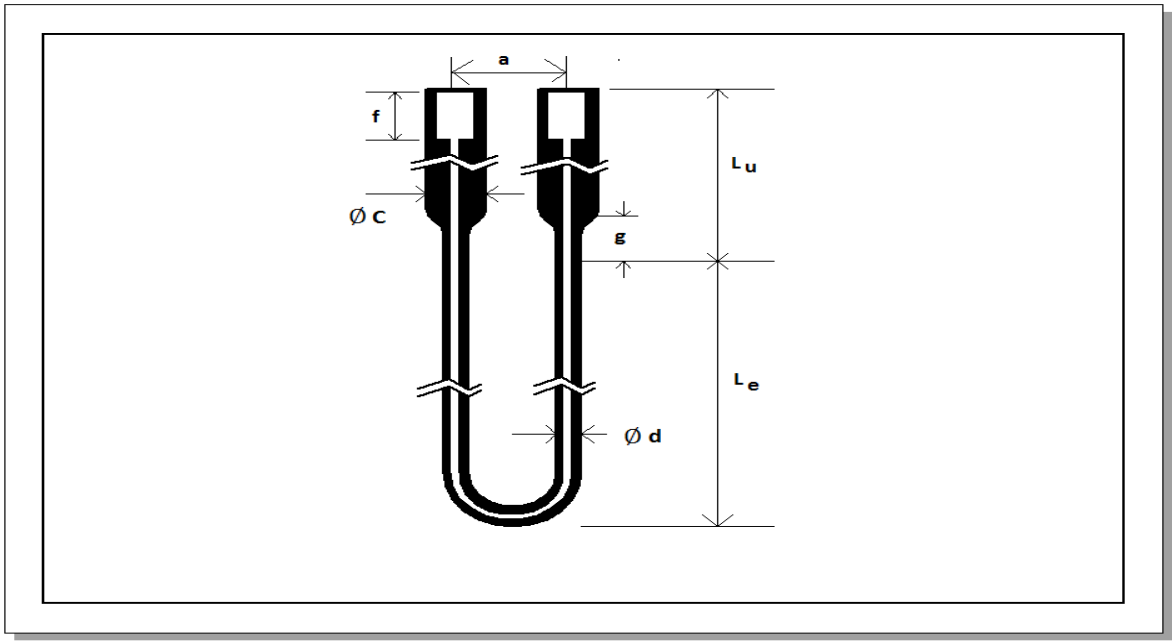


Figure -1: Heating elements in U-format (See parameters in Table below)

Element Size	Heating(Le) Zone, mm	Terminal (Lu)mm	a (standard) mm	a (minimum) mm	C Mm	d mm	f mm	g mm
3/6	3	6	25	20	6	3	25	15
4/9	4	9	25	20	9	4	25	15
6/12	6	12	50	25	12	6	45	25
9/18	9	18	60	40	18	9	75	30
12/24	12	24	80	50	24	12	100	40

Figure-2 :Table-Dimensional tolerances +- 5% (except c and d).

Now, wattage (P) is calculated depending on the applied voltage, and which is decided again from total resistance limiting current factor as 40 amp. which is again almost 12 W/cm2 as surface loading.

Voltage applied-220V to 60 V(by step- down transformer). Applied voltage is almost 60 V.

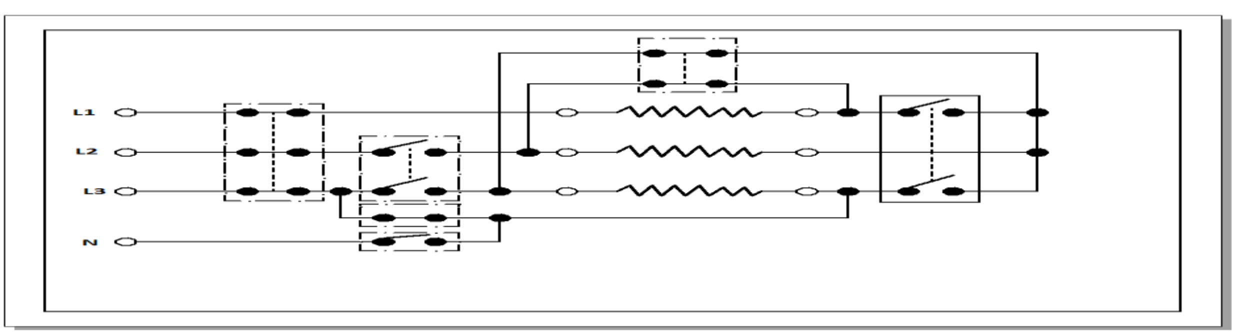


Figure -3: Wiring diagram for all heating elements directly star-connected to line voltage.

Temperature control , depending on furnace temperature (1600 C) is by 'Thermocouples-Pt-Pt/13Rh type' having structural change in platinum and diffusion of rhodium at the junction.

B) New design on insulation to attain optimum thermal efficiency, with skin temperature as the room temperature.

Materials for the present study is zirconium based plates,(make: GERMANY) or hollow section having a cavity holding vacuum (most efficient) one layer facing the hot face of the chamber. Second layer is supposed by high density 'MUILITE tiles',(make: Universal Carborundum) followed by zirconium based ceramic fiber boards (make: Murugappa), so, total insulation is 90 mm (maximum) to achieve our desired results is the basic materials for the present studies, compared with conventional high temperature insulation with 'Fire bricks' of was 300 mm—350 mm thickness in all the dimensions.

Methodology:

The basic material is the form of "ZIRCONIUM board" with binding material. That "BOARD" put into vacuum system (vacuum furnace) and heated to 1200C and vacuumised to remove the binding material, that creates the annular space inside the "BOARD" (through a chemical reaction). In present study, to introduce an air-jacket all around the furnace body so that the skin temperature is better way controlled (maximum 50 degree C)..

C) Perfect control system to monitor on-going processes with 100% resolution (accuracy).

It meets the requirement of straightaway high temperature melting, heat treatment, material processing, and conditioning processes. It consists of Programmable PID (make: Honey-well), thyristor Power pack (make: our indigenous design and assembled), sensing element : TC (thermo-couple) Pt-Pt-Rh 13% (make: Arora-Mathe), recrystallised alumina tube (make: Haldenwanger, Germany).

Semiconductor based circuit that controls power and current to system to the requirement] step-down and thereby control the voltage automatically with transformer [depends on size, that is working area, and 40 amp (I), 220 V (single phase) – 60 V step-down] auto current limiting facilities.

In addition, it has over temperature controlling digital-controller and power shut-off system timer based , when total process is completed. Our control system include PID programmable controller with RS 232 port to connect P.C.(personal computer) and printer for documentation.

The programmable controller has minimum 4 programs, each program has 9 to 16 segments of rampant soaking time adjustment.

'Thermocouples—Pt-Pt/13 Rh type' having structural change in platinum and diffusion of rhodium at the junction.

Methodologies: A compatible thyristor power pack developed and fabricated at very reasonable cost locally is based on the principle of 'phase-angle change of silicon diode' having input of 0—10 Volt D.C. or, 4—20 miliamps current, and output of high current (up to 45 amps) and variable voltage (40—250 volt A.C.). Figure-4 shows **thyristor (SCR) control.**

The heating elements normally, while heating, changes the resistance which normally increasing with heating accordingly self-adjustment of the electronic circuit in built-up Thysistor system.

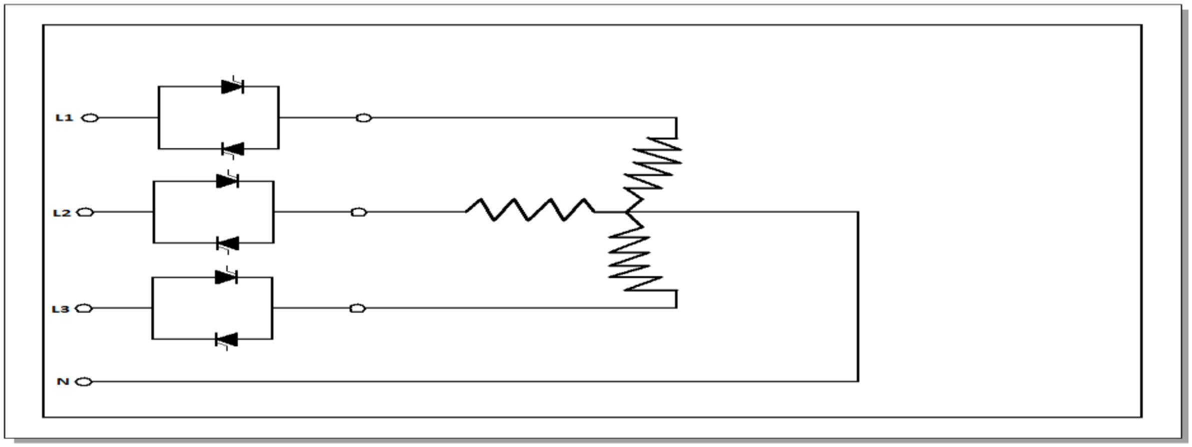


Figure -4: Application with thyristor (SCR) control: Three phase applications (Four wire star).

RESULTS & DISCUSSION: Studies of the parametric analysis for :

A) Compound heating systems: First of all, focus is clearly on the heating elements, first to attain a temperature as high as 1400 degree C from the ambient temperature using silicon carbide. As SiC is having re-crystallization temperature over 2500 degree C, so no problem is found in raising temperature up to 1400 C for SiC element, followed by molybdenum di-silicide (MoSi2) to reach the remaining temperature up to 1600 degree C (from 1400 degree C) successfully.

This type of arrangement will facilitate to meet the first range of temperature from ambient temperature to 1400C in a range of 500C to 1400C consuming 3KW and 16-18 amps (max.) of current, where as using next molybdenum disilicide elements (to attain next 1400C to 1600C), it would require 35-40 amps. Hence, this type of compound heating system can be uniquely elaborated by relevant parameters as below.
Following figures nos.**5 to 13** shows various parametric changes during heating periods:

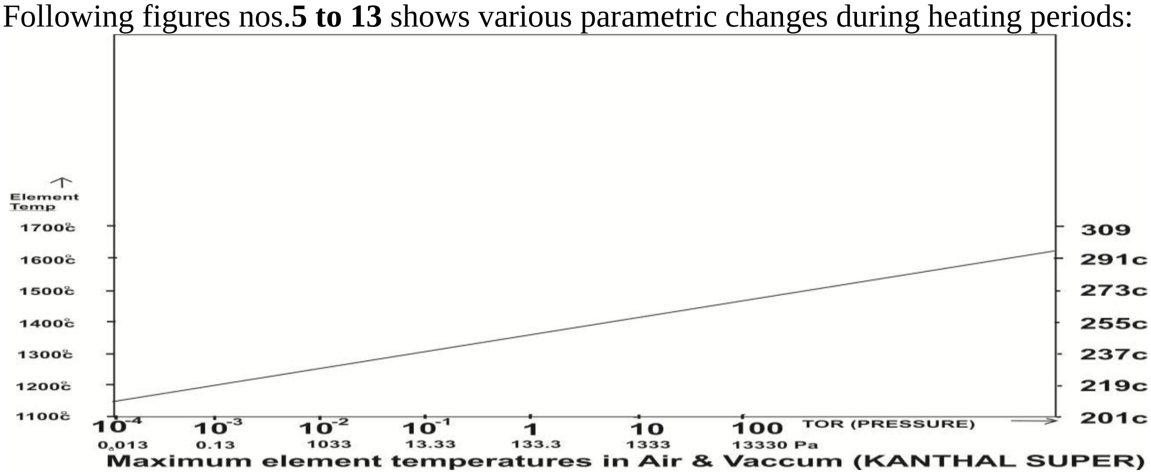


Figure -5: Maximum element temperatures inside chamber filled in air.

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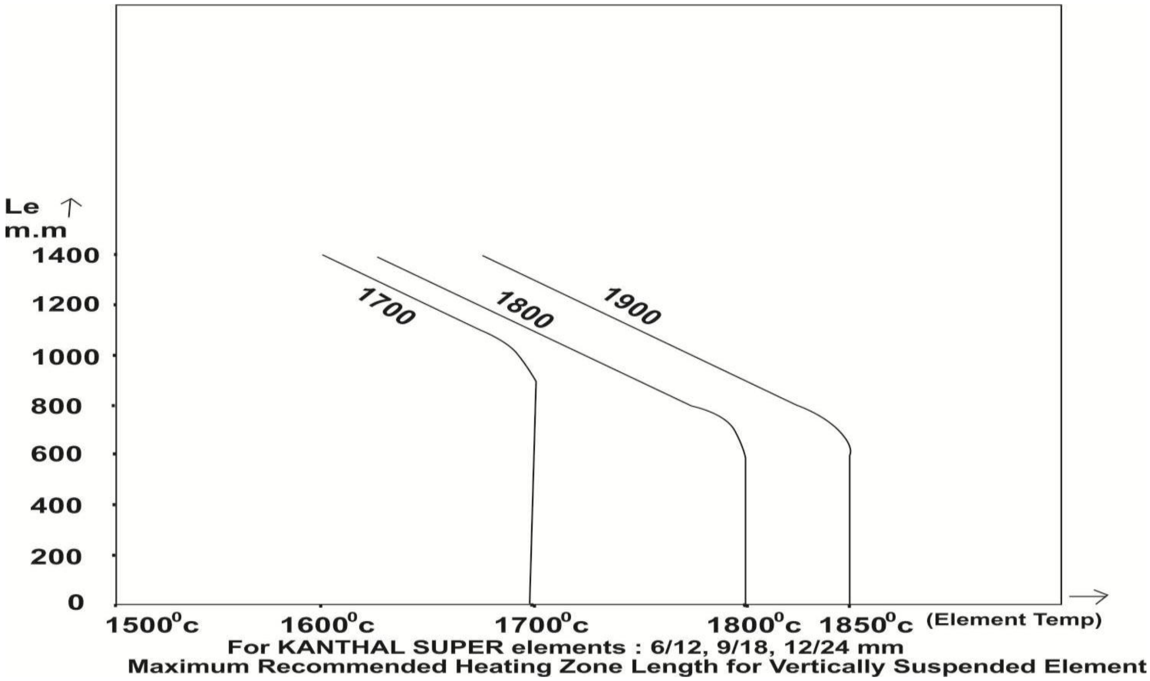


Figure-6 : Maximum temperatures recorded at different heating zones (Le).

'Molybdenum disilicate (MoSi2)' material which is high resistive to the flow of current. That is how heat gives resistance of high order and a smaller length and cross-section produce high-heat-energy.

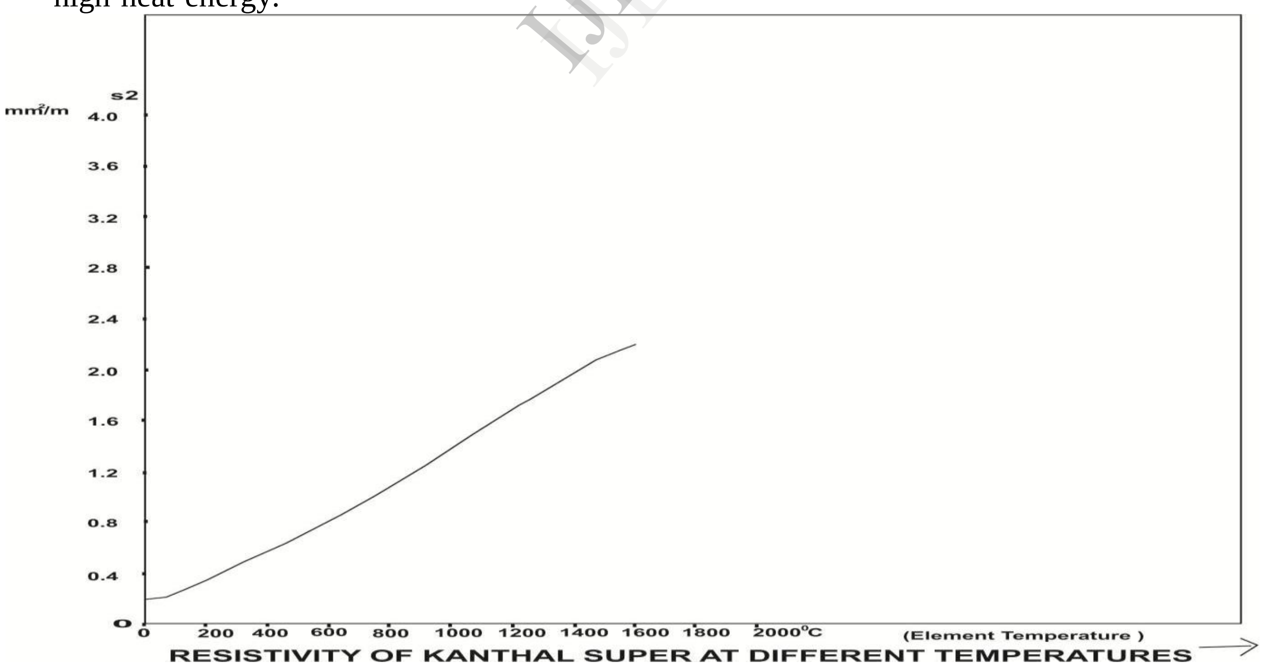


Figure-7: Regarding resistivity of KANTHAL SUPER elements shown.

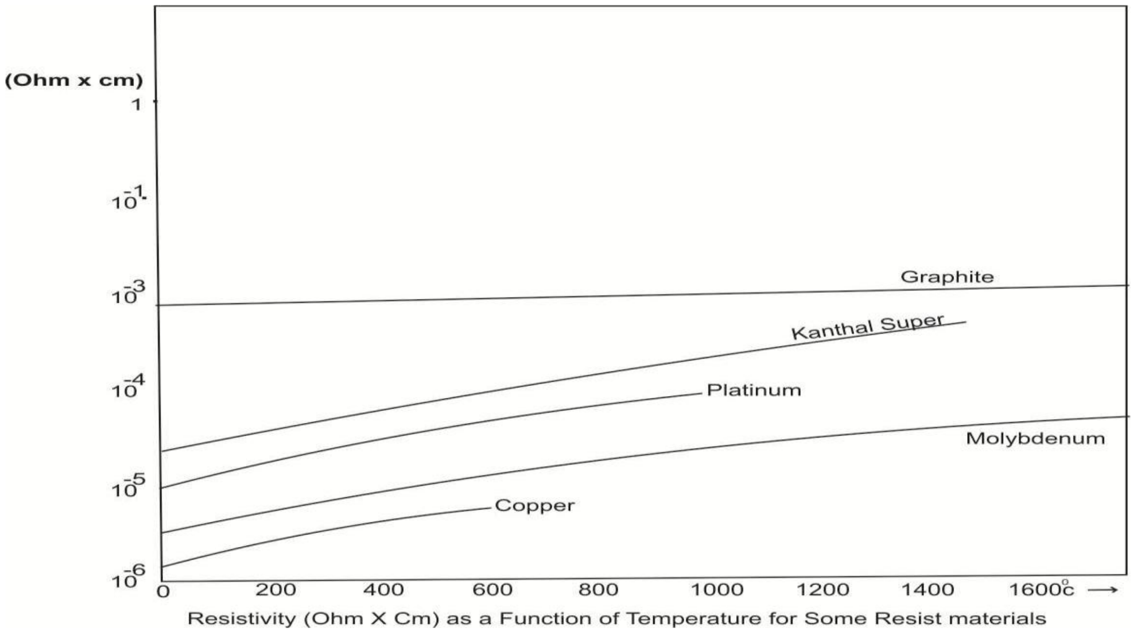


Figure-8 : Resistivity change with temperature for different materials.

Note: It also does not appreciably change its resistivity (R) in cold or hot conditions and also during long use. So, these elements can be used cold and new in combinations in series or in parallel connections.

Using SiC up to 1400C, a surface load of maximum 14—16 W/cm2 can be applied, beyond which it is not safe, but, using MoSi2, a surface load up to 74 W/cm2 can be applied, within the small heating area at a faster pace. So reaching 1400C SiC elements are cut off (which controls the circuit takes care of by its automatic switching device, starting MoSi2 to attain next up to 1600C range of temperature). Following figure shows surface loads of elements.

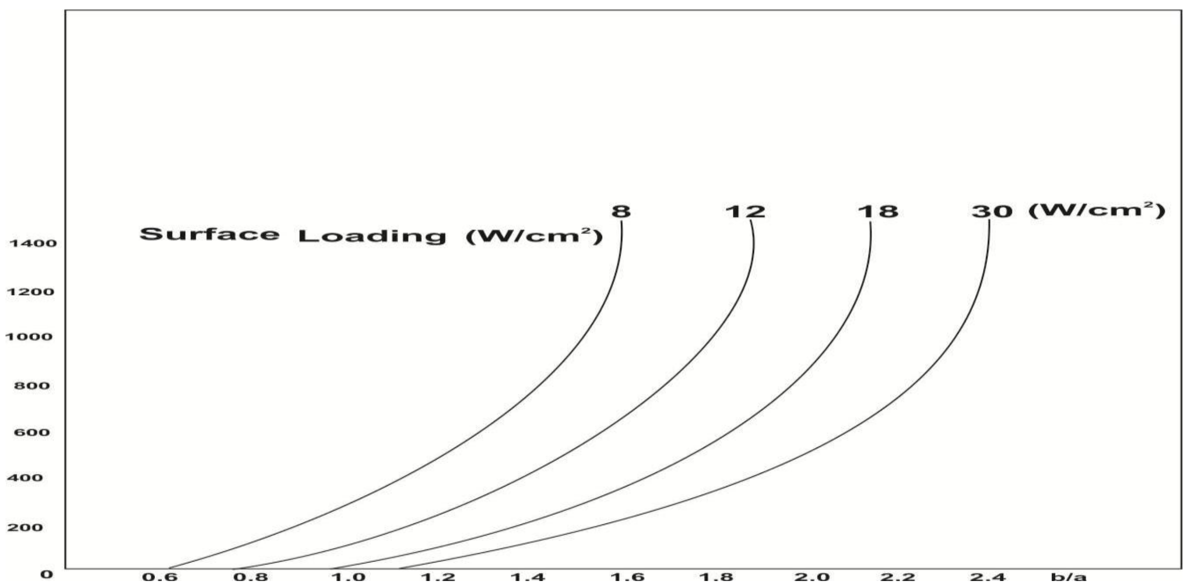


Figure -9: Surface loading variations with heat zone length is shown.

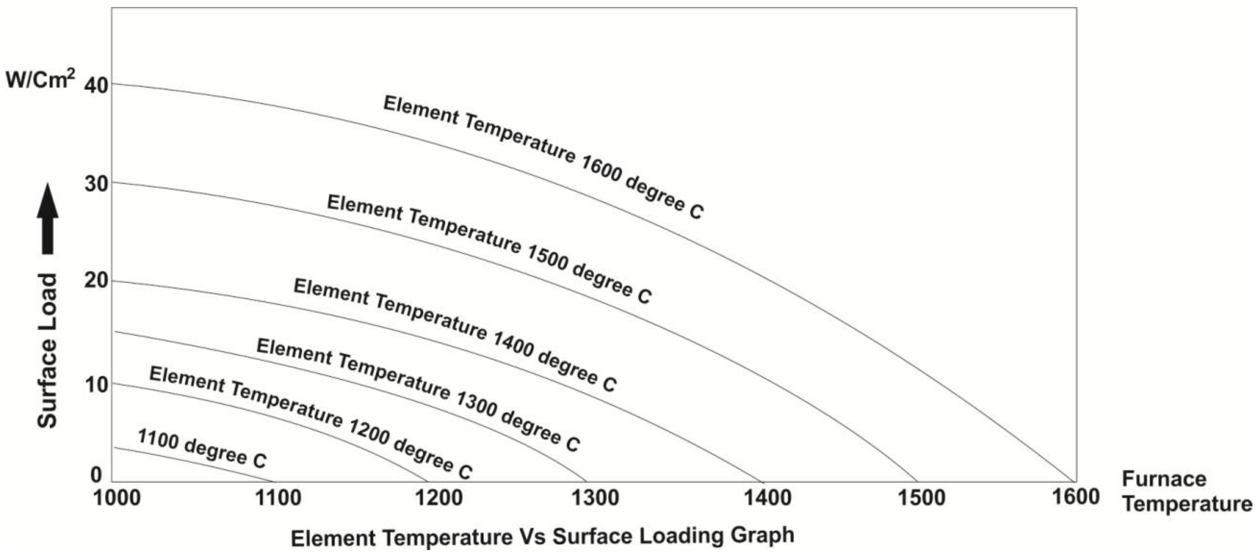


Figure- 10: Element temperature vs surface loading variations are shown.

Thus, for first 1400C using SiC, cost effectiveness (in terms of current consumption and related costs) is achieved, rather than using MoSi2 for the entire range of heating from ambient temperature to 1600C, (without using SiC) for same cycles/ working hours).

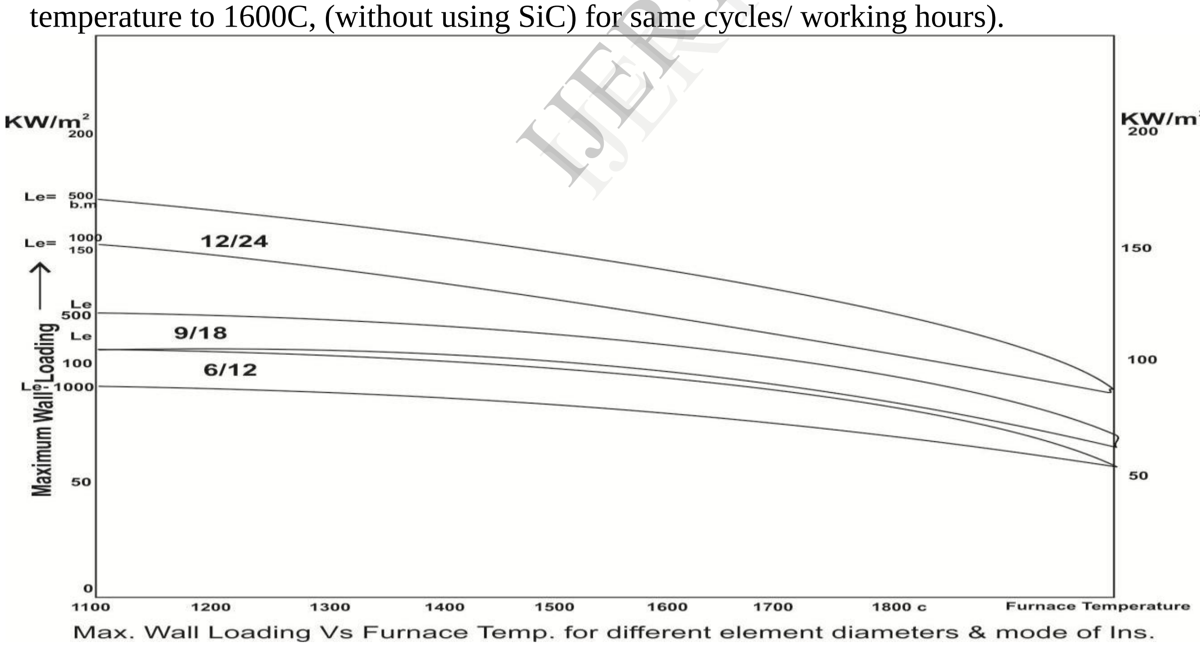


Figure-11: Maximum wall loading vs furnace temperatures shown.

With respect to life span of elements of both SiC and MoSi2, is fixed for 8 hrs /day or totally 200 hrs of working. But, the note worthy point is that MoSi2 elements are soft and ductile above 13C and below it becomes hard and brittle (mechanical properties) after 10—12 operations, when the elements becomes brittle, 10-12 times reaching 1600 degree C.

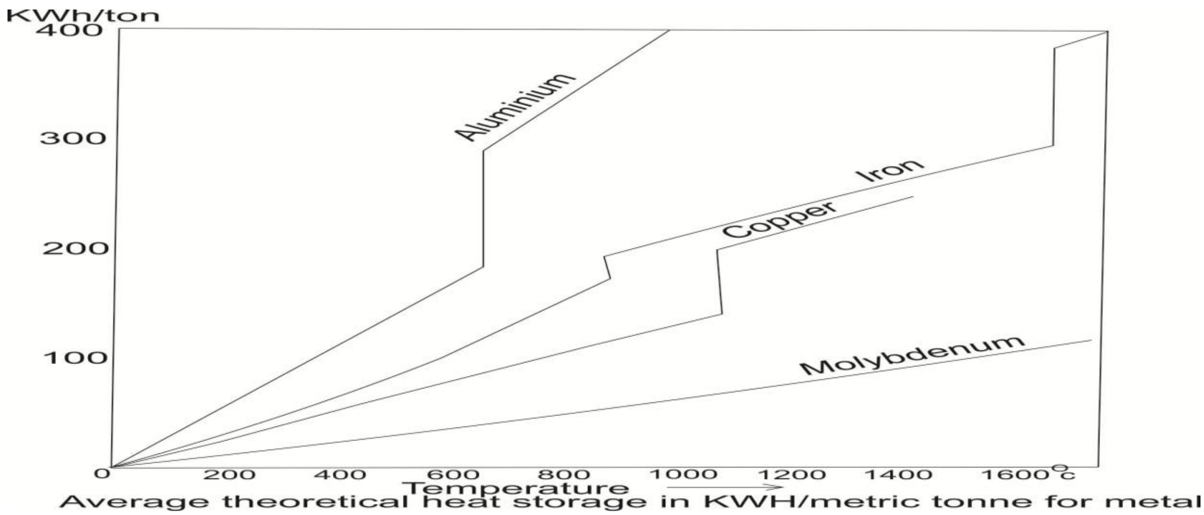


Figure-12: Heat storage values with different temperatures shown.

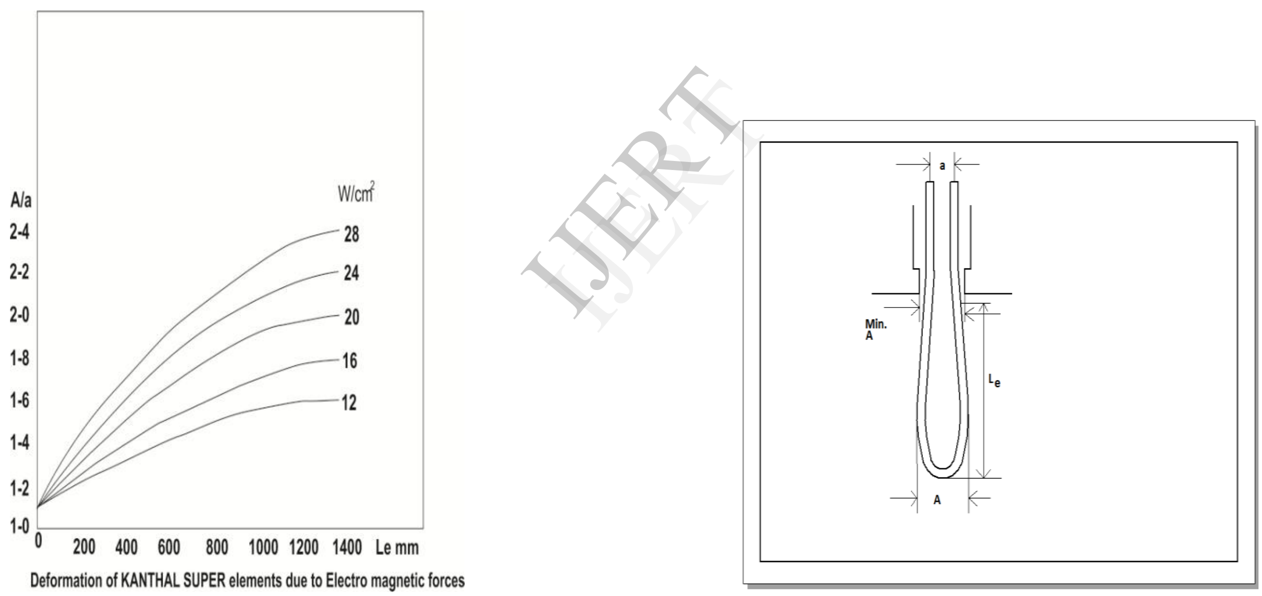


Figure-13: Deformation of Kanthal elements due to eletro-magnetic forces, (for all sizes).

In choosing 'Thermocouples-Pt-Pt/13Rh type', alloying the platinum with rhodium, the usable temperature increases. A high content of rhodium in both shanks gives the highest permissible furnace temperature and, also EMF (electromotive force) decreases affecting the accuracy of the measurement. So, Pt-Pt/13 Rh type is the best for 1600C.

B) Effect of heating ZIRCONIUM boards (the insulation materials) :

The basic material ZIRCONIUM board when heated and bubbled under vacuum to create vacuumized annular space, it gives radical improvement in insulation value, and weight-wise it has no comparison with conventional system, not even hundredth of the conventional method.

The present study is with these available materials to reduce the optimum insulation thickness from 350 mm to 90 mm (one-fourth), with main focus in weight consideration, mobility and tremendous improvement in K (thermal conductivity) value. Following figures (14 and 15) will elaborate with parameters:

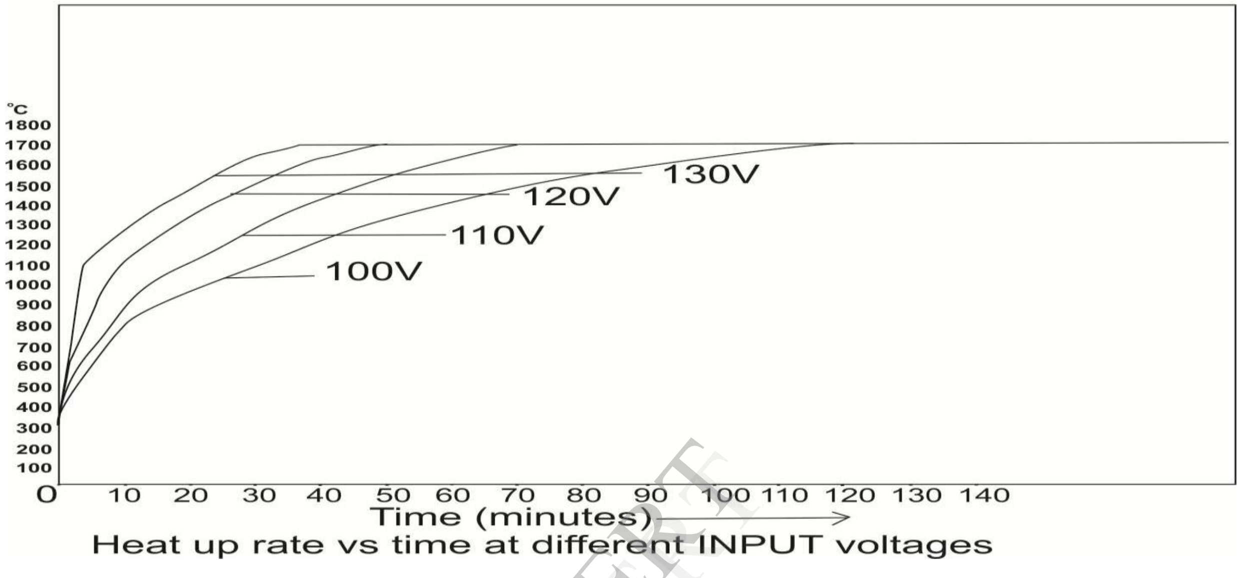


Figure -14: Heat up rate at different input voltages shown.

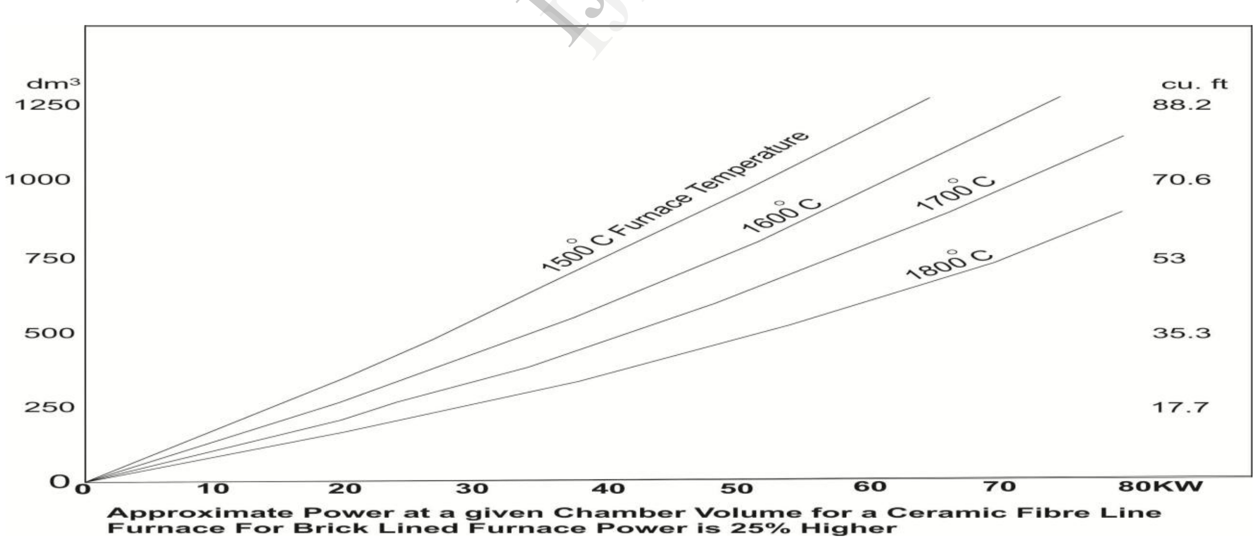


Figure-15: Power saving using zirconium compared with conventional bricks.

Thus, attempt was to arrest the chamber wattage and temperature intact, to control the high costs and also sandwiching the different density of materials improved considerable thermal conduction and control of skin temperature (50C).

C) Performance of the Control systems :

Regarding the design of the control system, main focus is the application-friendliness and to fulfill the different applications in practically used environment. That is why it meets the requirement of straightaway high temperature melting, heat treatment, material processing, and conditioning processes. Following figures (16 to 18) would show parametric functioning of PID controller shown during the tests:

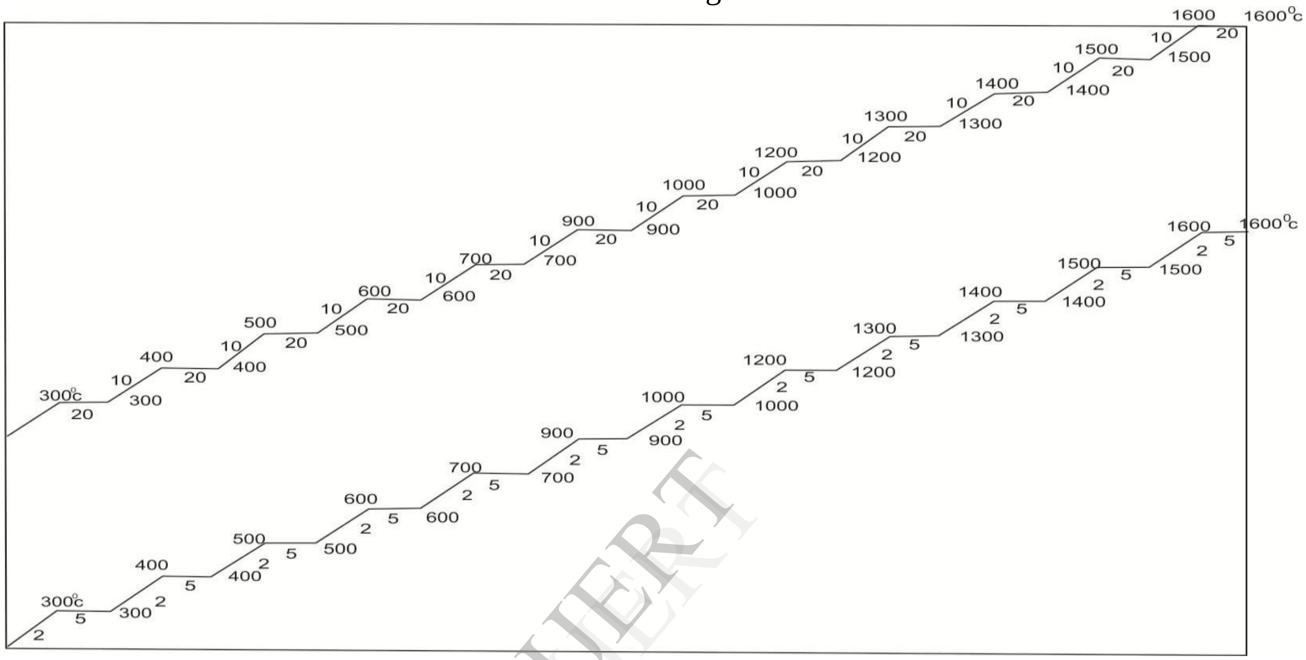


Figure -16: Temperature soaking and variation curves shown.

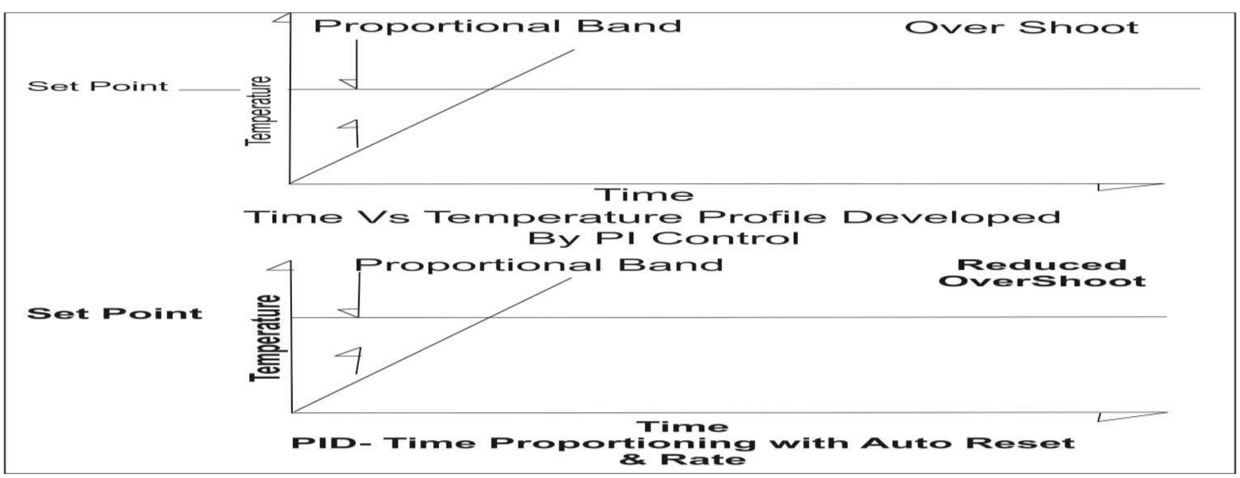
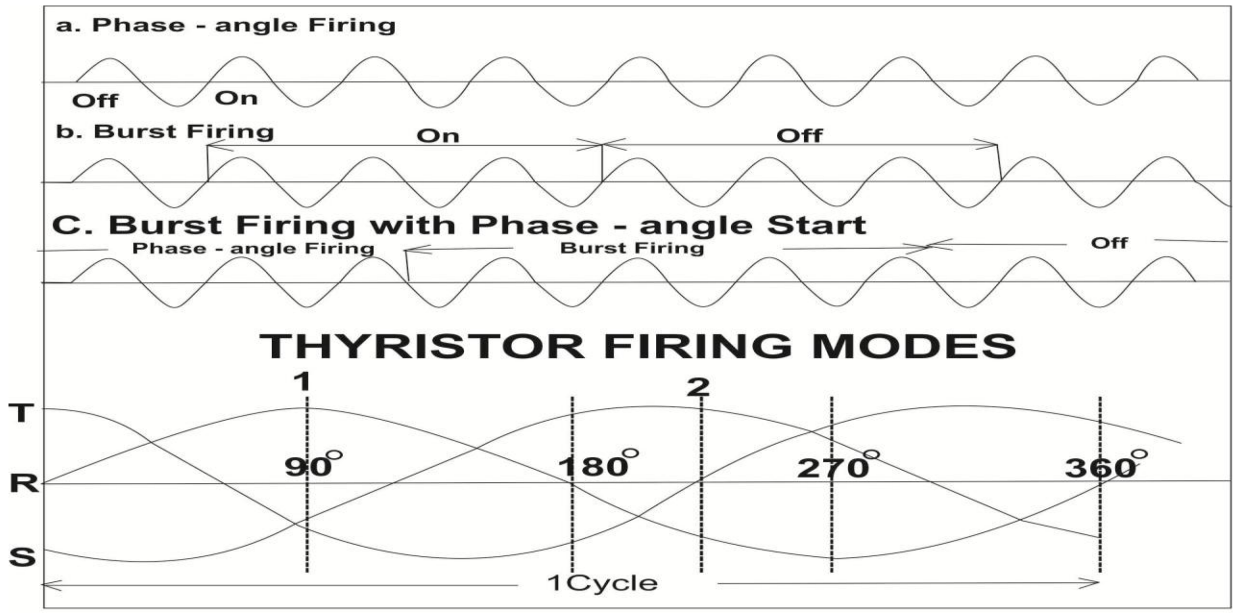


Figure-17: PID –Time proportioning with auto-reset and rate shown.



Sine Curve Variations in a 3-Phase System

Figure - 18:Thyristor firing modes (sine curves variations in a 3-phase system) shown.

CONCLUSIONS: on the basis of the above parametric analysis for :

A) Compound heating system : These elements can be used for low and high temperature rise from ambient to 1650C –1700C occasionally, and 1600C for continuous operation. So, in single furnace all type of rampant soak adjustment can be done.

Here, the considerable point is that SiC if get damaged for long working hours, it is low cost, so can be easily changed, also, if breaks during operation, whole set of 3 elements can be replaced by a new set; but, for $MoSi_2$ being very costly, only that broken element and not the set, to be changed, and SiC set is changed after 1 and ½ years of service periodically. So, present design of this type of compound heating elements arrangement to achieve 100% result.

B) For **insulation:** In the present study,main focus is about insulation which as a major advantage over the conventional system in weight consideration, mobility and tremendous improvement in K (thermal conductivity) value.

Thus, effort is to arrest the chamber wattage and temperature intact, to control the high costs and also sandwiching the different density of materials improved considerable thermal conduction and control of skin temperature (50C).

This arrangement not only saves current consumption, but also helps us to handle the entire unit easily due to lesser in weight, also in volume too.

C) For CONTROL systems : T.C.(thermo-couple) basically at this range of temperature (1600 C), use of only Pt 13% Rh. This system is very very rugged and reliable performance-wise, it can attain a temperature resolution of +- 1C and with a sensitivity of 0.5 C, that is, it will show in reading if there is a change of even 0.5C temperature.

D) High efficiency (minimum loss of temperature or minimum thermal losses) :

The present design in order to achieve high thermal efficiency is based on the concept of varying the densities of the three insulating materials, vi, first layer of zirconium followed by 'muilite tiles ' followed by 2 inch thick zirconium ceramic fiber with total 90 mm thick insulation (in present work instead of 350 mm thick conventional insulation required for maximum 1600 degree C working temperature).

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REFERENCES:

1. KANTHAL SUPER HANDBOOK, KANTHAL AB, SWEDEN.
2. Journals (Control of Thermal Systems), Sigma Automation (P) Ltd.
3. Furnace Module User's Guide, Zircar Zirconia Inc., FLORIDA, U.S.A.

4. S. R. Wilson, M. E. Burnham, M. Kottke, R. P. Lorigan, S. J. Krause, C. O. Jung, J. A. Leavitt, L. C. McIntyre Jr, J. Seerveld and P. Stoss (1989). An analysis of high temperature (1150 °C) furnace annealing of buried oxide wafers formed by ion implantation, Journal of Materials Research, **4** : 167-176 5. Evans M.N.(2008). A reactor for high-temperature pyrolysis and oxygen isotopic analysis of cellulose via induction heating, Rapid Commun Mass Spectrom,**14**:2211-9.

6. Hideo Yamada, Koichi Uchino, Hideaki Koizumi, Tamotsu Noda and Kazuo Yasuda (1978).Spectral Interference in Antimony Analysis with High Temperature Furnace Atomic Absorption, Analytical Letters,**11**: 855-868.
7. A. Hasan,S. Guo and M. Wahab (2009).Analysis of fracture in high temperature vacuum tube furnace, Journal of failure analysis and prevention.
8. R.D. Schueller and F.E. Wawner ().An analysis of high-temperature behavior of AA2124/SiC whisker composites, Journal of Materials Science Department, University of Virginia, USA.
9. C. Feist and A. Plankensteiner (2011).Multi-Physics Analysis of a Refractory Metal ACOperated High Temperature Heater with Abaqus, SIMULIA Conference.

10. S.T. Misture (2003).Large-volume atmosphere-controlled high-temperature x-ray diffraction furnace , Measurement Science and Technology, **14 :1091.**

11. H.M.Kerch, H.E. Burdette and G.G.Long (1995). A High-Temperature Furnace for *In Situ* Small-Angle Neutron Scattering during Ceramic Processing, Journal of Applied Crystallography, **28:** 604-610.
12. A. J .Martin and K L Edwards (1959). Linear voltage temperature furnace for thermal analysis, Journal of Scientific Instruments, **36:**170.
13. Longtsong Ju, Shrliang Ju and Naivee Lin (2010). The use of high-temperature electric furnace process technology for the 18–8 stainless steel sensitized effects , IEEE, **2** : 443 – 447.

14.C. A.Pickles (2008). Thermodynamic analysis of the selective chlorination of electric arc furnace dust, Journal of Hazardous Materials,**11**: 110.

15. H. A. McKinstry (1970). Low Thermal Gradient High-Temperature Furnace for X-Ray Diffractometers , J. Appl. Phys., **41**: 5074.

16. Earl A. Gulbransen (1947). High Temperature Furnace for Electron Diffraction Studies, Review of Scientific Instruments, **18**:546.

17. F. Tuinstra and G. M. Fraase Storm (**(1978).**.A universal high-temperature device for single-crystal diffraction, ***J. Appl. Cryst.*****, 11: 257-259.**

18. Li Feng Ma, Xiao Fei Ding, Jun Zhang, Kai Tian Mao, Li Jing Gong (2012).State Analysis on Reactor Furnace Pipe Used over a Design Cycle, Advanced Materials Research, **535 – 537:** 529-532.

19. Qibo Jiang, Fuzheng Yang and Pitchumani, R.(2005). Analysis of coating thickness variation during optical fiber Processing, Journal of Lightwave Technology, **23**: 1261 – 1272.

20. Li, Zhen-Zhe; Shen, Yun-De; Heo, Kwang-Su; Lee, Jae-Woo; Seol, Seoung-Yun; Byun, Young-Hwan; Lee, Chang-Jin (2007).