Marathon TempSens

Engineered Solutions For Heating & Sensing

Heater Hand Book

• Process Heaters • Component Heaters • Furnace Heaters

MARATHON HEATER (I) PVT. LTD.

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www.marathonheat.com

About the Company

MARATHON HEATER (INDIA) PVT. LTD is a part of **TEMPSENS** Group which was established at Udaipur, INDIA. Today Tempsens is one of the largest manufacturer of temperature sensors & heaters with world class manufacturing facilities in India, Germany and Indonesia.

Tempsens is an ISO 9001:2015, ISO 14001:2015 certified company with NABL Accredited Laboratory.

The company is involved into manufacturing of Thermocouples, RTDs, Thermowells, cables, Non-Contact Pyrometers, Heaters and Calibration Equipment etc. with Covered Area of 36000 Sq. Ft.

MARATHON HEATER (INDIA) PVT. LTD Equipped with modern infrastructure, innovative technologies and a dedicated team of qualified Engineers, we have evolved over the past years to become one of the most trustworthy manufacturers of Industrial heating solutions. Marathon continues its constant endeavor of delivering solutions for critical and challenging process requirements.

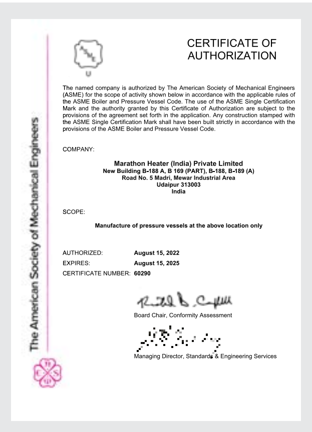
We are constantly looking for ways to improve not only our products but also maintain order processing, design process and product literature. Quality and customer satisfaction were and will be our prime motto.

We design, develop and manufacture Electric Heaters (Electric heat exchanger) for various processes in the Oil and Gas Industry, Refinery, petrochemicals, power, chemical, Marine and various other industrial and process applications.

Our well experience Technical team also provides extensive support to privileged customers with Electric heaters required for Research and developments.

Marathon Heaters also manufacturing Metallic Elements, high temperature furnaces, Industrial ovens, Temperature sensors as per customers required and international specifications.

Certificates


The American Society of Mechanical Engineers

CERTIFICATE OF AUTHORIZATION

COMPANY:

Marathon Heater (India) Private Limited

SCOPE:

Manufacture of pressure vessels at the above location only

AUTHORIZED: August 15, 2022

EXPIRES: August 15, 2025

CERTIFICATE NUMBER: 60290

Board Chair, Conformity Assessment

Managing Director, Standards & Engineering Services

'U' Stamp Certified


THE NATIONAL BOARD OF BOILER & PRESSURE VESSEL INSPECTORS

Certificate of Authorization

This is to certify that

Marathon Heater (India) Private Limited

Udaipur 313003

India

Metallic

Repairs and Alterations

At The

Shop Location

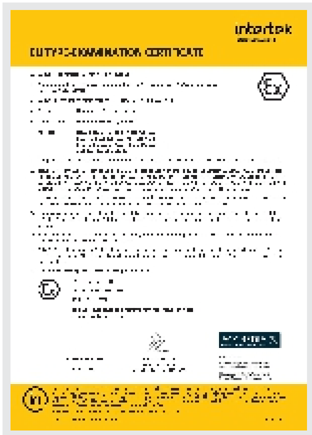
Certification Number: 12016

Issue Date: August 11, 2022

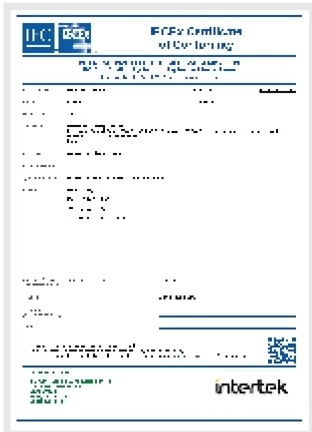
Expiration Date: August 10, 2025

Executive Director

'R' Stamp Certified



ATEX Certificate



IECEx Certified


Certificate of Compliance

Underwriters Laboratories Inc.

MARATHON HEATER (I) PVT LTD

Heaters, Specialty - Component

Look for the UL Listing Mark on the product

UL Certified


PESO Certified


TÜV NORD

CERTIFICATE

ISO 45001: 2018

MARATHON HEATER (I) PRIVATE LIMITED

IAF

ISO 45001-2018 Certified


BIS Certified

Foreword

Dear Friends,

We are delighted to bring the first edition of the heater handbook published in 2023. This handbook provides the technical details about the heaters which are widely used in the industries. The handbook also contains the important aspect of the fabrication of the heater. If you have any suggestion that can further improve the quality of content, please feel free to write us at: info@marathonheat.com.

Marathon will celebrate its 15^{th} anniversary in 2023. The company is involved in the manufacturing of engineered solutions for heating and sensing. Since its establishment we have been evolved as the leader in the manufacturing of heaters for various industrial sectors like oil and gas industries, petrochemical industries, chemical industries, food and packaging industries, defence etc. With our strong R&D team we have developed many customized solutions. We are privileged, in fact blessed with the support by our esteemed clients.

We are ready to face more demanding applications related to heaters. Marathon heater would actively pursue all possible demanding application for our scope of products in the industry.

We invite you to visit our facilities for first-hand experience of our capabilities and potential. We know the only way to keep our business successful is to provide consistent, accurate and reliable products and prompt services to our customers.

With these few words, we dedicate this publication to our valuable customers.

TEAM MARATHON

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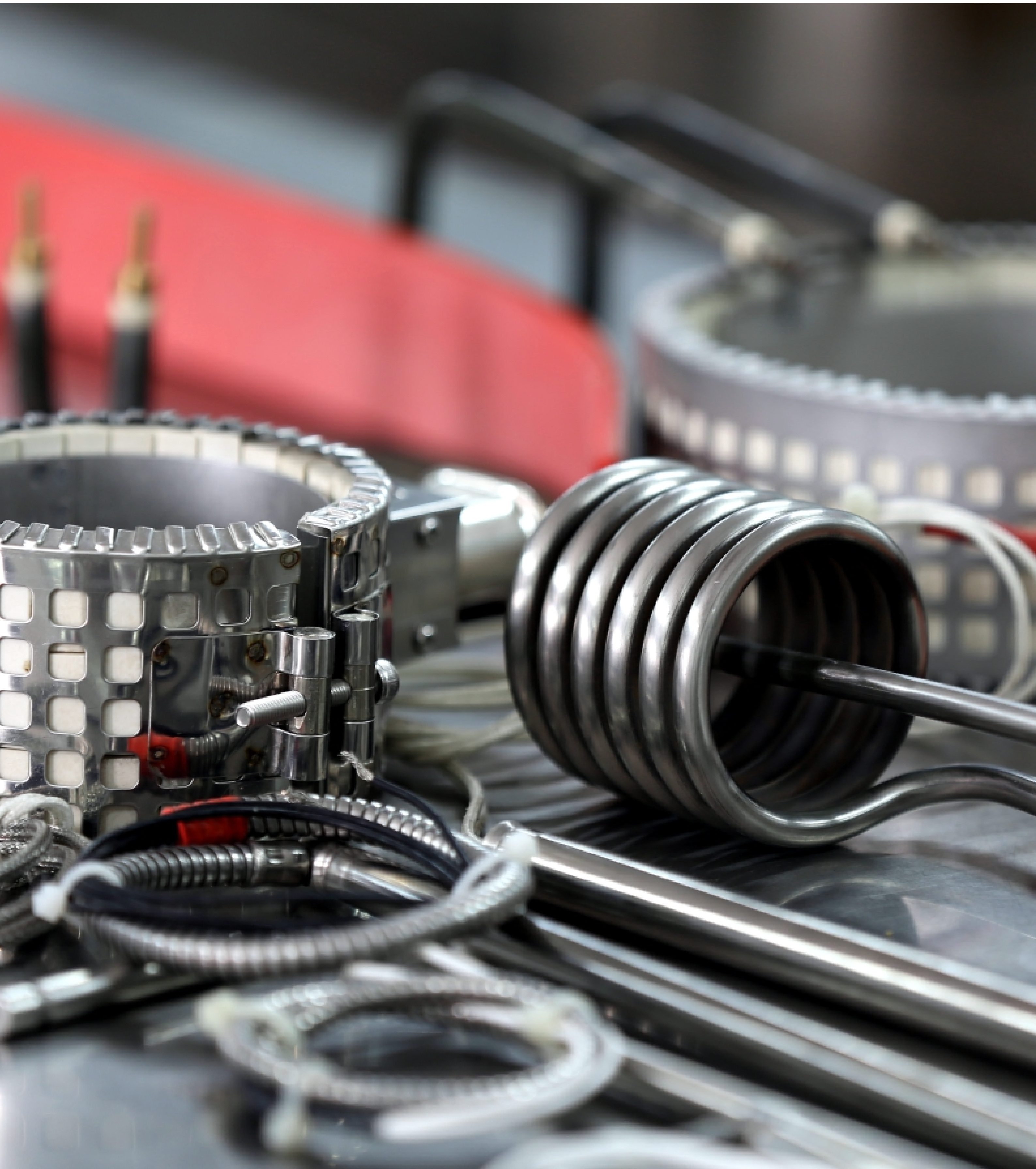
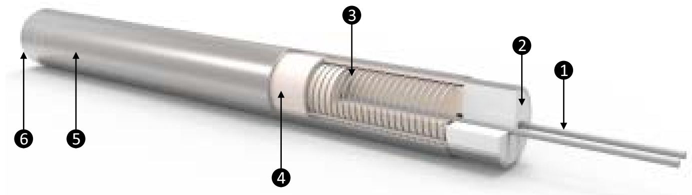
Component Heaters



ENGINEERED SOLUTIONS FOR HEATING & SENSING

Hot Rod Cartridge Heaters

The engineers at Marathon Heater instruments have developed a cartridge heater that exceeds the performance and durability of other cartridge heaters. Through refinements in the swaging process, specially designed cores, careful selection of magnesium oxide fill, nickel chromium resistance wire, stainless steel tubing, and carefully controlled production processes, HotRods routinely outperform other cartridge heaters in difficult applications.
HotRods are available in a wide variety of diameters and configurations.



1. High temperature lead wires for temperatures up to 550°C.
2. High impact ceramic cap retards contamination and is suitable for high vibration applications. Deep holes in cap prevent fraying of leads when bent.
3. Nickel-chromium resistance wire for maximum heater life, evenly wound for even heat distribution.
4. High purity magnesium oxide fill selected for maximum dielectric strength and thermal conductivity, highly compacted for maximum heat transfer.
5. Stainless steel sheath / Inconel sheath for oxidation and corrosion resistance in wide variety of environment.
6. TIG welded end disc to prevent contamination and moisture absorption.

Standard Specification

Nominal Diameter	Minimum Diameter	Maximum Diameter	Max. Lead Wire Gauge	Max. Amps	Max. Volts
1/8"	2.97	3.17	24	5	300
1/4"	6.19	6.32	22	9	300
6mm	5.82	5.97	22	9	300
6.5mm	6.35	6.47	22	9	300
5/16"	7.77	7.89	22	9	300
8mm	7.84	7.97	22	9	300
3/8"	9.37	9.49	18	15	300
10mm	9.56	9.98	18	15	300
12mm	11.83	11.96	18	15	300
12.5mm	12.34	12.48	18	15	480
1/2"	12.55	12.67	18	15	480
13mm	12.85	12.97	18	15	480
17/32	13.33	13.46	18	15	480
5/8"	15.72	15.84	14	26	480
16mm	15.84	15.97	14	26	480
17mm	16.84	16.96	14	26	480
11/16"	17.32	17.44	14	26	480
19mm	18.84	18.97	14	26	480
3/4"	18.89	19.02	14	26	480
20mm	19.86	19.98	14	26	480
1"	25.24	25.37	14	26	480
25.4mm	25.24	25.37	14	26	480

Maximum Allowable Watt Density

Clearance (mm)	Block temperature (°C)					
	649	538	427	316	205	94
0.050	140	270	300	300	300	300
0.076	120	205	295	300	300	300
0.101	100	175	240	300	300	300
0.127	90	145	200	285	300	300
0.177	70	100	150	200	250	300
0.254	60	90	110	150	200	225
0.381	50	75	95	110	140	165
0.762	40	60	80	90	100	110
1.524	30	40	50	55	65	65
2.540	25	35	45	50	50	50

Clearance is determined by taking the hole diameter and subtracting the heater diameter.
Watt density is calculated by:

$$\frac{\text{Wattage}}{\text{Heated Lth x Diameter x 3.14}}$$

Cycling reduces heater life and high cycling applications should use lower numbers.

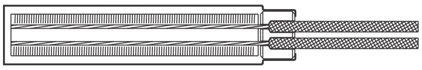
Lead Wire Characteristics

Wire Type	Temperature	Max. Temperature	Comments
Ultralead	250°C	450°C	Excellent, durable wire, good for high temperature application
Teflon	250°C	450°C	Good for areas where a small diameter wire is needed
Silicon Rubber	250°C	450°C	Good moisture resistance
Braided Silicon Rubber	250°C	450°C	Inexpensive wire good for non abrasive applications
MGT	250°C	450°C	Good high temperature wire
SJO Cord	94°C	90°C	Rubber jacket, resistant to all and moisture. for use on 3/8" dia. and larger

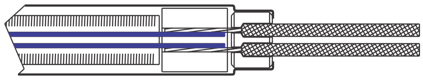
Hot Rod Cartridge Heaters

Swaged in Leads

Swaged in leads are ideal for applications where there is a lot of movement or the leads must be bent sharply upon exiting the heater.



In heaters under 3 " long, the leads go directly in to the core, resulting in an unheated section the length of the ceramic end piece.



In heaters over 3 " long the leads make a connection with the power pins in a short unheated section.

Teflon Seal

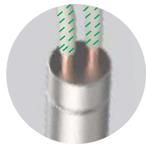
When an effective moisture or oil seal is needed, a swaged in teflon seal with teflon leads provides an effective barrier.

Silicone Rubber Seal

A high temperature silicone rubber seal used with silicone rubber lead wires provides an effective moisture seal up to 400°F (200°C). It is generally the most impervious of the moisture seals.

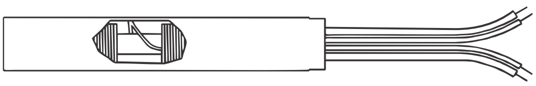
Epoxy Seal

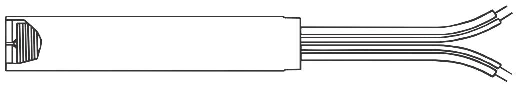
Epoxy potting forms a good moisture seal with more mechanical strength than a silicone rubber seal. Regular epoxy is rated at 350°F(177°C)and epoxylite is rated at600°F(316°C). In order to protect the seal.



Thermocouples

Type 'J' and type 'K' thermocouples can be installed to monitor part temperatures. A thermocouple mounted against the heater sheath in the center of the heater gives a good approximation of block temperature, especially when there is a good fit between the heater and the block. A thermocouple mounted in the tip is useful for monitoring liquid temperatures, or material flowing past the end of the heater. Unless otherwise specified thermocouple leads will be the same length as the heater leads. Standard thermocouple wire insulation is teflon, other types are available upon request.





Swaged in Braid

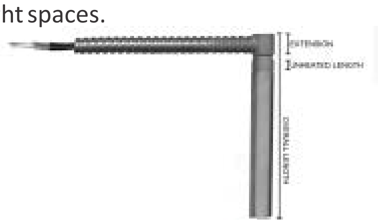
Swaged in stainless steel braid provides excellent abrasion protection while allowing the leads to be bent in a tight radius. Because the braid is swaged in, it is extremely resistant to pulling out of the heater.

Distributed Wattage:

Distributed wattage Hotrods (with a higher watt density on the ends than the rest of the heater) can be used to compensate for end losses in blocks. Distributed wattage Hotrods are available in all diameters.

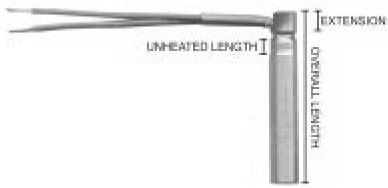
Right Angle Stainless Steel Conduit

Right angle stainless steel conduit offers the same advantages as swaged in stainless steel conduit but allows use in tight spaces.



Right Angle Leads

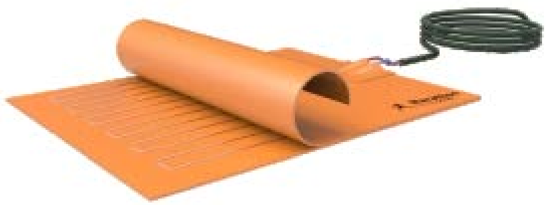
Right angle leads are ideal for applications where space is limited. Leads are covered with a silicon impregnated fiberglass sleeve where they exit the heater



Silicon Rubber Heaters

Wire Wound Silicone Rubber Heaters

Marathon Heater flexible heaters provide outstanding performance in applications up to 250°C under a variety of operating conditions. Properly applied silicone rubber heater life routinely exceeds 10 years. Silicone rubber has a high dielectric strength and is flame retardant and non-toxic. Design versatility permits special heat profiles allowing zones of higher or lower heat concentration as needed. Their flexible construction makes them very easy to install on a variety of surfaces. Silicone Rubber Heaters can be mounted to flat or curved surfaces. They are not affected by vibration, flexing or repeated mechanical shock.

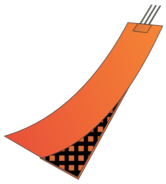


Design Options

Marathon Heater offers several design options to meet various application requirements.

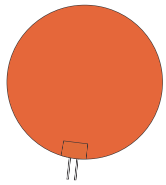
Ground Mesh

For grounding purpose a second layer of insulating material and a conductive grid can be added to the heater. The heater comes with a ground wire.



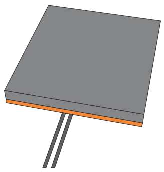
Round Heaters

Round shapes are also available. Round heaters are best attached to tooling with PSA.



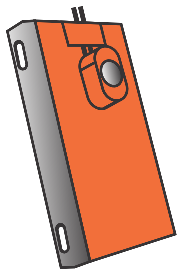
Silicone Rubber Sponge Insulation

To improve heater efficiency, 1/16", 1/8", 1/4", 3/8" or 1/2" insulation can be bonded to the outside of the heater. Closed cell silicone sponge is extremely flexible and has a Temperature range of "-75°C to 250°C".



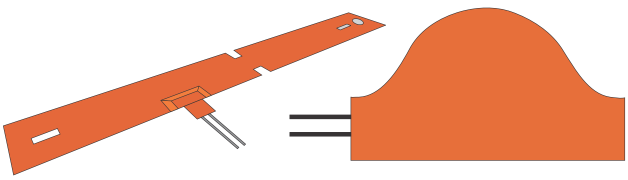
Silicone Rubber Enclosure Heaters

Enclosure heaters are used to maintain temperature in any type of electrical box. Typical applications include ATM's, control boxes, traffic signals, utility boxes, cabinets and switch gear. Enclosure heaters are excellent for controlling humidity or moisture within an electrical box. Silicone rubber heaters are typically mounted to an aluminum plate and have an ambient sensing thermostat.



Various Shapes for Various Applications

Odd shapes are available to fit those hard to heat devices. Holes and cutouts help fit those irregular shaped tools.



Other Design Options

- Dual Voltage
- Three Phase
- Distributed Wattage
- Thermocouples
- Thermostats
- Temperature cut-off
- Pull tabs

Mounting Methods

Pressure Sensitive Adhesive

There are several options for installation or mounting Silicone Rubber Heaters. An easy mounting method is to peel and stick. PSA is attached directly to one side of the heater. Just peel away the protective liner and attach the heater to the desired tool. PSA is rated to a continuous temperature of 300 F and a maximum intermittent temperature of 400 F. It is not recommended for curved surfaces. The heater should be installed within 6 months of manufacture.

Factory Vulcanizing

Another method of installation is to send your tool to the Marathon Heater factory. The tool is placed in a vacuum able and the SRH is vulcanized directly to the tool. This is the strongest bond available.

Field applied adhesive

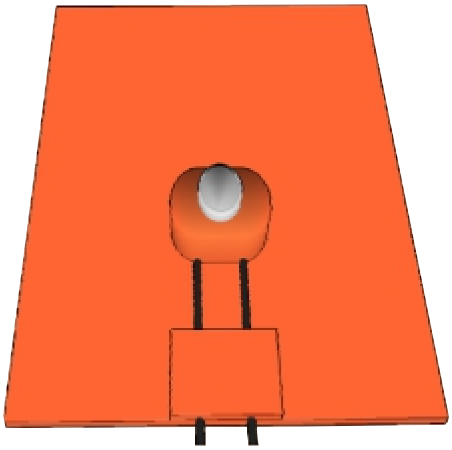
SRH may also be attached with field applied adhesive, Marathon Heater will supply the required RTV to adhere the heater to the desired surface. We offer a room temperature curing adhesive. Apply a thin film of RTV on the entire bottom of the heater. After positioning the heater on the part, use a roller to remove all air trapped between the heater and the part. The RTV should be allowed to cure for 24 hours.

Silicon Rubber Heaters

Temperature Controls For Silicone Rubber Heaters

Marathon Heater Silicone Rubber heaters can accommodate pre-set or adjustable thermostats, thermal cut-offs, RTDs and Type J Thermocouples. Each has a specific temperature range and maximum amperage capability. Please contact the factory for availability.

The most common type of temperature control are pre-set and adjustable thermostats. They can be mounted to sense the temperature of the surrounding atmosphere or to sense the part temperature. Not recommended for low voltage applications.
Thermocouples & RTDs are small and are easily embedded anywhere on the heater. Almost any type of Thermocouple can be used. Type J is the most common.



Drum Heaters

Marathon Heater drum Heaters are an easy way to heat up drum contents. Various sizes and lengths allow you to heat up practically any drum, pail or barrel. Uniform heat prevents scorching or degradation of the contents. The silicone rubber band heater is placed below the level of the fluid. The easy spring lock-up provides movement of the band when content levels fluctuate. The band style drum heater can be used on plastic, alloy or just about any material.

Mounting Methods

Springs and Grommets

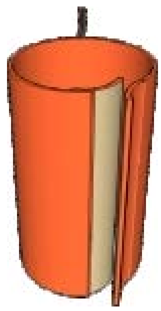
Each end of the spring is attached to a grommet, securing the heater to the
tool. Grommets are spaced approximately 2” apart.

Band Style Drum Heater applications include:

- Freeze protection
- Viscosity control
- Speeding up the flow of liquids
- Maintaining product consistency

Velcro

1” wide Velcro straps secure the heater to the tool.
Temperature rating –35°C to 200°C



Features

- Easy installation with spring loaded fastener.
- 3 conductor cord set.
- Internally grounded.
- Can be wrapped around any object
- Options thermocouples, RTD’s, holes and cut-outs.

Mica Band & Strip Heaters

Mica Insulated Strip heaters / Plate heaters are sheathed in rust-resistance steel or in stainless steel sheath as it provides physical strength and good thermal conductivity.

- High temperature oxidation resistant metal sheath
- Highest grade mica insulation provides excellent electrical insulation at high temperatures and is resistant to moisture.
- Clamping band is low thermal expansion stainless steel construction designed to maintain clamping pressure at elevated temperatures.
- Nickel/Chromium resistance wire evenly wound for uniform heat distribution and reliable accuracy.
- Standard 10” fiberglass leadwires are UL rated and provide protection up to 450°C.
- Approximately 1/8” thick.

Maximum Allowable Watt Density in Watt/Sq.Inch

Cylinder Temp. °C	94	150	205	260	315	370	425
1.5-3" I.D.	52	51	50	46	41	37	29
3-10"I.D.	47	46	45	42	38	33	25
10" and > I.D.	41	40	39	36	31	27	20

Ceramic Band Heaters & Blower Assembly

Ceramic band heaters are medium-to-high temperature heaters that have 648°C as a maximum working temperature. These durable heaters can have optional in-built ceramic fiber jackets that make them energy efficient. Ceramic band heaters are available with different terminal styles, are fully flexible, and can accommodate holes and cut-outs.

In a ceramic band heater, nickel-chrome wire is embedded in a flexible outer wall made of special, interlocking ceramic tiles (KNUCKLES) , which are assembled like a brick wall. A ceramic fiber insulating mat and a stainless Steel/Aluminised Steel jacket cover this assembly. This construction prevents heat loss and reduces electrical consumption by 20%.

Ceramic band heaters can be manufactured with different clamping mechanisms, terminations styles, holes and cut-outs, perforations.

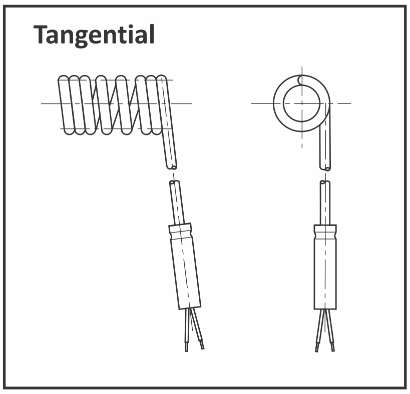
Features and Benefits

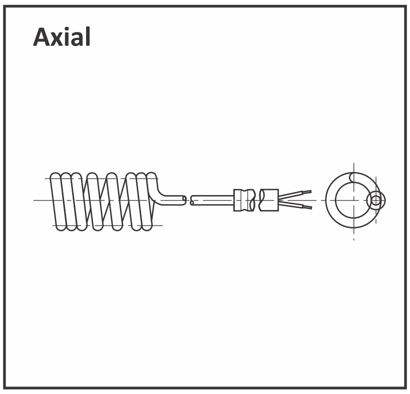
• Reduce power consumption	• Uniform heat distribution
• Conserve heat	• Various termination styles
• High degree of flexibility	

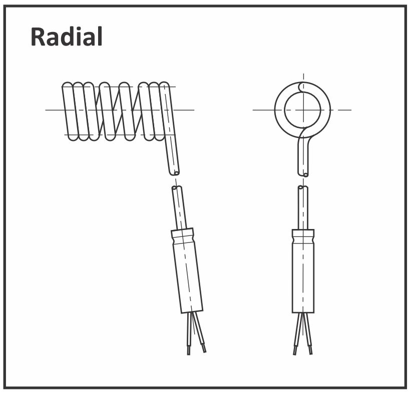
Coil Heaters

Coil heaters are an advance concept of thermal engineering, is also known as high performance tubular heaters or cable heaters. The basic construction of these heaters consist of compacted MgO, high temperature resistance wire and Chrome Nickel Steel tube. These heaters can be constructed with or without built in thermocouples.

Types of Termination Exits







Specifications

Sheath Material	Chrome Nickel Steel
Insulation material	High purity MgO
Heating element	NiCr 80:20
Thermocouple	'J' type (Fe K), 'K' type (Cr Al) grounded or ungrounded
Connection Wires	Stranded Nickel wires with PTFE coating
Voltage Range	24 to 250 volts
Power rating	Depending on application
Power tolerance	± 10%
H. V Testing	800 V (Bent heater),500 V between T/Cand heating element
Insulation Resistance	> 5 MW
Current Leakage	< 0.5 mA
Sheath Temperature	750°C max
Adapter Temperature	150°C max
Length Tolerance	Heated length ± 2%
Unheated Length	5-10 mm on bottom end, 50 mm at the adapter end. Larger lengths available on request.

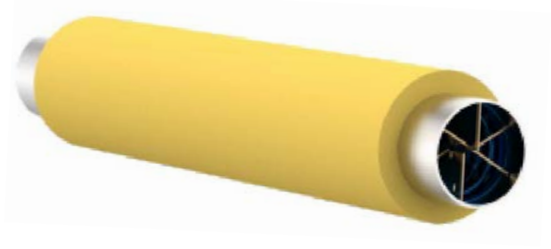
Applications

• Hot Runner Nozzles & Bushings	• Sealing and cutting bars and jaws for packaging machines
• Tube Extrusion	• Small Manifold Heating
• Pipe Forming	• Hot metal forming dies and punches
• Hot runner distribution plates	• Semiconductor manufacturing and wafer processing

Air Heaters

Marathon made air heaters features an open coil of high resistance wire electrically isolated in a stainless steel sheath. Using an open coil for heating is the most efficient type of electric heating and is also the most economically feasible one. As it exposes the maximum heating element surface area directly to the airflow, it provides fast heat up time and improved efficiency. It design facilitates lower maintenance and easy, inexpensive replacement parts.

It is constructed of high grade nickel chromium wire coils Evenly wounded on mica sheet, placed in center of an SS304 Sheath, and electrically isolated using a layer of flexible mica wrapped inside of sheath. These heaters are widely used in hot air dryers



Specifications

Sheath Material	SS304
Sheath Outer Diameter	63.5 mm, 101.6 mm
Wattage	Various Wattage available ranging from 2 kW to 30 kW
Watt Density	Up to 77 W/inch2
Glass wool Insulation	Up to 1200°C
Wattage tolerance	+5%, -10%
Resistance tolerance	-5%, +10%

Advantages

- Fast heat up time
- Increased Efficiency
- Lower maintenance
- Easy installation
- Easy and inexpensive replacement

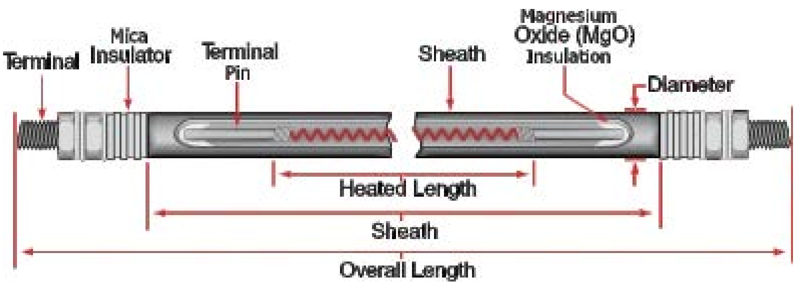
Applications

- Hot Air Dryer
- Hand Dryer
- Plastic Welding
- Sealing

Process Heaters

ENGINEERED SOLUTIONS FOR HEATING & SENSING

Tubular Heaters

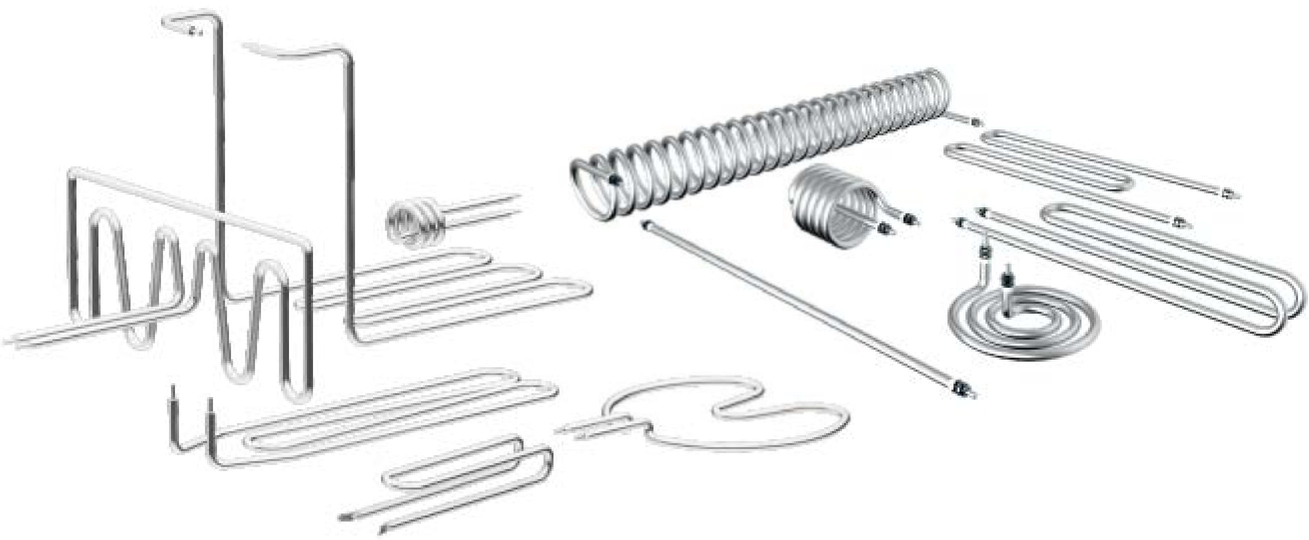


Tubular heating element consists of a resistant nickel chromium wire type 80/20 inserted into a protective metal tube (outer sheath) filled with high purity electro-melt Magnesium oxide (MgO). The assembly will be compacted by rolling/swaging process to ensure excellent heat transfer. Each edge of the sheathed component consists of a non-heating zone, where the electrical connection is made.

The electric heater is custom-made with a maximum length of 10500 mm, along with different diameters (8, 11, 12.50, 13.50& 16 mm).

Material of construction : Steel (ERW /seamless)

Stainless as per ASTM Grade 304/304L/310/316/ 316L/321 Alloys 600, 625, 640, 800, 825, 840



Specifications

Material of outer sheath	Application
Stainless Steel	Immersion Heating's in Water, Alkaline cleaning solutions, Tars, Mild Corrosive liquids, food processing equipment, Indirect and Radiant heating Air heating/ Gas heating. Hopper & tank heatings Large process plant applications.
Alloy 800	Cleaning and degreasing solutions, Corrosive liquids / gases. High temperature / High pressure
Alloy 600 series	Plating and pickling solutions, acid
Titanium	High Corrosive liquids
Temperature	Upto 1800°F

Immersion Heaters

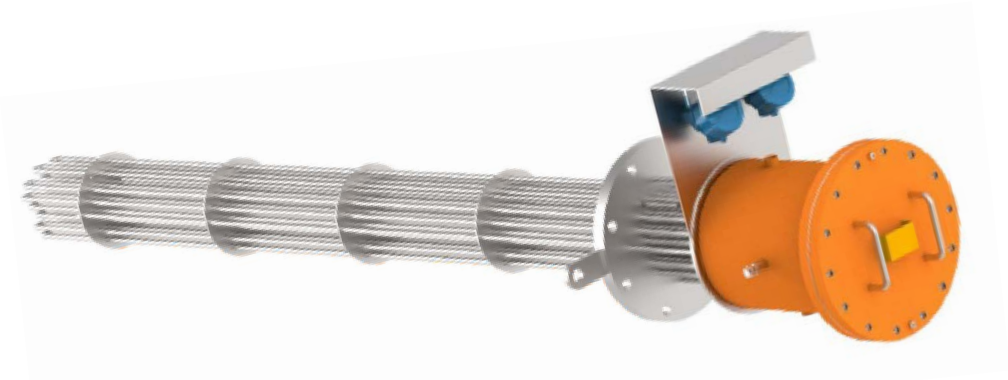
Immersion Heater

Industrial immersion heaters are used widely in all kind of industrial applications such as chemicals, liquids, gases and food processing industries. The immersion heaters are also used in special applications in petrochemical industries such as Flare KO drum heating application and other heating applications in power as well as nuclear applications.

Immersion heaters are designed and constructed in various forms based on the application and mounting requirement. Some of the common types of immersion heaters are.

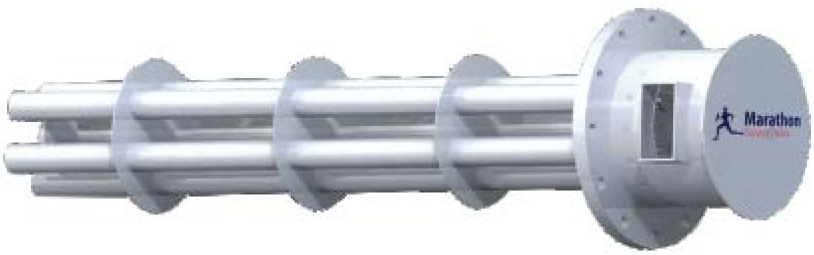
Direct Immersion heater

The heater bundle will be directly mounted inside the Tanks & process fluid will be directly in contact with the process fluid.



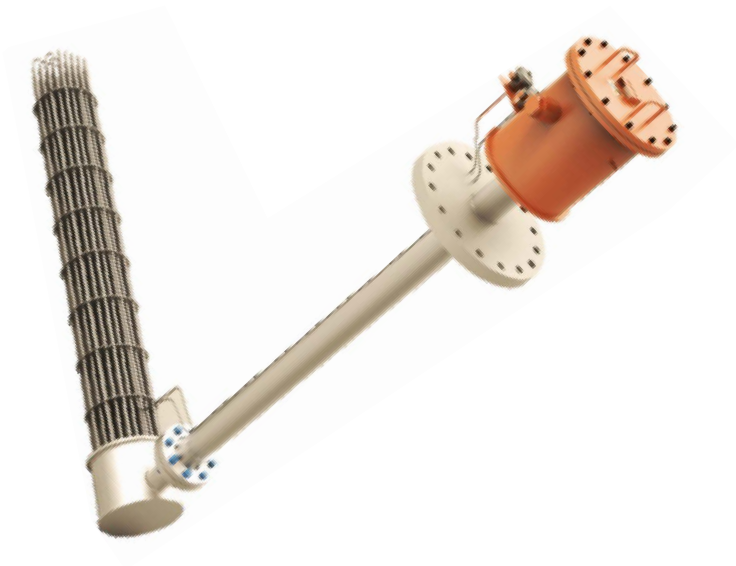
Indirect Immersion Heater

The heating elements will be mounted inside the pockets welded to tube sheet. The heat from the elements transferred to the pocket tubes and in turn to the fluid. These kinds of heaters are used in large storage tank heaters, in which heater replacement can be done without draining the complete system.



L Shape Heater

In some critical process where the heater is required to be mounted vertically but also expected to cover maximum tank area horizontally or at bottom of the tank, the “L” shape heaters are best preferred design.



Air Duct Heaters

Electric tubular heating elements are commonly used to heat air in ducted systems primarily for air drying purposes in various industrial applications.

Duct or air heaters are used in heating ventilation and air-conditioning systems (HVAC) in residential and industrial complexes, as well as in hotels, airports and stadiums etc. for the purpose of maintaining temperatures. The same system is applied in offshore environments.

In industrial applications such as power plants and painting applications, the duct heaters are used for the applications which required hot air purging, or drying purposes.

Typical Applications for Duct or Air Heaters Include

- Comfort Air Heating
- Heating, Ventilation and Air Conditioning (HVAC)
- Drying
- Industrial Hot Air Generation

Typical Industries Include

- Power plants
- Automotive
- Chemical
- Industrial and Residential Buildings
- Facilities for Onshore and Offshore Platforms

Screw Plug Heaters

Screw Plug Heaters are smaller version of Immersion Heaters in which heater flange in replaced with a Threaded Plug. A Single or multiple tubular heating elements are fitted into a thread hexagonal head which are then screwed directly through a threaded coupling in the tank wall or vessel, or installed at process line.

Screw plug heaters are an easy way to heat up solutions in smaller containers that may or may not require auto control on temperature. The Heaters can be installed either horizontally or vertically in the tank. The heater is compatible for both Single phase as well as three phase power supply.

Specifications

Sheath Material	SS , Alloy 600 series, Alloy 800 series, Hastelloy, Titanium, copper etc
Rating	0.1kW to 50kW
Screw Plug Material	CI, Carbon steel, Brass, SS etc
Screw Plug NPT fittings	1”, 1.1/4”, 1.1/2”,2”,2.1/2”, 3” (BSP/ NPT) or equivalent Metric threads
Voltage	120 to 690V AC Single phase or three phase
Terminal Enclosure	Safe / Hazardous
Control	Thermostat/RTD/Thermocouple.

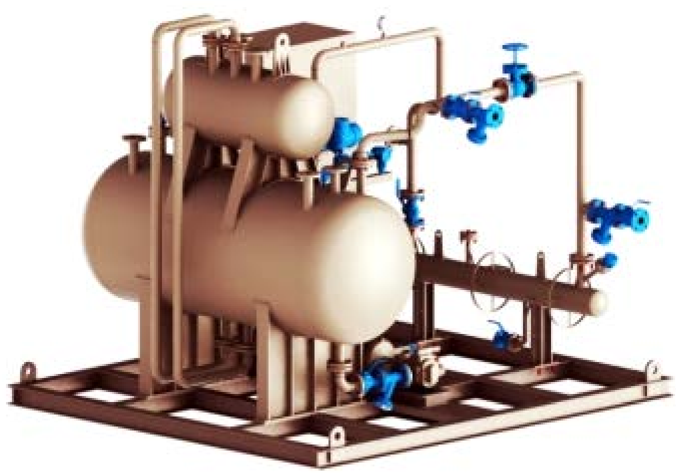
Applications

- Crude oil / HFO/ Lubricant Oil Pre Heating in the tanks.
- Clean Water heating.
- Alkaline and corrosive solvent heating.
- Water & other liquid Vaporizers.
- Gas heating Systems
- Pre Heaters
- Anti condensation heating in the motors
- Oil pre heating in compression units.
- Solar water baths
- Chemical heatings
- Storage chamber heating.
- Small ovens

Heating Skid

Each heater skid is custom made design to suite respective process specifications. A Typical Heater Skid consist of

- Electric Heater bundle
- Pressure Vessel or housing for the Heater Bundle
- Control Panel for the Heater operation control
- Temperature sensors such as RTD's, thermocouples, temperature transmitters, etc.
- Pressure Safety Valve
- Valves for flow control
- Power & Instrument wiring
- Skid base for easy installation at site.



Additional Scope such as extended piping, scrubber installation, Instrumentation for flow, pressure & level monitoring etc. can be provided on specific requirement.

In recent years, In response to the growing demand for more different versatile applications we have broadened design range for manufacturing skids. Thus, we produce mobile heaters shaped as compact skids, of application in both heating and cooling processes. We perform “customized” executions by designing each skid in accordance with the needs of the end user, either composed of thermal oil heater, or only by re-circulation units or secondary groups. The main targets of these skids are asphalt sector and petrochemical industry; the automotive industry or wood sector, for heating presses, etc.

Features

- Single point piping connections for flow and return.
- Optional stainless-steel terminal box and control panel.
- Single point terminations for field power and instrumentation cabling.

Circulation Heaters

Circulation heater is a combined unit of Electric heater bundle inserted inside a Pressure vessel or shell, in which fluid will flow continuously. It is a compact heating system which provides fast heating of the process fluids.

The Circulation heaters are designed in such a way that cold process fluid enters the pressure vessel through inlet nozzle at a low temperature, passes though the active zone of the heater bundle and leaves the vessel through outlet nozzle at desired high temperature. The system is designed in such a way that heating element skin temperature and the pressure drop across the nozzles are maintained within permissible limits. The Circulation heater system can be designed in single stage vessel or multi stage vessels based on the process requirements. The System can be installed vertically or horizontally based on the requirement and space availability

Specifications

Rating	From 1kW to 10,000kW (Max) in Single Bundle or combination
Design Temperature	-40°C to 650°C
Design Pressure	Upto 350 bar(g)
Pressure Vessel	LTCS/ CS / SS, Alloys etc
Heating Elements	Mineral filled insulated Heating Elements or Tubular heating Elements with Ni-Cr (80-20) as heating Coil and suitable outer sheaths.
Terminal Enclosure*	As required (Weather proof or Flameproof).
Control System	Thyristor control Panel + Local control Stations. (Safe area or Hazardous area)
Protections & control:	Element Skin Temperature controls process temperature control Earth leakage protection. Overload current protection. Temperature class Protection (for Hazardous area only)
Installation	Horizontal / Vertical
Certification	Will be provided based n Requirement. (U,U2, PED, ATEX, IEC Ex, CCOE, DOSH etc)

Control Panel

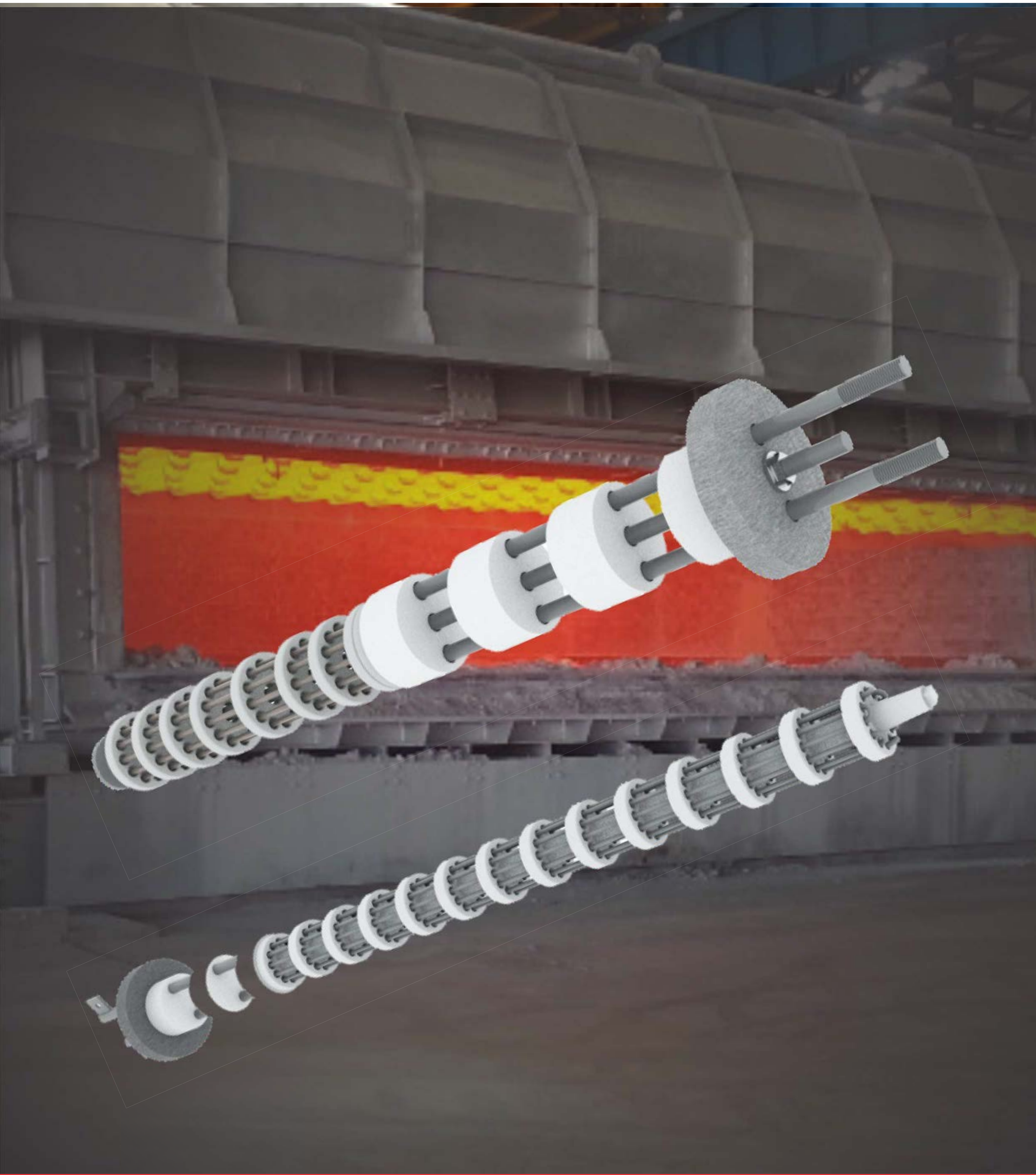
The performance of the Electric heaters mainly depends on the well-designed control Panel. To meet the complex and stringent process control, Marathon is continuously working and developing the control Panels to improve various performance and safety features.

Generally all the process heaters are accompanied with a Thyristor (SCR) control Panel. The large powers of the heaters are divided into multiple small banks for easy and effective control.

Features of Standard Control Panel

• Panel indication lamps for	• Controls
• Power ON/OFF	• Heater On /OFF
• Heater ON/OFF	• Local /Remote
• Element over temperature	• Trip Reset
• Tube sheet over temperature (for ATEX heaters)	• Door mounted potentiometer
• Panel Over temperature	• Lamp test button
• Earth leakage indication and relay	• Earth leakage reset
• Current &Voltage	• Emergency shut down
• Annunciator (for fault indications)	

Furnace Heaters



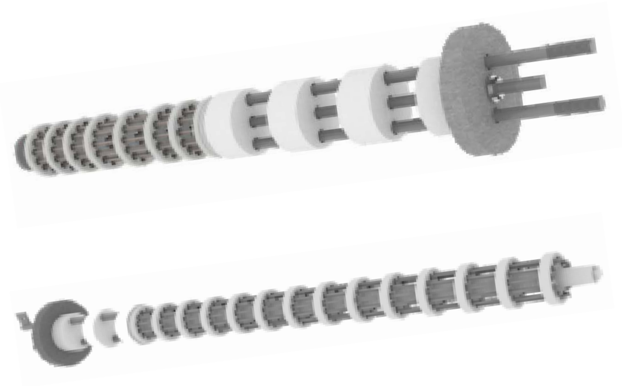
ENGINEERED SOLUTIONS FOR HEATING & SENSING

Furnace Heaters

High Temperature Bundle Rod Heaters and Metallic Heating Elements are used for different furnace applications including Annealing Furnaces, Galvanizing Furnaces etc.

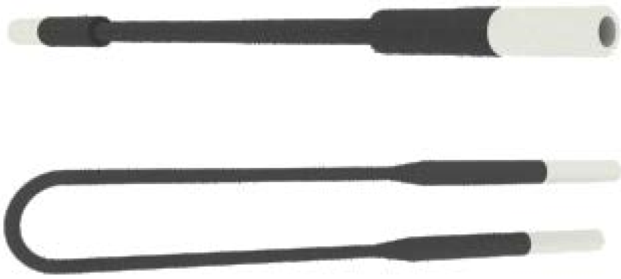
Bundle Rod Heaters

Temperature Range	Upto 1100°C
Heating Element	NiCr 80:20, Ferritic Alloys (FeCrAl) (Powder Metallurgical Heating Element
Radiant Tube Material	HU, Alloy-600 etc. (Customized Diameters and Length)
Application Areas	Annealing Furnace, Spherodizing Furnace, Other Heat Treatment Furnaces



Silicon Carbide Heating Elements

Temperature Range	Upto 1600°C
Heating Element	ceramic material with relatively high electrical conductivity
Application Areas	Aluminium Holding & Melting Furnace, Industrial Ovens, Glass feeder & Float Glass Line, Laboratory Furnaces



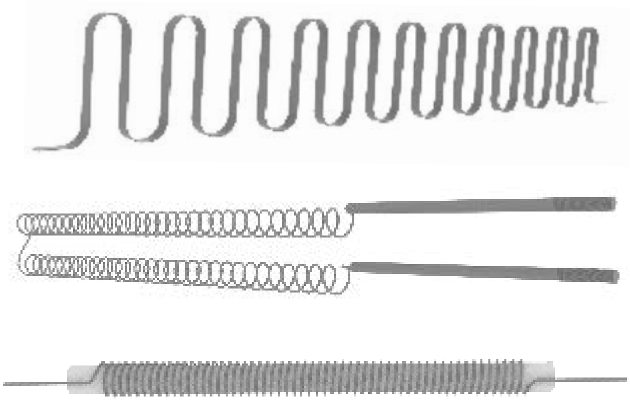
Edge Wound Heaters

Temperature Range	Upto 1100°C
Heating Element	NiCr 80:20
Radiant Tube Material	HU, Alloy-600 etc. (Customized Diameters and Length)
Application Areas	Annealing Furnace, Spherodizing Furnace, Other Heat Treatment Furnaces

Furnace Heaters

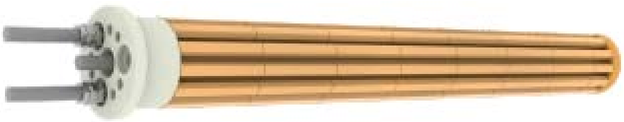
Metallic Heating Elements

Temperature Range	Upto 1100°C
Strip Element	NiCr 80:20, Ferritic Alloys (FeCrAl) (Powder Metallurgical Heating Element
Application Areas	Ammonia Cracker, Furnace Elements etc.



Ceramic Bobbin Heaters

Temperature Range	Upto 800°C
Heating Element	NiCr 80:20
Application Areas	Ammonia Cracker, Furnace Elements etc.



Accessories

Radiant Tube Material

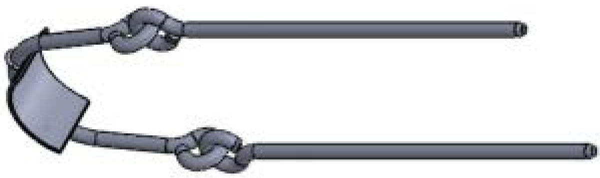
HU, HK-40, Alloy-600/800, SS310

Hanger Material

NiCr 80:20

Radiant Tubes

Hangers



Hangers

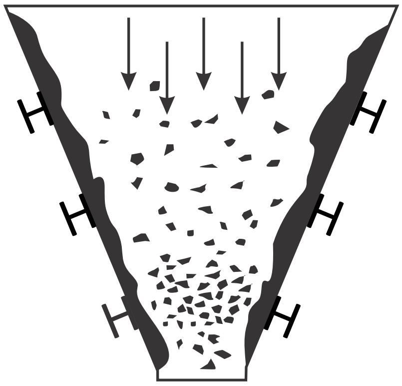
Hopper Heaters

Hopper Heating Modules for Power Plants

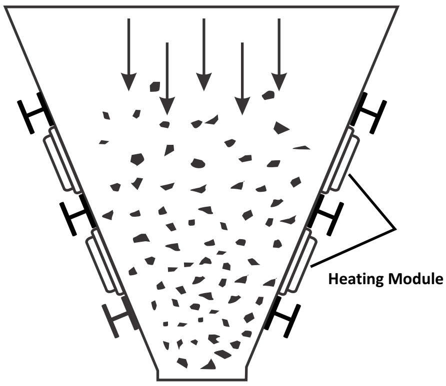
Conveying coal/oil (other material) from stockpile to boiler during winter months is a well-documented nightmare for plant operators. Identical conveying problems exist within the mining industry as coal is moved around the mine site. Coal stored outdoors on the stockpile or delivered by unit train or barges picks up moisture from rain and snow. When this wet or frozen coal is conveyed, it inevitably comes into contact with the plate steel of the various hoppers and chutes within the coal handling system. During winter, this plate steel is below freezing for extended periods.

When wet or frozen coal encounters steel at sub freezing temperatures an instantaneous bond is formed. This bond causes immediate and often catastrophic blockage of the hopper and chutes. The bond and resultant blockage are so severe that often pneumatic drilling equipment and explosives are required to free up the system. This problem, known as Flash Freezing, is extremely inconvenient and very costly. Several cases are documented where utility and industrial boilers have been shut down due to blocked conveying systems.

The Hopper Heating specifically addresses the flash freezing problem.



Cross Section of Unheated Hopper



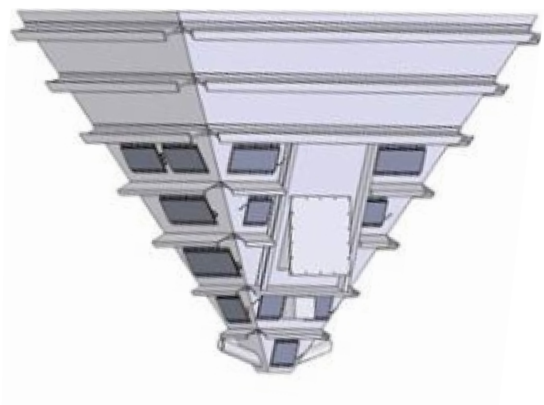
Cross Section of Heated Hopper

Marathon Hopper Heating Module

They are exclusively developed to address the unique and specific requirements for the prevention of condensation in fly ash hoppers and are also custom designed to provide low watt density, uniform heating over the lower areas of the hopper also.

Ratings

- Maximum watt density : 3 W/Inch^2
- Maximum supply voltages : 415 V
- Max. operating temperature : 200°C



Fiber Glass Heaters

Fiber glass heating jacket are ideally suited to raise or maintain elevated temperature of the contents in reaction vessels, storage tank, tankers and process equipment in industries.

Heat Tracing Solutions

ENGINEERED SOLUTIONS FOR HEATING & SENSING

Self Regulating heating Cables

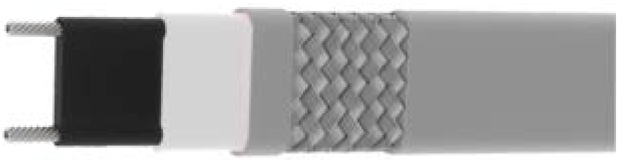
Marathon Heaters' self-regulating heating cable provide the maximum versatility in heat trace design and applications. Constructed of a Semi-conductive heater matrix extruded between parallel bus wires, a self regulating cable adjusts its output to independently respond to ambient temperatures all along its length. As temperatures increase, the heater's resistance increase which lower the output wattage. Conversely, as the temperature decrease, the resistance decreases and the cable produces more heat. So it is no need thermostat in some applications. It will never overheat or burnout even when wrapped by itself(overlapped). It can be cut to any length. So it is an convenient ,easy to use and energy saving product.

LTSRH

Output wattage at 10°C	10, 15, 25, 30, 35 W/M
Braiding covering area	Over 85%
Max. maintain temp @10°C	65°C
Max. exposure temp.	105°C
Min.installation temp.	-40°C
Bending radius	5 times*cable thickness
Voltage	208-277 V
Insulation color	Black
Regular size to insulation	10*4mm (Width*Thickness)

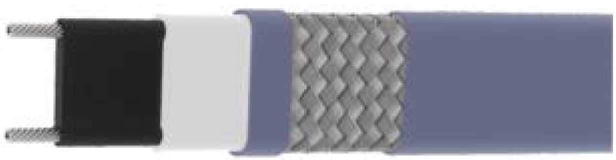
MTSRH

Output wattage at 10°C	40, 45, 50, 60 W/M
Braiding covering area	Over 85%
Max. maintain temp @10°C	105°C
Max. exposure temp.	135°C
Min.installation temp.	-40°C
Bending radius	10 times*cable thickness
Voltage	208-277 V
Insulation color	Grey
Regular size to insulation	11.8*3.4mm-polyolefin insulation 11.6*3.2 Fluoropolymer insulation (Width*Thickness)



HTSRH

Output wattage at 10°C	40, 55, 60, 65 W/M
Braiding covering area	Over 85%
Max. maintain temp @10°C	135°C
Max. exposure temp.	205°C
Min.installation temp.	-40°C
Bending radius	10 times*cable thickness
Voltage	110-120/208-277 V
Insulation color	Dark Grey
Regular size to insulation	9.8*3.3 mm (Width*Thickness)

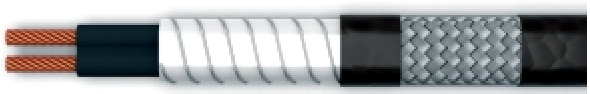


Constant Wattage Heat Tracing Cables

CWPHT (Constant Wattage Parallel Heat Tracing)

Constant wattage parallel circuit heating cables are designed to put out a certain amount of wattage per linear foot of cable. These are generally constructed of two #12AWG polymer insulated parallel bus wires with a nickel alloy heating element wire wrapped alternatively along the insulated bus wires. These connections are made at the 'NODE' point where the nickel-alloy heating element is either welded or connected by rivets. The entire element assembly is then dielectrically insulated with an additional polymer jacket. The power output per unit length is constant, regardless of the overall length of the heating unit. The parallel arrangement preserves systems integrity i.e. if any section of cable should fail, the rest of the heater will continue to operate. Ideally suited for applications where a particular watt density is required at all times such as freeze protection and many other low temperature process control applications

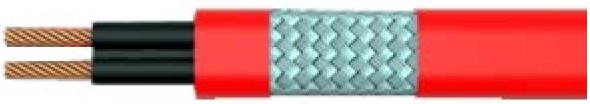
Output wattage at 10°C	20, 30, 40, 50, 60 W/M
Braiding covering area	Over 85%
Surface Temperature	200°C
Max. exposure temperature	230°C
Cut to Length	Yes
Min Bending radius	25 mm
Voltage	230 V / Customise
Insulation	Dark Brown



CWSHT CWPHT (Constant Wattage Series Heat Tracing)

Series resistance-type heater cables use single or multiple resistive conductors to create a heating circuit. Power output of these cables is relatively constant and as voltage is applied, the power output is determined by a combination of the length of the cable and the overall resistance of the conductor. Heating cable's current and resistance is equal to the length of heating cable, so the heating is equally distributed, and does not result in the power of terminal end to be lower than the beginning end with the increasing length of heating cable. It is suited for long line pipes and large diameter pipe's heat tracing or temp. maintenance.

Output wattage at 10°C	Customize W/M
Braiding covering area	Over 85%
Surface Temperature	200°C
Max. exposure temperature	230°C
Maximum Circuit Length	3 KM
Min Bending radius	45 mm
Voltage	230 V / Customise
Insulation	Red

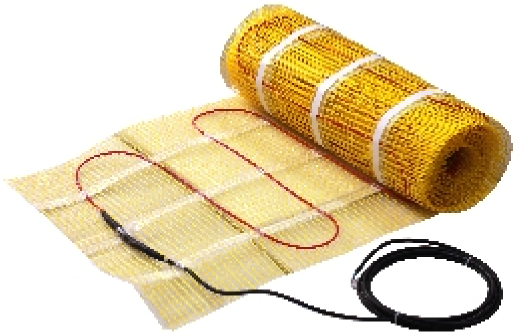


Floor Heating Cables & Mats

Nothing matches to radiant floor heating. It is more comfortable than any other type of heating system. Radiant floor heating is the most energy-efficient way of delivering heat. There is no other floor heating option that compares in terms of comfort. Radiant floor heating is a low-temperature technology that may be regulated individually in each area. Because it warms the people and item directly rather than heating air.

Floor Heating Cables

Floor Heating Mats



Specifications

Shielding Coverage	100% Coverage
Bending Radius	5 times of cable thickness
Jacketing	Heat Resistant and Flame Retardant Jacketing
Flexibility of Cable	Excellent Flexibility for easy installation
Long Cold Lead	3.5 meter cold tail (Can be customized as per requirement)
Comfort	Higher degrees of comfort can be achieved by using heating cables with close and consistent spacing, as well as thermostat to determine temperature needs.
Range	Standard heat loads are available in 100 watt to 3300 watt. As part of the offered product range, several sizes for various types / sizes of flooring are also available.
Custom-Built	In addition to this broad range, cables can be customized to meet specific length requirements, as well as heat loads and voltage needs.

Applications

- Remove any trash and sharp protrusions from the subfloor.
- Prior to installation, consider deflection and structural factors.
- Before installing the cable, check its applicability according to the instructions.
- Prior to putting floor coverings, consider using a scratch coat or a thin leveler.
- Install Heat Resistant Insulation Sheet if want to reduce heat loss (Optional).
- Install Marathon Floor Heating Cable on Plastic Molded Spacer or Aluminium Mounting Tape or similar spacer according to the manufacturer's installation directions.
- Set up a digital temperature controller with thermostat for sensing the floor.
- Install the floor covering according to the manufacturer's directions.

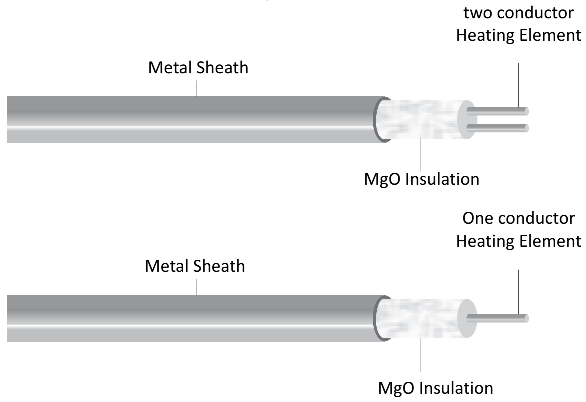
Mineral Insulated Heating Cables

Marathon Mineral Insulated Heating Cables are the most rugged heating cable in Marathon's product line. Constructed of a solid series resistor element embedded in highly compacted mineral insulation, MI cables are built to handle high temperature, high wattage applications. The series resistor and mineral insulation are encased in a metallic jacket of INCONEL 600/800, SS304/316/321 or Copper for different high temperature or corrosive applications.

Heater is Comprised of Three Components:

1. A central conductor of an electrically resistive metal (Conductor can be helically coiled or straight) enables the design of a large range of lengths and wattage.
2. Highly compacted Magnesium Oxide provides insulation of the resistance wire for voltages up to 600V.
3. Sheathed with a metal covering of copper or Stainless Steel or INCONEL 600/800 provides excellent resistance to Pitting, Chloride- stress, acid and alkali corrosion.

Mineral Insulated Heating Cable Construction



MI heating cables can be used for applications with the following requirements:

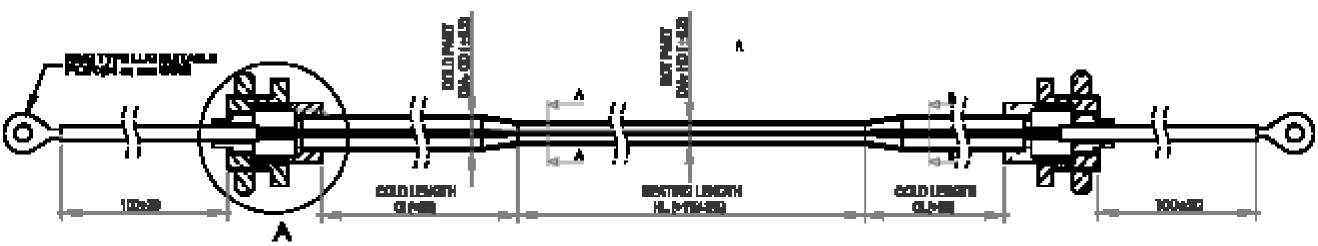
Max. Maintenance Temp. (°C)	Max. Exposure Temp. Power off (°C)	Max. (W/m)	Voltages	Size
550	650	250	Up to 600 Volt	As per Requirement

Higher temperature and power capabilities are available; contact Marathon Heater Management for additional information. Heating cables are supplied as complete factory-fabricated assemblies consisting of a heated section joined to a length of non heating cold lead section, pre-terminated and ready to fasten into a junction box with an NPT-threaded connector.

Special Heating Cable Design Configurations

Marathon Heater offers customized designs in MI Heater Configurations to fulfill customer requirements.

Marathon Heater ECR (Extended Cold Region) Heaters are examples of such special type of MI Heaters, which are manufactured with extended cold ends from the Heating Length of the heater which suits to Critical Nuclear applications.



Extended Cold Region (ECR) Mineral Insulated Heater

Applications

This cable is suitable for the following applications:

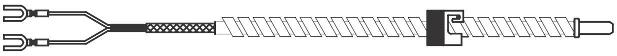
- Under-water Radiator
- Container Heaters
- Valves Heaters
- Pipe-accompanying Heaters
- Industrial Process Heaters
- Panel Heaters
- Immersion Heaters

Thermocouples & RTD's

Thermocouple Sensors

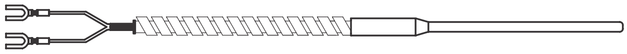
Marathon Heater is pleased to present our line of premium temperature sensors. We offer standard and customized thermocouples, mineral insulated thermocouples, and RTDs. We use only the highest grade materials and offer a variety of sheath materials for any environment or temperature range. All sensors are subject to rigid quality control procedures and a thorough inspection process. Expert engineering assistance is readily available for any order size, large or small.

Adjustable Depth Thermocouples w/ Stainless Steel Armor



Standard Features
- Fits standard bayonet adapters
- 12" spring with bayonet cap
- Spade lugs
- Grounded & Ungrounded construction
- 24 ga. Fiberglass leads with stainless steel armor

Bendable Probe Thermocouples

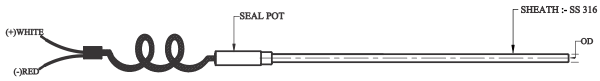


Standard Features
- 24 ga. Fiberglass leads w/ SS armor
- Grounded & Ungrounded construction
- Spade lugs

Adjustable Depth Thermocouples w/ Stainless Steel Overbraid (Metric)

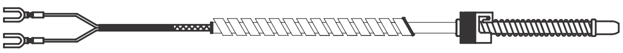
Standard Features
- Fits metric bayonet adapters
- Metric bayonet cap with two slots
- Spade lugs
- Grounded & Ungrounded construction
- 24 ga. Fiberglass leads w/ SS overbraid

Miniature Mineral Insulated Thermocouple for HotRunner System



Standard Features
- 0.5, 1.0, 1.5, 2.0 upto 6.0mm diameter
- Grounded or ungrounded Constructions
- Kapton Insulated Lead Wire
- High temperature sealing upto 300°C

Fixed Depth Thermocouples



Standard Features
- Fits standard bayonet adapters
- Spade lugs
- 24 ga. Fiberglass leads with SS armor
- Grounded & Ungrounded construction

Washer Style Surface Thermocouples

Standard Features
- Grounded construction
- 24 ga. Fiberglass leads w/ stainless steel overbraid
- Spade lugs

RTD Sensors

Brass Washer on RTD

Standard Features
- 2 wire or 3 wire
- Flexible probe
- Stainless steel braid
- Spade lugs
- RTD probe also available in other TC styles

Facilities

Welding and Brazing

- Laser Welding Machines
- Programmable Micro Plasma Welding Machines
- TIG Welding Machines with Pulse Modulation And Rotary Positioner
- Induction Brazing Machines
- Resistance Welding Machines
- Brazing Sets (Oxy-Acetative)
- Deep Penetration Welding Machines

Machining

- CNC Turning Centers
- Turn Mill Centers
- VMC Machines
- Deep Hole Drilling Machines upto 1500mm Drilling Capacity
- Milling Centers
- Manual Lathe Machines
- Cutting Machines

Heater Plant

- Swaging Machines
- Laser Marking Machines
- Laser Cutting Machine
- Bright Annealing Machine
- Engraving Machines
- Coil Making Machines
- High Frequency Annealing Machines
- MgO Filling Towers
- Rolling Machine & Skinning Machines
- Vacuum Presses
- CNC Breading Machines

MI Cable Plant

- Draw Bench 50 meters, Horizontal Draw Benches
- Annealing Furnaces
- MI Polishing Machines
- MgO Plant

Testing and Facilities

- Digital Multimeter
- Digital Clamp Tester
- High Voltage Tester
- Digital Insulation & Continuity Tester
- Micrometer
- Vernier Caliper (0-200mm)
- Vernier Caliper (0-1000mm)
- DFT Meter
- Pressure Gauge
- Digital Lux Meter
- Sound Level Meter
- X-Ray Machine
- Vibration Test Bench
- Temperature Gun
- RT Film Viewer
- Ultrasonic Thickness Gauge

Chapter - 1

Temperature

The temperature of a substance is its degree of hotness or coldness. A substance is said to have a high temperature if it is hot, and a low temperature if it is cold. A substance's temperature provides information about its molecules' average kinetic energy. The random motion of the atoms and molecules is because of the temperature. All random motion ceases at absolute zero temperature. There are different scales of temperature on which the temperature is measured. The Celsius and Kelvin scales of temperature are very popular.

Any material having a temperature greater than absolute zero contains energy. The higher the energy level of a material, the higher its temperature will be. In other words, if two identical material samples of the same mass have different temperatures, we are confident that the sample at the higher temperature will have a higher level of energy than the sample at the lower temperature.

Chapter - 2

Heat

We all know from experience that warm food left in a room cools down and warm food kept in the refrigerator cools down. This happens because energy is transferred from the warm medium to the cold one. Warm food cools down because it gives off energy to its surroundings. The energy transfer is always from the higher temperature medium to the lower temperature medium, and this energy transfer stops when the two mediums reach the same temperature. Warm food is at a higher temperature, and the room temperature is lower than the temperature of warm food. There is a temperature difference between warm food and the surrounding room temperature. This temperature difference causes the heat energy from warm food to flow into the room. As a result of this heat transfer, warm food gets cooler and the surrounding room's air temperature increases.

We know there are various forms of energy. Out of all the forms of energy, heat is one of the form of energy which is transferred from one system to the other as a result of temperature difference. It is the energy in transit. It is measured in Joules or Calories. The science that deals with the determination of the rates of such energy transfer is known as "heat transfer rate." The rate of heat transfer is measured in J/s or watts.

A temperature difference is a necessary condition for heat transfer. There can be no net heat transfer between two mediums that are at the same temperature. The temperature difference is the major driving force for the heat transfer, just like voltage difference is for electric current flow. The rate of heat transfer per unit area normal to the direction of heat transfer is called heat flux, and the average heat flux is expressed as

$$q = \frac{Q}{A} \qquad (W/m^2)$$

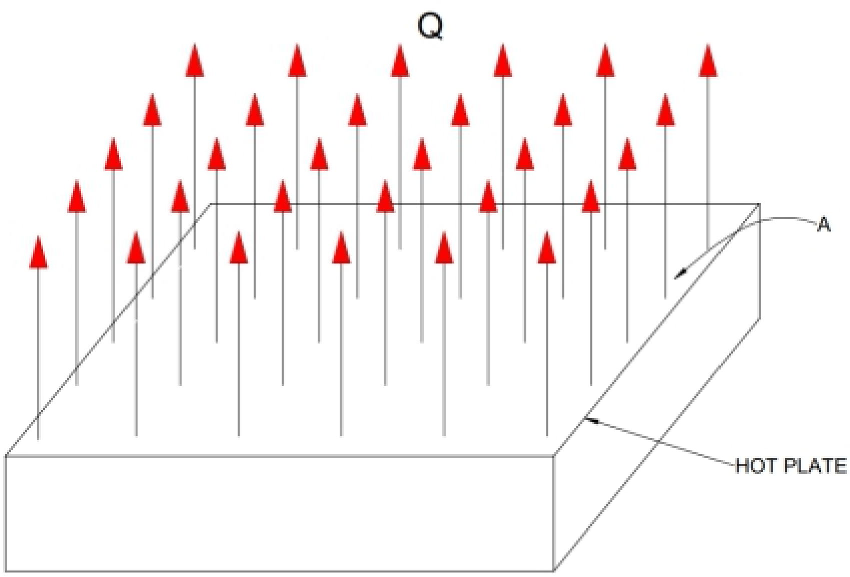


Fig. 1 Heat Flux

where A is the heat transfer area. For example, 100 W of heat is being transferred from a plate having an area of 10 m^2 normal to the direction of heat transfer, so the heat flux is 10 W/m^2.

Chapter - 3

Mechanism of Heat Transfer

Heat can be transferred in three different modes: Conduction, Convection and Radiation. All modes of heat transfer require the presence of a temperature difference, and in all modes, heat transfer takes place from a high temperature to a lower temperature. For radiation, hot objects transfer heat to cold objects, and cold objects transfer heat to hot objects, but the net rate of radiation heat transfer occurs from the hot object to the cold object.

3.1 Conduction

Conduction is the transfer of energy from more energetic particles of a substance to the adjacent less energetic particles. Conduction primarily takes place in solids, but it can take place in all types of matter, i.e. solids, liquids and gases. In gases and liquids, conduction is because of collisions and diffusion of molecules during their random motion.

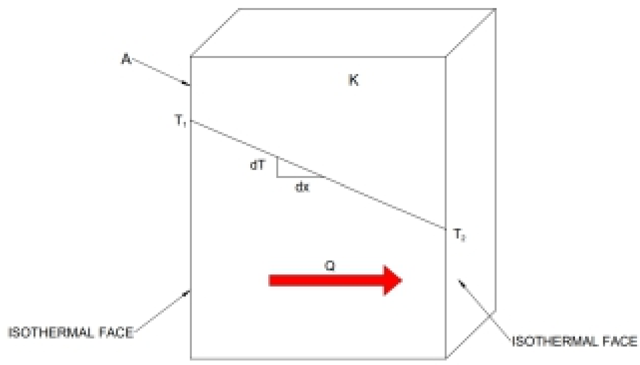


Fig : 2. Steady State Heat Conduction

In solids, conduction happens due to the transport of energy by free electrons and the vibration of the molecules in the lattice. Conduction heat transfer is directly proportional to the area of heat transfer and the temperature gradient. The rate of heat transfer by conduction is governed by Fourier's law of heat conduction.

$$\dot{Q}_{cond} = -KA\frac{dT}{dx}$$

where K is the thermal conductivity, which is a property of the material, and A is the surface area perpendicular to the heat transfer as shown in the above figure. It is the ability of the material to conduct heat energy through it. A higher thermal conductivity of a material promotes faster heat transfer through conduction.

So materials whose thermal conductivity is more like that of metals are used to transport the thermal energy quickly. On the other hand, less thermally conductive materials like ceramic and glass wool are used as the insulating material. In other words, we can say that materials with lower thermal conductivity are often used to prevent heat loss. It makes the thermal system more efficient.

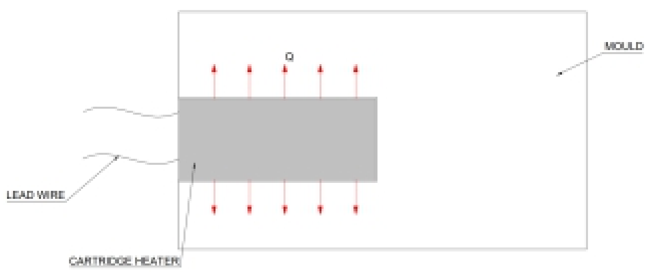


Fig : 3. Heat Conduction from Cartridge Heater to the Mould

3.2 Convection

Convection is the mode of heat transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion. In convection, there is always bulk fluid motion. The layer in contact with the solid surface comes to rest because of the no-slip condition. In this mode of heat transfer, first the heat is conducted to the first layer of stationary fluid, then the energy is transported by the moving fluid in the form of enthalpy.

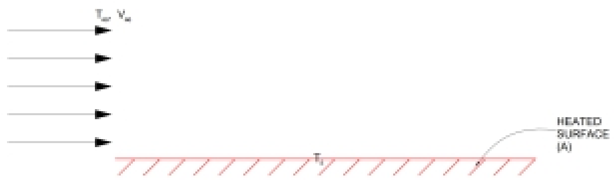


Fig. : 4 Forced Convection from Heated Surface to the cold air

If the fluid motion is faster, then the heat transfer rate through convection is higher. There are two types of convection: forced convection and free or natural convection. If the fluid is forced over the heated or cooled surface by external devices such as a fan, pump, blower, etc., then it is called forced convection as shown in figure 4.

In contrast, convection is called natural or free convection if the fluid motion is caused by buoyancy forces that are induced by density differences due to the variation of temperature in the fluid. In other words, when the liquid or gas heats up, it becomes lighter and rises.

Forced convection increases the heat transfer rate as compared to natural convection for the same surface at the same temperature. So we can put more heat energy into the heater. How we can add the more heat energy? The watt density of the heater should be increased. Forced convection allows us to use higher wattage since the heat transfer rate is enhanced due to the bulk motion of the fluid particles.

Suppose the fluid is flowing over the heated surface, which has a surface area of A and a uniform surface temperature Ts, as shown in figure 4. The temperature of the fluid at free stream is T_∞.

According to Newton's law of cooling, the rate of convectional heat transfer is proportional to the area of heat transfer and the temperature difference between the surface and the fluid. Convectional heat transfer can be expressed as

$$Q_{conv} = hA(T_S - T_\infty)$$

where h is the convection heat transfer coefficient in W/m2K. A is the surface area through which the convection heat transfer is happening. Ts is the surface temperature, and T_∞ is the temperature of the fluid sufficiently far from the surface.

For forced convection, heat transfer is greater than natural convection for the same area and temperature difference. So the heat transfer coefficient, h is higher for forced convection than for natural convection.

Due to convection, heat is transferred from the immersion heater to the water in the tank. If the water is flowing from some inlet to outlet with the help of pump, then it will be referred as forced convection but if water is in the closed tank and water is stationary in the tank then the heat will flow from immersion heater to water by free or natural convection.

3.3 Radiation

Energy emitted by matter in the form of electromagnetic waves is known as radiation. In this mode of heat transfer, the presence of an intervening medium is not required. In a vacuum, radiation heat transfer can also occur. Sun's energy reaches to the earth by radiation. Radiation travels at the speed of light in a vacuum. Thermal radiation, which is the type of radiation emitted by bodies as a result of their temperature, is of specific interest in heat transfer studies. It differs from other types of electromagnetic radiation that are not related to temperature, including x-rays, gamma rays, microwaves, radio waves, and television waves. All bodies at a temperature above absolute zero emit thermal radiation in all directions into the hemisphere above the elemental surface area dA, as shown in figure.

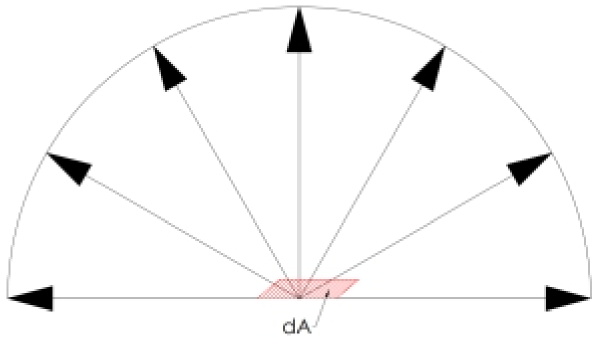


Fig. : 5 Radiation emitted from the blackbody

The maximum rate of radiation that can be emitted from a surface at an absolute temperature T (K) is given by the Stefan-Boltzmann law as

$$\dot{Q}_{emit,max} = \sigma A T^4$$

Where σis the Stefan Boltzmann constant. The ideal surface that emits radiation at this maximum rate is called a blackbody, and the radiation emitted by a blackbody is called blackbody radiation. The above equation tells us the total energy emitted by a blackbody per unit time at a particular temperature T K. However all the energy is not equally distributed. The energy is distributed unevenly at different wavelength which has been shown in the graph. These graphs are drawn for blackbody. Actually the total radiant power for blackbody is the sum of all the spectral (at particular wavelength) radiation power.

Radiation Curve

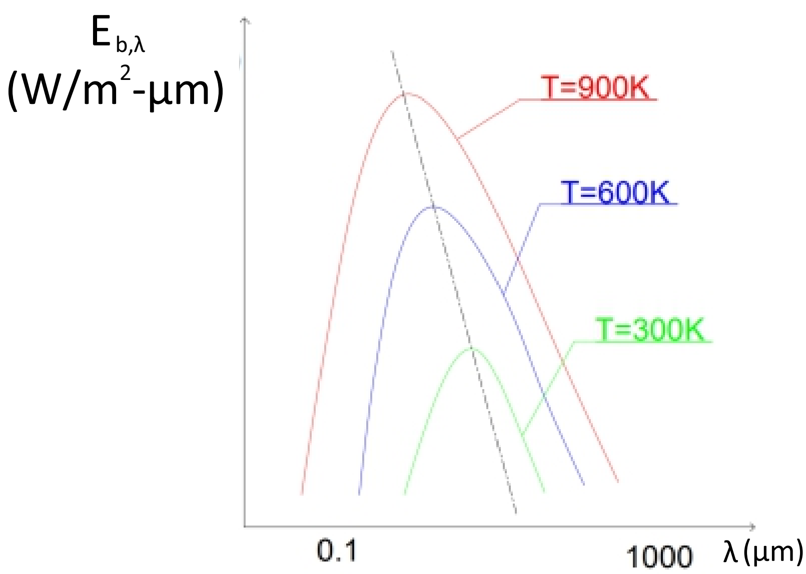


Fig. : 6 Spectral distribution of Radiation for black body at temp 300K, 600K, 900K

The radiation emitted by the entire real surface is less than the radiation emitted by a blackbody at the same temperature. The radiation emitted by a real body can be expressed as

$$\dot{Q}_{emit,real} = \varepsilon \sigma A T^4$$

Є is the emissivity of the surface. Its value is in the range of 0-1. It is a measure of how closely a surface approximates a black body. For blackbody, emissivity is one.

The radiation energy that strikes the object per unit surface area is called irradiation. Some part of this incident radiation is absorbed by the object, some part is reflected by the object, and the remaining part is transmitted through the object. If the object is opaque, then there is no transmitted part. Another important radiation property of a surface is its absorptivity, which is the fraction of the radiation energy incident on the surface that is absorbed by the surface. If absorptivity is higher, then a greater amount of incident radiation is absorbed by the object. The absorbed portion is responsible for the temperature increase of the object that we want to heat up with radiation. Like emissivity, its value is in the range from 0 to 1. A black body absorbs the entire radiation falling on it. A black body is a perfect absorber.

Suppose we are heating an object with the help of a radiant heater then for the maximum absorption of radiation the absorptivity of the target object should be as high as possible. Ideally, it should be one.

The net radiation heat transfer between two bodies maintained at constant temperatures T_1 and T_2 and emissivity

$$\dot{Q}_{rad} = \frac{\sigma \times (T_1^4 - T_2^4) \times A_1}{\frac{1}{\varepsilon_1} + \frac{A_1}{A_2}\left(\frac{1}{\varepsilon_2} - 1\right)}$$

Suppose the radiant heater is very small with respect to the enclosure or the enclosure surface is black i.e. $\varepsilon_{surr} = 1$ as shown in figure.

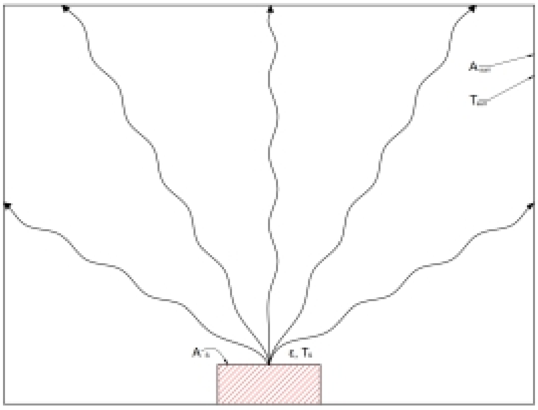


Fig.: 7 Radiation Heat Transfer from a real body to the surrounding

$$\frac{A_s}{A_{surr}} \rightarrow 0$$

or

$$\varepsilon_{surr} = 1$$

then

$$Q_{rad} = \frac{\sigma \times (T_s^4 - T_{surr}^4) \times A_s}{\frac{1}{\varepsilon_s} + \underbrace{\frac{A_s}{A_{surr}}\left(\frac{1}{\varepsilon_{surr}} - 1\right)}_{\boxed{0}}}$$

$$Q_{rad} = \sigma \times (T_s^4 - T_{surr}^4) \times A_s \times \varepsilon_s$$

emissivity, the more energy it can radiate to an object at any given temperature. And if the absorptivity of the target object is also higher then the maximum part of the radiant energy the object can absorb, it can heat up faster. Ideally, the emissivity of the heater should be one and the absorptivity of the target object should be one. To achieve the higher emissivity and absorptivity of the heater and object, we can coat the surface with some suitable paint or oil.

In radiation analysis, the emissivity and absorptivity of a material are considered to be the same according to Kirchhoff's law.

Absorptivity of a surface may depend upon wavelength. For some wavelengths, the absorptivity may be high. If we know which wavelengths of radiation are best absorbed by a material, we can adjust the heater's temperature to radiate most of its energy at those wavelengths. For heater which is radiating the energy if we increase the temperature of heater then most of its energy is shifted to shorter wavelength.

View Factor :

It is generally represented as F_{12} which means the percentage of radiant energy leaving the heater surface that is actually received by the target object. Its value lies in the range 0 to 1. View factor 1 means all the radiation energy is falling on the object. Suppose that the view factor between the heater and the object is 0.40. It means that 40% of the heater's heat actually hits the object and the remaining 60% escapes without touching it.

$$0 \leqslant F_{12} \leqslant 1$$

For heating an object by radiation, the view factor of the object should be maximum, and for the maximum absorption of this falling radiation, the absorptivity of the target object should be maximum. In order to increase the view factor, the target object should be kept close to the heater, and we can also increase the view factor by increasing the surface area of the target object. In this case, "target object" refers to the component that we want to heat up using radiation.

Chapter - 4

Heat Capacity

It is defined as the energy required to raise the temperature of given mass of substance by one degree. It is expressed in J/K. Heat Capacity is represented by capital letter C and is given by

$$C = \frac{Q}{\Delta T} \quad J/K$$

$$Q = C\Delta T$$

Heat capacity depends upon the mass or quantity of the substance. More is the mass more will be its heat capacity. So it is an extensive property. Extensive properties are those thermodynamic properties which depends on the mass of the system.

Chapter - 5

Specific Heat

Specific heat is similar to heat capacity but it is defined for unit mass of the substance. It is an intensive property as it does not depend on the mass. It is defined as the energy required to increase the temperature of a unit mass of a substance by one degree. The specific heat is measured in J/KgK. The higher the specific heat, the greater the heat storage ability of the material. For example, there are two-unit mass i.e. 1Kg mass objects one is having the specific heat of 2KJ/KgK and other object have the specific heat of 4KJ/KgK. The object that has a specific heat of 2KJ/KgK needs 2000J of thermal energy to raise its temperature by one degree, while the object that has a specific heat of 4KJ/KgK needs 4000J of thermal energy to raise its temperature by one degree. So a 4KJ/KgK-specific heat object has a higher heat storage ability than a 2KJ/KgK-specific heat object.

This energy depends on how the process is executed. There are two kinds of specific heat: specific heat at constant volume C_v and specific heat at constant pressure C_p. Specific heat at constant volume C_v can be defined as the energy required to raise the temperature of a unit mass of a substance by one degree when the volume is constant. Specific heat at constant pressure C_p can be defined as the energy required to raise the temperature of a unit mass of a substance by one degree when the pressure is constant. These two specific heats are relevant for gases because gases are compressible, and the amount of heat that is to be added or removed in the system depends on how the process is executed during heating or cooling.

For the gaseous system, the amount of heat to be added at constant volume is given by

$$Q = mc_v\Delta T$$

Similarly, the amount of heat to be added at constant pressure is given by

$$Q = mc_p\Delta T$$

The constant volume and constant pressure specific heats are identical for incompressible substances. Solids and liquids are considered incompressible substances. Therefore, for solids and liquids (incompressible), specific heat can be represented by a single letter c. This means that $c_p = c_v = c$.

$$Q = mc\Delta T$$

In the above expressions, the specific heat is assumed to be constant in that temperature range. Specific heat is not always constant. It depends on the temperature. In that case, the amount of heat will be determined with the help of integration.

$$Q = \int_{T_1}^{T_2} mcdT$$

Chapter - 6

Watt Density

The watt density of a heater is defined as the amount of power (in watts) produced by an electric heater per square meter of heated surface area. It is expressed in W/m^2 or W/cm^2.

If an electric heater has a wattage of 5000W and a heated area of 100 mm x 100mm, its watt density is given by

$$\text{Watt Density} = \frac{5000W}{100 \times 100mm^2} = 0.5W/mm^2$$

For specific set of circumstances, heater operating temperature is determined by watt density (watts per square mm of heater surface area). The watt density is determined by how well the material being heated distributes heat throughout its volume. Metals, light oils, and water, for example, have high heat distribution rates, permitting the use of high watt densities. Syrups, heavy oils, and hydraulic fluids with poor heat transfer require lower watt densities to avoid overheating in specific areas. Operating temperature, flow rate, and heat transfer rates all affect safe watt density values. The elements may burn out if the watt density is too high. If the watt density is too low, the heater price will be high because of the high material cost. The heater's life will be at its maximum when it has the lowest watt density.

In general, watt density is determined by three factors:

1. Maximum outlet temperature
2. Type of fluid heated
3. Fluid flow rate

Watt density gets directly impacted by wattage rating of the heater. If we increase the wattage of the same heater in the given space, then we have to increase the watt density.

One way to increase the heater's life is to reduce its watt density. Reducing the watt density of a heater will always reduce its internal operating temperature in any given application. If the watt density is greater than the maximum watt density for the given application, then the heater's life will be shorter.

Too much reduction in the watt density will surely increase the heater's life, but simultaneously, more length of the heater will be required for the required wattage, and thus the initial cost of the heater will be higher.

Chapter - 7

Effect of Viscosity on Watt Density Selection

Viscosity is the property of fluids that resists the relative motion between the fluid layers. Higher-viscosity liquids flow slowly, while lower-viscosity liquids flow easily. For example, honey and water. Honey is difficult to flow because it has a high viscosity, whereas water is easy to flow. Water is less viscous than honey. So lower viscosity liquids like water can carry away the heat faster from the heater, so we can use high watt density for them, but for the liquids whose viscosity is higher, they will flow very slowly, so we prefer to use low watt density heaters for them. If a high-watt density heater is used for the liquids that have a higher viscosity, then the heater may fail or burn out very soon because of overheating.

Chapter - 8

Thermal System

A thermal system is defined as the system by which we could heat up the substance to a certain desirable temperature. Any thermal system consists of a heat source device, a temperature sensor, a temperature controller, and the workload. Workload is the substance that needs to be heated. It can be solid, liquid, or gas. The heat source is the device that generates heat, like an electric resistance heater. This heat is transferred to the workload either by conduction, convection, or radiation. A temperature sensor measures the current temperature of the workload. There are various types of temperature sensors, like RTDs, thermocouples, and thermistors. The temperature controller is the device that actually regulates the temperature of the workload according to the set point temperature. The temperature controller gets the signal from the temperature sensor, and it gives a response according to this temperature information. The set point temperature is the temperature at which we want to heat the workload. For example, we want to heat up the water from 30°C to 100°C. So in this case, our set point temperature is 100°C. Initially, when the heater is turned on, the temperature is 30°C. The heater will add heat to the workload as time progresses, thereby increasing the temperature of the workload. The heater will stay on until the set temperature is reached. Once the temperature crosses the set point temperature, let's say it becomes 105°C, the temperature controller will send the signal to the heater that no more heat is to be added. So the heater will be turned off. Let us suppose that the temperature of the water drops from 105°C to 95°C. Then the current temperature of the workload is less than the set point temperature, so heat needs to be added to the system to achieve the set point temperature. The temperature controller will send the signal to turn on the heater. The process of turning on and off the heater to maintain the set point temperature when the temperature of the workload exceeds or falls in relation to the set point temperature is known as "thermal cycling."

A temperature controller will always attempt to achieve the workload's set point temperature. If the current temperature of the workload is less than the set point temperature, the temperature of the workload must be raised by adding more heat, and if the temperature of the workload exceeds the set point temperature, the temperature of the workload must be reduced so that no more heat must be added.

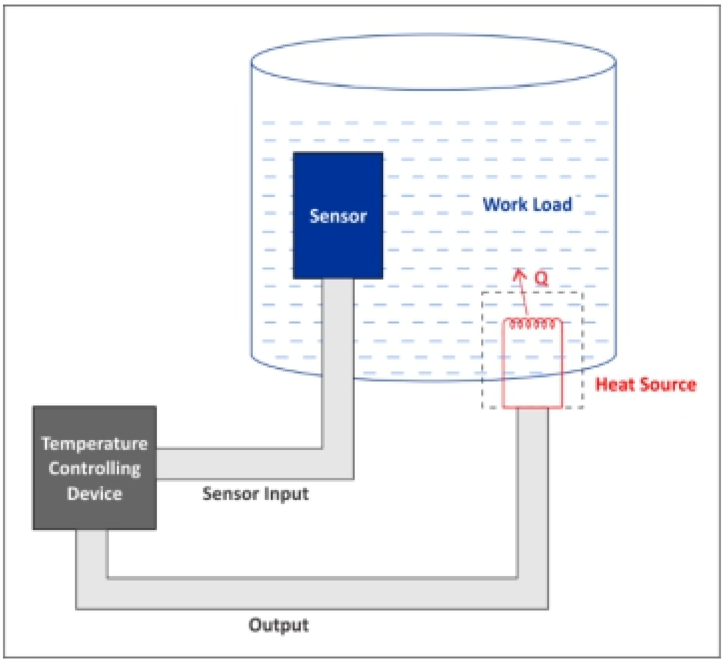


Fig.: 8 Thermal System

8.1 Electric Heaters

An electric heater can be used as the heat source device. In an electric heater, the electrical energy is converted into thermal energy. It generates the heat through resistance heating when power is supplied to the heater. In general, an electrical heater consists of a resistance element, insulation, and sheath.

8.2 Resistance Element

It is the main heating element that produces heat when power is supplied. Heat is generated in the wire because of Joule's heating or ohmic heating or resistance heating. The resistance element could be in the form of a coil, small-diameter straight wire, ribbon, etc. Because of its good formability and ability to withstand high temperatures, nichrome wire is commonly used as the resistance element material.

8.3 Insulation

The insulation is provided to electrically isolate the resistance element. It is an electrical insulator but thermally conductive. Rapid heat transfer from the resistance element to the sheath and then from the sheath to the workload is ensured by high thermal conductivity. High dielectric strength ensures good electrical insulation properties. We select insulation in heaters that has high dielectric strength and good thermal conductivity, preventing short circuit of the resistance element with sheath due to high dielectric strength but allowing heat transfer through it due to good thermal conductivity. It also keeps the heating wire in place. A cross section of the heater is shown in the figure to show where the insulation is located.

At marathon, we use magnesium oxide and mica as the insulating materials. We use magnesium oxide in powder form as well as in solid core form, and mica is used as insulation in sheet form.

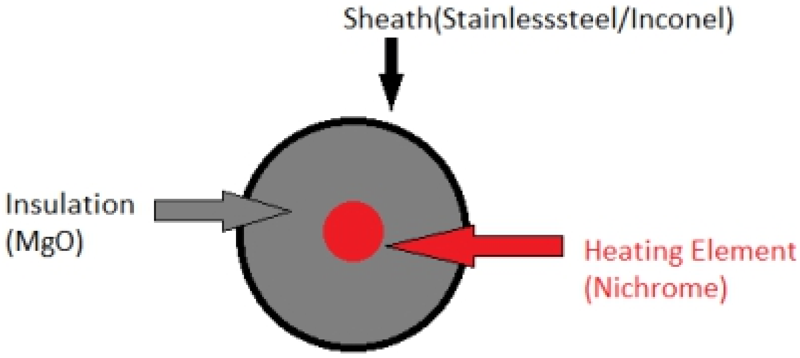


Fig.: 9 Cross Section of Tubular Heating Element

MgO : Magnesium oxide has the properties of good dielectric strength and better thermal conductivity. So it suits well for the use of insulation in electric heaters. But there is a big drawback to magnesium oxide: it is hygroscopic in nature. Hygroscopic means it absorbs the moisture. Because of moisture penetration in the heater tube, the dielectric strength of the heater will go down and leakage current from the resistance element to the sheath (tube) will increase. We will not be able to use the heater if leakage current is high because it may be accidental to use the heater.

So we do not want that moisture to penetrate into the tube because it is bad for the heater. To ensure that any moisture or humidity will not enter the tube, we apply suitable sealing material at the end of the tube that is exposed to the atmosphere.

Insulation Characteristics of MgO : The insulation property of MgO (both thermal and electrical insulation) decreases with an increase in temperature. In other words, the dielectric strength and thermal conductivity of MgO decrease as the temperature increases. So when the heater is started, the temperature increases and the dielectric strength of MgO decreases, as a result of which leakage current increases.

Another aspect is the compactness of MgO. Thermal conductivity of MgO increases with increase in compactness. So it should be ensured that MgO is compacted sufficiently well so that heat generated in the resistance wire can be transferred to the sheath at a faster rate. The compactness of MgO is achieved through drawing and swaging operations. If MgO is not compacted well and there are pores in it, its thermal conductivity will be less. As a result of poor compactness, thermal contact resistance between the sheath and MgO insulation will also increase. Because of these two reasons, the heat will be transferred to the sheath at a slow rate, which can overheat the resistance wire, and the wire may fail or melt because of insufficient compactness.

Boron Nitride (BN) : It can also be used as the insulation material in place of MgO. Its insulation characteristics are better than those of MgO. The disadvantage of Boron Nitride is that it is expensive. So using BN as the insulation material in the element will increase the heater's cost.

Mica : Its temperature limit is less than that of MgO. It is in the form of thin sheets. These sheets are inserted between heating wire and metal sheath. If insulation is not provided, the heating wire will touch the sheath and a short circuit will take place.

8.4 Sheath

Sheaths receive heat generated in the resistance element indirectly via conduction via insulation. It provides the heater with physical strength. It allows the heater to be manufactured in different shapes depending on the application. It keeps the insulation and resistance elements from coming into contact with the heated atmosphere. Sheath material can be steel, stainless steel, Inconel, aluminum, etc. The selection of sheath material depends upon the process fluid to be heated and the operating temperature. Some fluids may chemically react with or corrode the sheath material. As a result, the sheath material should be selected so that corrosion or chemical attack do not occur with the fluid to be heated. It must be ensured that the maximum temperature of the sheath does not go beyond its operating temperature.

8.5 Termination

Termination of the heater means access is given in the heater to connect with the electrical power source, like flexible lead wires provided in the cartridge heater for easy and smooth connection of the power supply with it. At Marathon Heaters, a variety of termination options are available that customers can easily and safely connect to their electric power supply.

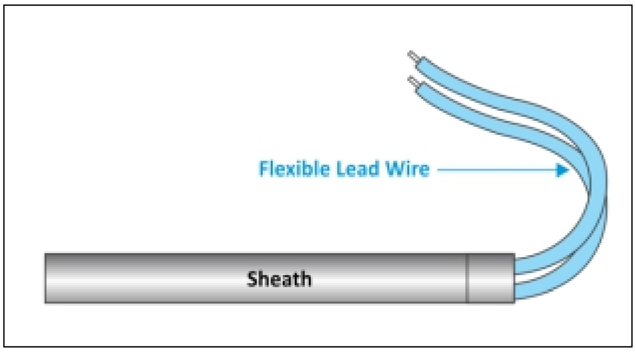


Fig.: 10 Cartridge heater with flexible lead wire

Chapter - 9

Controlling Action of the Heater

Heater temperature can be controlled by closed loop control system as shown in figure. The set point is our targeted temperature, which we want to achieve. Sensors sense the current temperature of the heater and pass this information on to generate the error signal, as shown in figure. The error signal is the difference between the set point temperature and the feedback signal (output temperature). The temperature controller reads this error signal and tries to reduce the error signal to zero. If the error signal is positive, then the set point temperature is not achieved, and heater power should remain on to achieve the desired temperature (set point temperature). If the error signal is zero, then the output temperature is equal to the set point temperature, there is no need for power input to the heater, and the heater remains in the off condition.

One of the temperature-controlling devices is the thermostat. It controls the temperature by turning on and off the power. A thermostat is widely used in the process heater to regulate the temperature according to the set point. The set point temperature of the thermostat can be changed by turning the range adjustment screw.

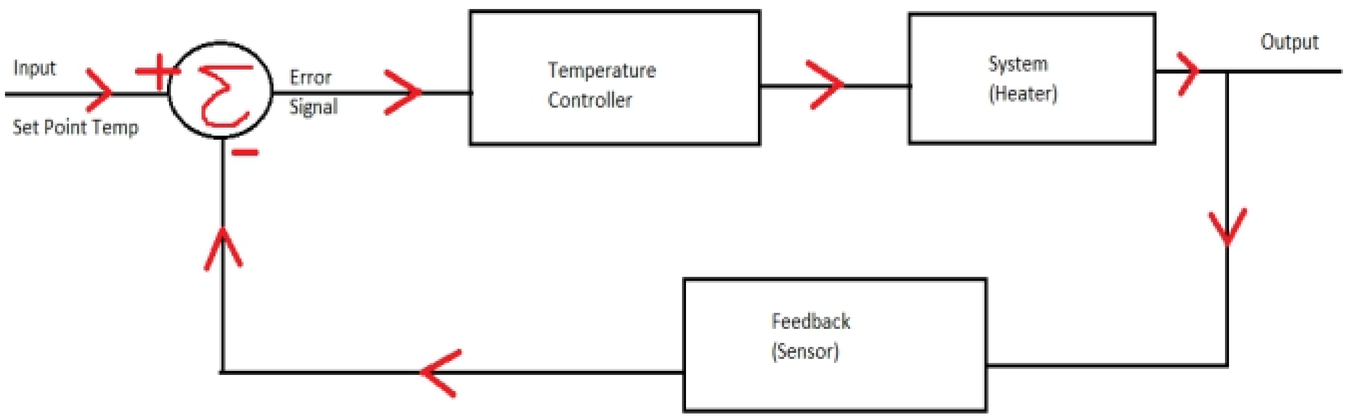


Fig.: 11 Closed Loop Control System for temperature Control

Chapter - 10

Transient vs Steady State in the Heater

A transient state is one in which the temperature at a given point changes over time, whereas a steady state is one in which the temperature at any given point remains constant. When the heater is turned on, its temperature increases with time, as shown in figure. In the transient state, the internal energy of the heating wire increases, which results in an increase in its temperature. After some time, it becomes constant, which means whatever power the heater generates is completely transferred to the workload. This means the heater is operating in steady state.

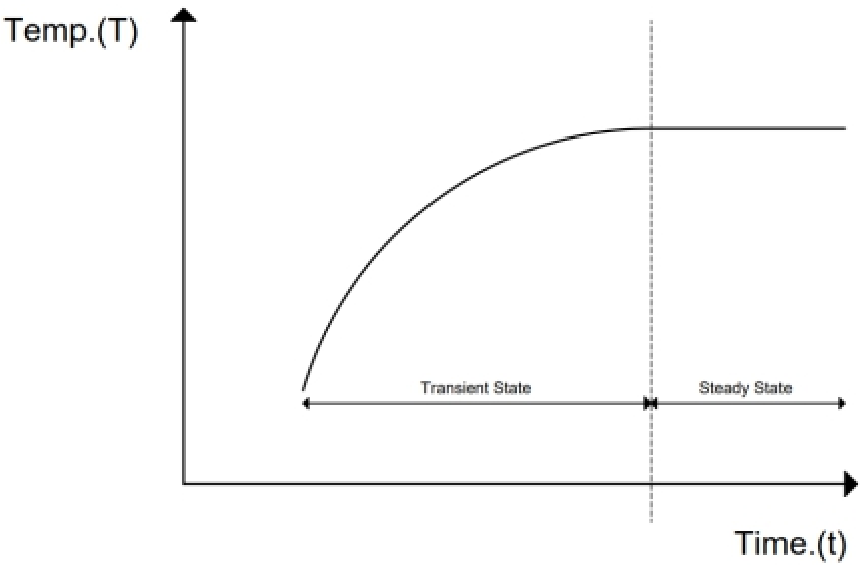


Fig.: 12 Transient and Steady state in the heater

Chapter - 11

Reduction of Heat Loss from the Heater

A heater may be installed inside the pipe or vessel to heat the working fluid that is flowing from the inlet to the outlet. In this heating process, the temperature of the pipe or vessel surface becomes higher than the ambient temperature. As a result of which heat will transfer from the pipe to the ambient air in the form of convection and radiation. So we are losing the energy to the surroundings, which increases the heater's operating cost. To prevent this heat loss, thermal insulating material like glass wool can be wrapped around the pipe. This insulating material has very low thermal conductivity. Further heat loss through the insulation is prevented by the cladding sheet. The cladding sheet is wrapped all around the insulating material. It is generally made up of material that has very high reflectivity and low absorptivity, like aluminium.

Chapter - 12

Heater Life and Watt Density Relationship

The resistance wire is the heating element in the heater. When we supply power, its temperature increases. First of all, this temperature must not go beyond the melting point of the heating wire. The higher the watt density, the higher the temperature of the heating wire. Oxidation of heating wire takes place in the presence of oxygen and this oxidation reaction becomes fast when temperature is more. When the temperature is higher, more oxygen reacts with the heating wire material and forms its oxide. Thus, oxide is formed on the surface of the heating wire or coil, which protects the inside material from oxidation, which is below this oxide layer. But there is another side to the coin. As we know, heaters undergo thermal cycling because of the temperature controller. To maintain the set point temperature, the temperature controller alternately turns on and off the heater. This on off of the heater by the controller, increases or decreases the temperature of the heating wire. Heating wire material and its oxide have different thermal expansion coefficients. So during the heating and cooling cycle, the cracks will develop on the oxide layer, and the oxygen will now attack the inside material through the crack passage. Hence thickness of oxide layer will keep on increasing and it will fall down. Ultimately, all the material in the heating wires will be eaten by oxygen.

We can slow down this oxidation reaction by making a low-wattage density heater. Heaters with a low watt density will operate at a lower temperature. The rate of reaction will decrease at low temperatures, and the heater's life will increase. But decreasing the watt density of the heater will increase the material cost because more length of heating wire is required to generate the same amount of power. So we have to optimize the watt density.

Chapter - 13

Electro-Heat Technologies

In earlier days, the primary source of heat was fuel. The heat energy was released by burning the fuel in the presence of oxygen or air. In this new development era, various new methods to get thermal energy have been developed. The various methods by which electrical energy is converted into heat energy, or thermal energy, are referred to as electro-heat technologies. It is the energy conversion process. The most popular electro heat technology processes are mentioned below:

13.1 Direct Resistance Heating

In direct resistance heating, electric current is directly passed through the material to be heated, as shown in the figure. The material must be a conductive fluid or solid. Direct resistance heating is applicable only to electrically conductive materials. The material to be heated is known as the charge. This heating method is used in salt bath furnaces and resistance welding of metal plates. The heat is generated in the material because of the internal resistance of the material to be heated. Since the material is heated up directly by passing current through it, it has high heating efficiency and reduced size of the heating equipment.

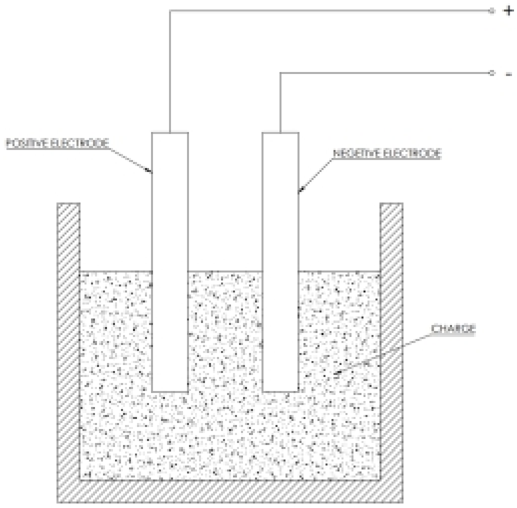


Fig. : 13 Direct Resistance Heating of Charge

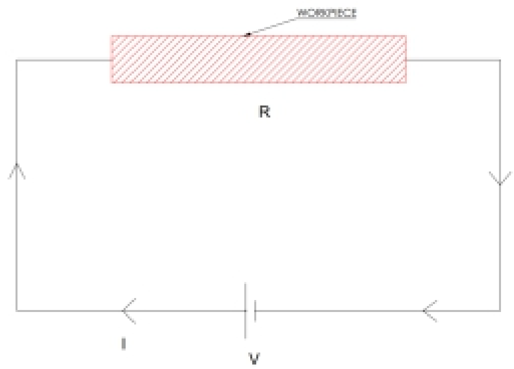


Fig. : 14 Direct Resistance Heating of Workpiece

If R is the internal resistance of the material then the amount of heat generated in t seconds is given by Joule's heating as

$$H=I^2Rt$$

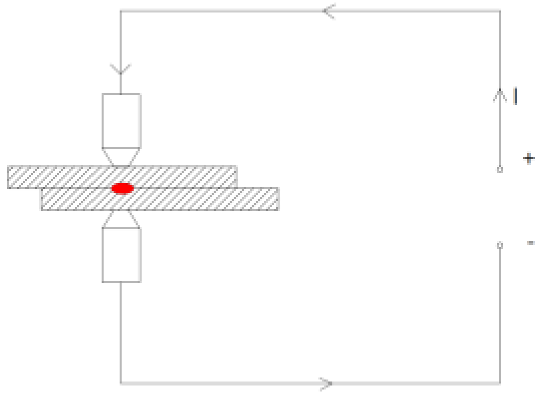


Fig. : 15 Direct Resistance Heating by spot welding

13.2 Indirect Resistance Heating

In indirect resistance heating, the current is passed through a high-resistance element. The heat is generated in this resistance element because of Joule's effect. This heat is transferred to the charge or workload through either of the mechanisms of heat transfer, i.e., conduction, convection, or radiation, or any combination of them. Both conductive and non-conductive materials can be heated by utilizing indirect resistance heating.

Indirect resistance heating is used to heat the fluid like water by immersion heater as shown in the figure. In this water immersion heater, when current is passed, heat is generated in the high resistance coil of nichrome. This generated heat is conducted to the outer sheath through insulation (electrical, not thermal), and then from the outer sheath, heat is transferred to the water by natural convection. Another example of indirect resistance heating is the heating of a molten bath (charge) by special external resistance that is isolated from the charge, as shown in the figure.

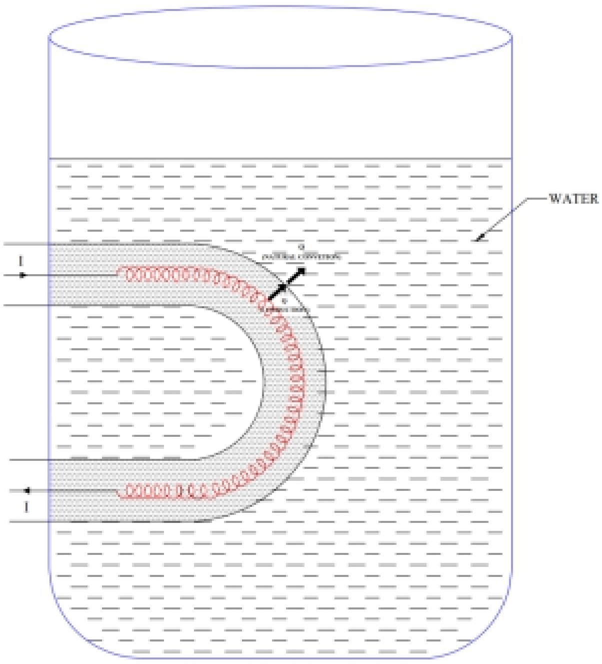


Fig. : 16 Indirect Resistance Heating of water by immersion heater

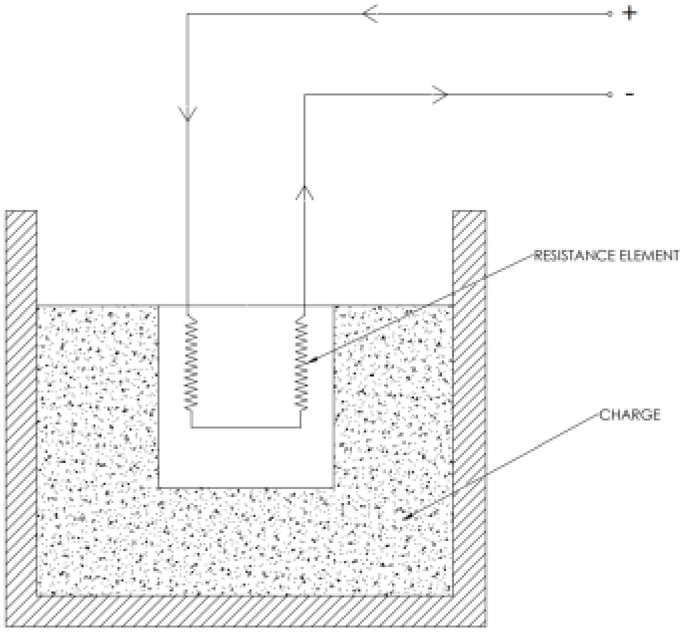


Fig.: 17 Indirect Resistance Heating of molten bath (charge)

13.3 Infrared or Radiant Heating

It is the process of heating an object using radiation. A heat source operating at a high temperature emits radiation toward the colder object that needs to be heated. The heat source can get its energy from an external power supply. At high temperatures, the heat source emits energy in the form of radiation. Most of the energy of the radiation lies in the infrared region of the radiation spectrum. That's why radiant heating is also referred to as infrared heating. However, the radiation consists of other wavelengths apart from those in the infrared region.

Infrared heaters are used to heat the object directly without any air heating because the air acts as a participating medium that transmits most of the radiation through it because it has a high value of transmissivity. To get the maximum amount of radiation energy from the radiant heater, the object should be placed as close as possible to the heat source. In other words, the view factor of the radiant heater with respect to the object should be high. The heating of the Earth by the sun is an example of radiant heating. Here, the sun is the heat source that emits radiation energy in the form of electromagnetic waves.

13.4 Arc Heating

Arc heating is the process of producing heat by forming a continuous arc between two electrodes. The material to be heated or melted is known as the charge. A very high temperature ranging from 2000°C to 3500°C can be created by the electric arc. When the arc is generated between the electrode and charge, it is known as "direct arc heating," as shown in figure. In direct arc heating, an electric arc comes into direct contact with the charge to be heated, as shown in figure. When the arc is generated between the two electrodes and this generated heat is transferred to the charge, it is known as indirect arc heating.

In indirect arc heating, the arc does not come into direct contact with the charge but transfers its heat to the charge by radiation to the top surface and by conduction from the top surface to the bottom surface. There is some gap between the electrode and the charge in direct arc heating and between the two electrodes in indirect arc heating. The electrons start to flow through this air gap at a very high velocity. The kinetic energy of the electrons converts into thermal energy when it strikes the surface. This gap is known as arc length. In the industrial sector, arc heating is used to melt metal. Arc heating is also used to generate the heat and join the two metal parts by fusion welding.

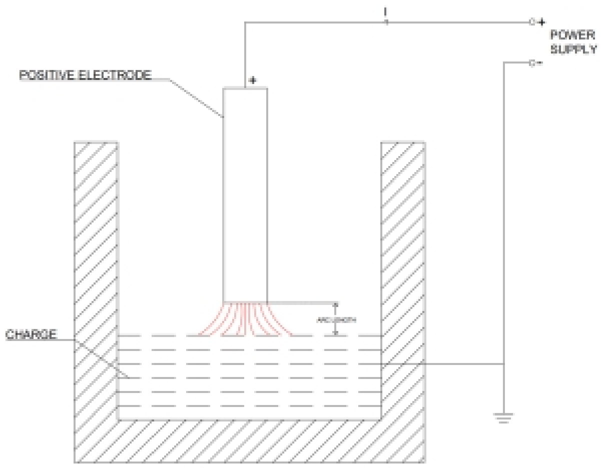


Fig.: 18 Direct Arc Heating of charge

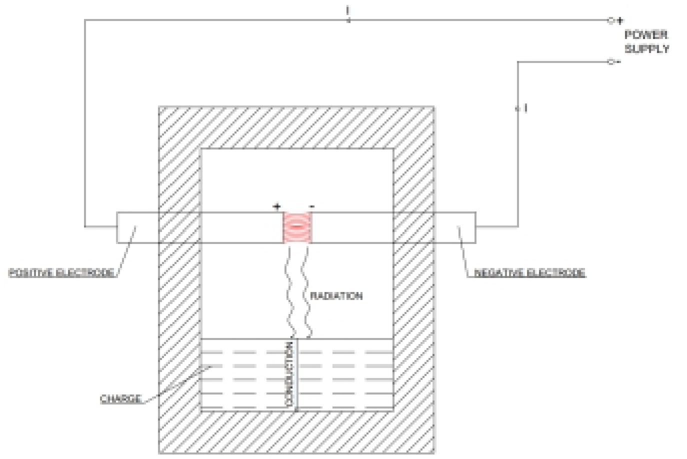


Fig.: 19 Indirect Arc Heating of charge

13.5 Induction Heating

This method of heating is applicable only for conductive work pieces. It works on the principle of electromagnetic induction, which states that an emf is induced in the conductor when it is placed in a varying magnetic field. The magnetic field varies with time when the solenoid (coil) is connected to an AC power source. This change in magnetic flux through the workpiece produces an emf in the workpiece. Eddy currents are formed as a result of the induced emf. Eddy current flows mainly on the surface of the conductor, so heat is confined only up to a certain depth. In induction heating, there is no uniform heating of the workpiece. It gets heated up by the eddy current because of Joule's heating. It is called direct induction heating. And if the heat produced by eddy currents in the conductor placed in the varying magnetic field is transferred to the body to be heated by radiation or convection, then it is referred as indirect resistance heating.

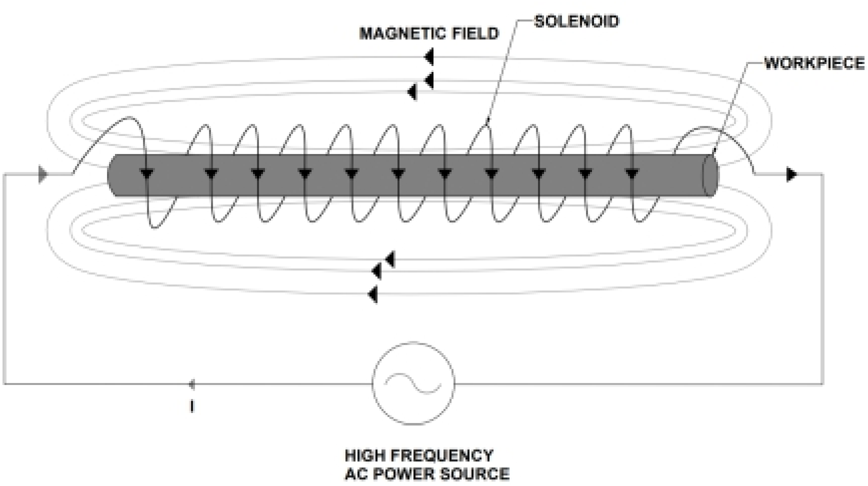


Fig.: 20 Induction Heating of Workpiece

13.6 Dielectric Heating

This method of heating is used to heat up insulating materials like plastic, rubber, glass, wood, etc. When an external electric field is applied to the insulator having asymmetrical molecular structure then the polarization of molecule occurs as shown in figure. In other words, an electric dipole is formed and aligned with the external electric field, as shown in Figure.

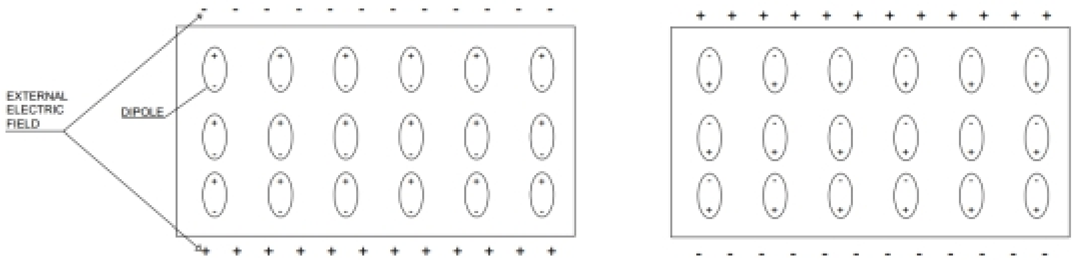


Fig.: 21 Polarization of molecules in the presence of external electric field

When this electric field is changed at high frequency, these dipole molecules rotate and align with the field. When the electric field direction is reversed, the dipole molecules also reverse their direction. Because of this rotation, there is friction between the molecules. The material gets heated up because of this internal friction, but the heating efficiency is lower. When the frequency of change of electric field is increased then the frequency of molecular rotation also increases. As a result, the intensity of heat generation increases. The direction of the electric field is changed by a high-frequency power supply. The heating is uniform here, unlike in the case of induction heating.

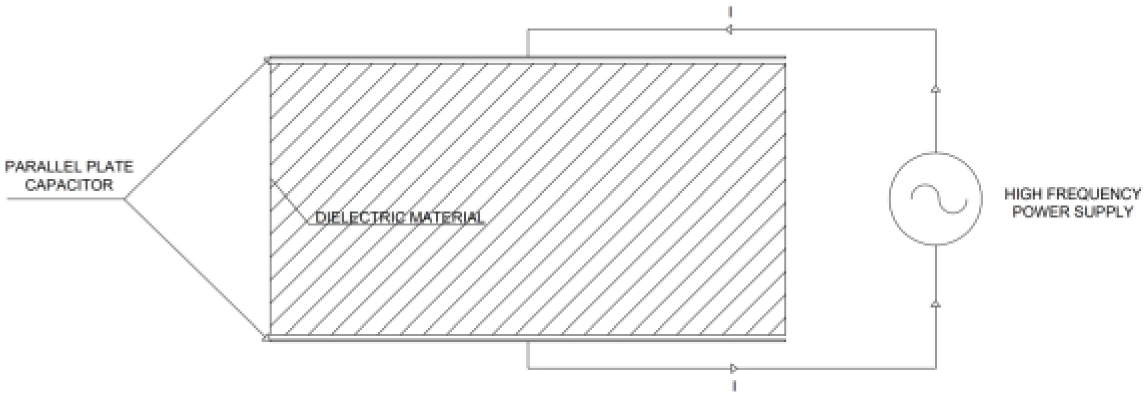


Fig.: 22 Dielectric Heating

Difference between Induction Heating and Dielectric Heating

In induction heating, the heating is more on the surface than in the interior but in dielectric heating, the heating effect is uniformly distributed throughout the material. Induction heating is applicable for electrically conductive materials, while dielectric heating is applicable for electrically insulating material.

Among the different electro-heat technologies mentioned above, resistive heating is the simplest, most efficient, and most useful technology. It is based on OHM's Law. Its applications include agro-food, petrochemicals, fine chemicals, pharmaceuticals, the packaging industry, machine tools, and ovens (baking ovens, baths, fryers, stoves, and many more).

Chapter - 14

Resistive Heating

An electric current flowing through a material that has some resistance (except a superconductor) creates heat. This resistive heating is equivalent to the work done by charge carriers to travel to a lower potential. Electric heaters are made up of a conductor whose resistance is chosen to produce the required amount of resistive heating.

There are two simple formulas for calculating the resistance of a conductor and the amount of heat dissipated in a resistor. This heat is measured in terms of power i.e., energy per unit time. Thus, we are calculating the rate at which energy is being converted into heat inside a conductor.

14.1 Ohm's Law

This law defines the relationship between electric current, applied voltage, and resistance. The law states that the amount of current in a circuit is directly proportional to the voltage applied to the circuit and inversely proportional to the resistance of the circuit.

Mathematically,

$$I = \frac{V}{R}$$

By using the Ohm's law we can calculate the resistance of the wire

$$R = \frac{V}{I}$$

Where V is the voltage, I is the current through the resistor and R is the resistance of the wire.
We can calculate the resistance from the Power formula

$$P = I^2 \times R$$

$$R = \frac{P}{I^2}$$

Where P is the power, I is the current and R is the resistance.

Power is measured in units of watts (W). It can also be expressed as joules per second, i.e., energy per unit time. It is important to distinguish how power depends on current, voltage, and resistors, as these are all interdependent.

The power dissipated is directly proportional to voltage and current. From the formula, it can be established that power increases with increasing resistance, assuming that current remains constant. In many situations, the voltage also remains (approximately) constant. Given a standard voltage, the resistance determines the amount of current drawn by the equipment according to Ohm's Law; higher resistance means lower current, and vice versa.

14.2 Joule's Heating

It is also known as resistance heating, ohmic heating, or the Joule effect. It states that when current is passed through a conductor that has some resistance, heat is produced in the conductor. The amount of heat produced per unit time is called power, which is given by

$$Q = I^2R \quad \text{(Watt)}$$

The amount of heat produced (in Joule) in t seconds is given by

$$Q = I^2Rt \quad \text{(Joule)}$$

14.3 Ohm's Law Circle

We can easily determine the relationship between power, current, resistance, and voltage using the ohm's law circle, as shown in figure.

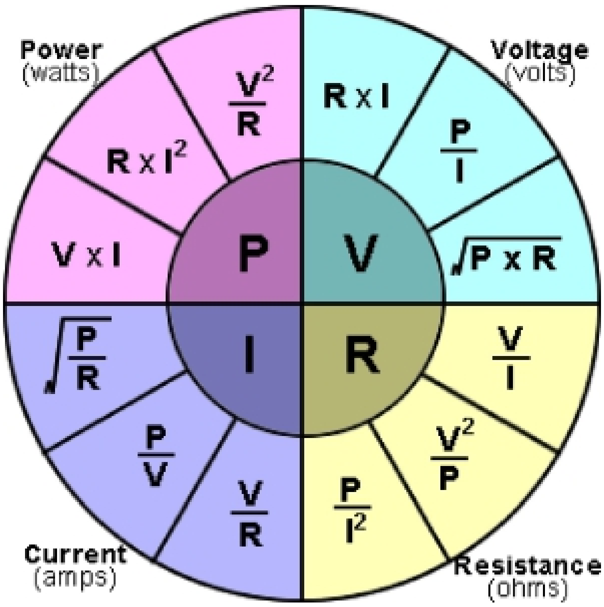


Fig.: 23 Ohm's Law Circle

Suppose we have to determine power then we can write power as

$$P = \frac{V^2}{R}$$

$$P = R \times I^2$$

$$P = V \times I$$

Suppose we have to determine current then we can write current as

$$I = \sqrt{\frac{P}{R}}$$

$$I = \frac{P}{V}$$

$$I = \frac{V}{R}$$

Similarly, we can calculate resistance and voltage using the ohm's law circle.

Chapter - 15

Equivalent Resistance Formula

15.1 Series

When the resistors are connected end by end as shown in the figure then it is referred as series connection. In series connection same amount of current flows through each resistance but voltage drop across each resistor may be different.

Equivalent Resistance Formula in Series

Let n resistances R_1, R_2, R_3,....,R_n are connected in series combination as shown in figure. The total voltage drop across the resistors is equal to the battery voltage

$$V = V_1 + V_2 + V_3 + \dots + V_n$$

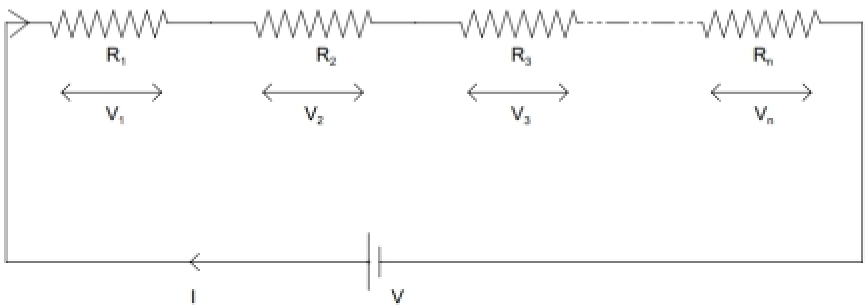


Fig:24 Electrical Circuit of Resistances in Series

From Ohm's law

$$V = IR$$

$$IR = IR_1 + IR_2 + IR_3 + \dots + IR_n$$

$$R_{eq} = R_1 + R_2 + R_3 + \dots + R_n$$

Through resistor electrical power is dissipated in the form of heat.

Power dissipated through 1st resistor = I^2R_1

Power dissipated through 2nd resistor = I^2R_2

Power dissipated through 3rd resistor = I^2R_3

Power dissipated through nth resistor = I^2R_n

Total Power dissipated = $I^2R_1 + I^2R_2 + I^2R_3 + \dots I^2R_n$

Total Power dissipated can also be found out by equivalent resistance

Total Power dissipated = I^2R_{eq}

When several heaters (resistances) are connected in series combination and if any of the heater is burned because of overheating due to any reason then remaining heaters will also stop working because current will not flow in open circuit.

15.2 Parallel

When the resistances are connected across common node then it is referred as parallel combination. In parallel combination the voltage drop across the resistors remain same but the current in the resistors may be different.

Equivalent Resistance Formula in Parallel

Let n resistances R_1, R_2, R_3,....,R_n are connected in parallel combination as shown in figure. The total current from the battery is equal to the sum of current in each resistances.

$$I = I_1 + I_2 + I_3 + \dots + I_n$$

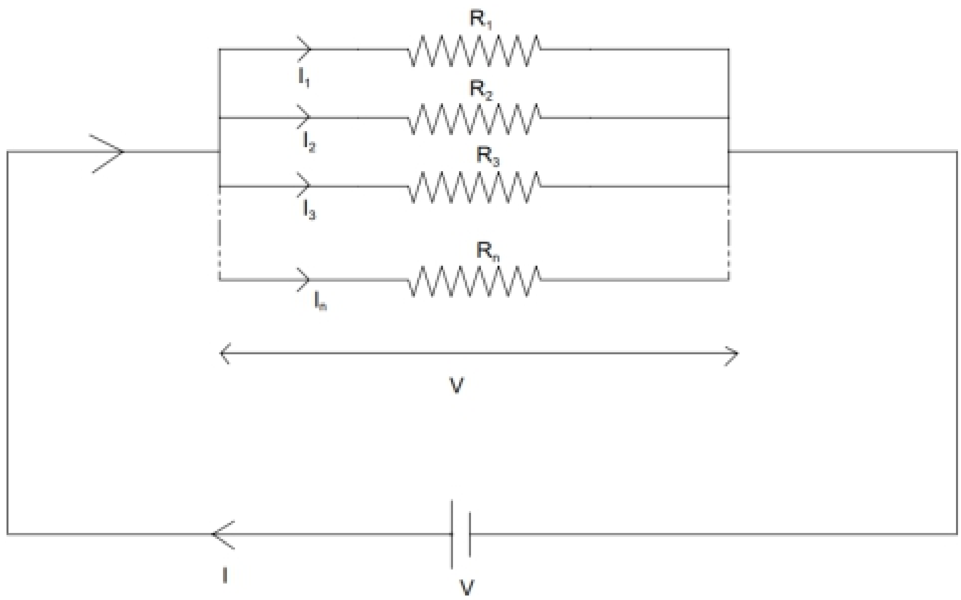


Fig.: 25 Electrical Circuit of Resistances in Parallel

From Ohm's Law

$$I = \frac{V}{R}$$

$$\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} + \cdots + \frac{V}{R_n}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n}$$

Through resistor electrical power is dissipated in the form of heat.

Power dissipated through 1st resistor $= \frac{V^2}{R_1}$

Power dissipated through 2nd resistor $= \frac{V^2}{R_2}$

Power dissipated through 3rd resistor $= \frac{V^2}{R_3}$

Power dissipated through nth resistor $= \frac{V^2}{R_n}$

Total Power dissipated $= \frac{V^2}{R_1} + \frac{V^2}{R_2} + \frac{V^2}{R_3} + \dots + \frac{V^2}{R_n}$

Total Power dissipated can also be found out by equivalent resistance

Total Power dissipated $= \frac{V^2}{R_{eq}}$

When several heaters (resistances) are connected in parallel, if any of the heaters are burned because of overheating for any reason, the remaining heaters will keep on working. This is the major advantage of parallel combination.

Advantages of Electric Resistance Heating

1. No exhaust gases or waste by-products are formed
2. If the system malfunctions, dangerous carbon dioxide gas does not form
3. No explosion hazard exists because it doesn't have any flammable materials.
4. In the event of a short circuit, breakers or fuses can offer a low cost, automatic shutdown mechanism, provided the electrical system has a good earth ground.

Chapter - 16

General Information about Electrical Heaters

16.1 Components of an Electrical Heater Tube

Tube/Outer Sheath : It protects the resistance wire so it can come into direct contact with the fluid to be heated. The selection of the tube depends on factors like operating temperature, type of fluid, and corrosion. Various grades of stainless steel tubes like SS 304, SS 316, SS 321, SS 347 and Inconel tubes like Inconel 600 and Inconel 800 are the most common tube materials.

Sealing : If we don't use seal, then the moisture can be absorbed by MgO because it is hygroscopic in nature. So sealing is done to prevent moisture in the tube.

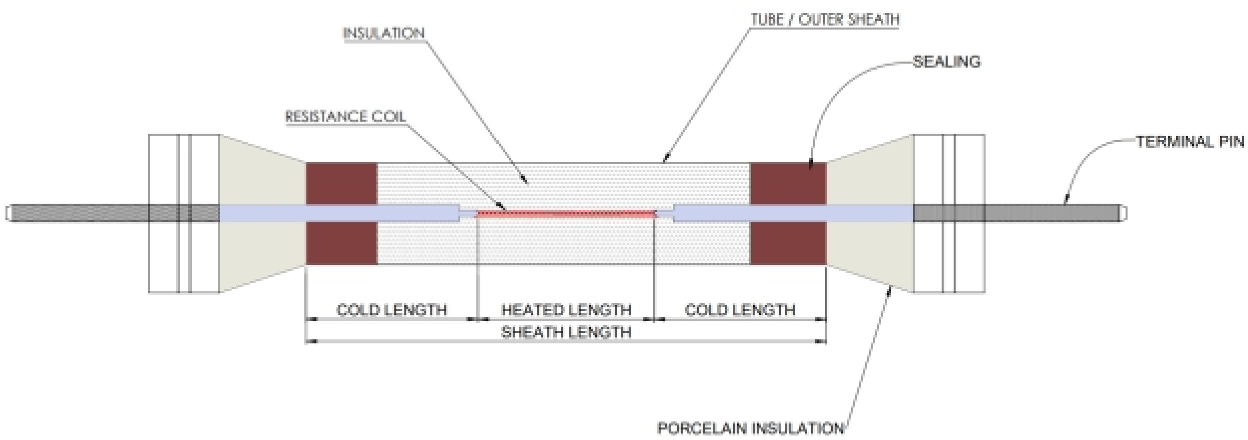
Resistance Coil : It is the main heating element. Generally, it is made of a nickel-chromium alloy. The composition of nickel-chromium can be 60:40 or 80:20. It is the active part of the heating element. Its resistance is very high. It gets hot when power is supplied because of the resistance heating.

Terminal Pin : Power is supplied to the resistance coil from the terminal pin. One end of the terminal pin is welded (ERW or brazed) to the resistance wire, as shown in the figure.

Insulation : MgO is used as the insulator, which ensures rapid heat transfer and makes a good dielectric insulator. It is filled and compressed in the tube.

Length : It consists of cold length and heated length. Actual heat is produced in the heating length, and external connections from the heater are made in the cold length. Generally, the hot length starts from the center of the inlet nozzle.

Porcelain Insulator : It is used to electrically insulate the sheath. If it is not used, the nut will touch the sheath and current will flow from the terminal pin to the sheath, which is not desirable. It is made of ceramic.



16.2 Methods for determining heater requirements

The following steps need to be taken for determining the requirements of a heater for any application:

1. **Define the heating problem.**
   - Gather application information.
   - Sketch the problem for visual reference.
2. **Calculate power requirements.**
   - Calculate the ideal power required for the heater by using information like mass, specific heat, and temperature difference required.
   - Calculate the operating heat loss.
   - Add the ideal power and operating heat loss
   - Add some safety margin to the heater's power.
3. **System Application Factors**
   - Operating temperature
   - Operating efficiency
   - Safe/permissible watt densities
   - Mechanical considerations like pressure
   - Operating environment factors
   - Heater life requirements
   - Electrical lead considerations
4. **Select Heater**
   - Type of the heater
   - Size of the heater
   - Quantity
5. **Select Control System**
   - Type of temperature sensor and its location
   - Type of temperature controller
   - Type of power controller

16.3 Transfer of Heat

When a body starts to generate heat, i.e., its temperature rises above that of other nearby objects, it is called a heat source. As its temperature increases, it starts to raise the temperature of the materials in its surrounding area using any combination of the three different modes of heat transfer. These three modes are conduction, convection, and radiation.

16.4 Temperature measuring scales

Three temperature measuring scales (Fahrenheit, Celsius, and Kelvin) are widely used today. Kelvin is the absolute temperature scale, having an absolute zero below which temperature does not exist. Kelvin is the SI unit of temperature.

On the Fahrenheit scale, 32°F is equal to the freezing point of water, while 212°F is equal to the boiling point of water.

Fahrenheit	This was invented by Gabriel Fahrenheit and the scale was named after him. The zero degree (0°F) was established by using a mixture of water, salt and ice.
Celsius	This was invented by Anders Celsius; it is also known as centigrade temperature scale. The melting point of water (0°C) and boiling point of water (100°C) defines this scale.
Kelvin	It was invented by Lord Kelvin. It is the absolute temperature scale. Zero kelvin is the minimum temperature on this scale. All the random motion ceases at zero kelvin temperature.

Relationship between Celsius, Fahrenheit and Kelvin

The three temperature scales discussed above bear a relationship as shown in the equation, which can be used to convert one temperature scale into another.

$$\frac{C}{5} = \frac{F - 32}{9} = \frac{K - 273}{5}$$

For conversion from Fahrenheit to Celsius use the formula:

$$C = (F - 32) \times \frac{5}{9}$$

For conversion from Kelvin to Celsius use the formula:

$$C = K - 273$$

Chapter - 17

Alloys for Heating Element

17.1 Operating Temperature of Heating Wire

The heating wire material is chosen based on its maximum temperature. One of the criteria for selecting an appropriate heating wire is maximum temperature. The Nichrome 80/20 material used as the heating element material is suitable up to 900°C while Mara FeCrAl is suitable up to 1100°C.

17.2 Heating Elements Classification

1. NiCr-austenitic alloys
2. Mara FeCrAl – Ferritic Alloys
3. SiC: Silicon Carbide
4. $MoSi_2$ Molybdenum Disilicide

NiCr and Mara FeCrAl are the metallic alloys; silicon carbide is the ceramic; and $MoSi_2$ is the ceramic metal. The heating element is chosen based on maximum temperature, atmosphere, life, and power or heat load required.

For any given heating element, the higher the operating temperature, the shorter the service life. The temperature of the heating element is always greater than the furnace temperature. The greater the temperature difference between the heating element and the furnace temperature, the higher the watt density. If the furnace temperature is higher, then watt density must decrease, so that element temperature would not be much higher than the furnace temperature. If the furnace temperature is high and the watt density of the heating element is high, the heating element may overheat and melt if the element temperature exceeds the melting point temperature.

The recommended Watt Density of the heating element vs temperature for Nichrome and Mara FeCrAl are shown in the figure. It is clear from the graph that as the temperature increases, the watt density decreases.

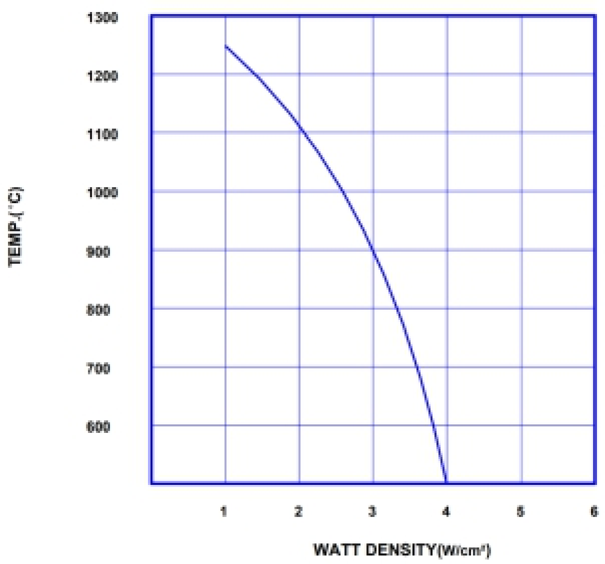


Fig.: 27 Watt Density vs Temperature for Elements (Nichrome80/20)

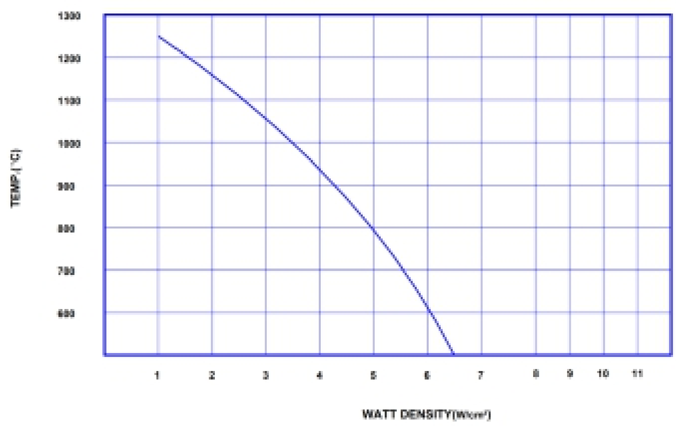


Fig.: 28 Watt Density vs Temperature for Elements (Mara FeCrAl)

The furnace may be operated in a different atmosphere. The atmosphere can be reducing or oxidizing, and it is important to choose the heating element material carefully based on the atmosphere in which it will be used, because the heating element material may react with the atmospheric gases present in that atmosphere. For example, if a heater is operating in an oxidizing atmosphere (O_2) the heating element may react and form oxide at an elevated temperature in the presence of oxygen. After the oxide formation, it may not perform its intended function. The oxide that is formed may be flaked off from the heater, which will decrease the heater's life.

The life of the heater depends on the watt density. The greater the watt density, the shorter the life of the heater. For the same power, we can use a higher watt density, resulting in a smaller amount of element material, but the life of the heater will be reduced. But if space is a limitation, then we have to use a high-wattage, high-density heating element to meet the high heating load.

Nickel-chromium alloys are the oldest electrical heating element materials. Even now, they are widely used in the heating industry. The reason for this is that they are ductile, formable, and have a high heat strength.

Mara FeCrAl is better than Nichrome alloys as far as operating temperature is concerned. It has a higher operating temperature, higher resistance, and lower density than Nichrome. But it has lower hot strength, less ductility, and it becomes brittle with service life.

17.3 Physical and Mechanical properties of Marathon heating element

Heating Element Grade		Mara FeCrAl Super	Mara FeCrAl 145	Mara FeCrAl 139	Mara FeCrAl 142	Mara N80
Standard chemical composition%	Al	6	6	5.5	4.8	Ni-80
	Cr	23	23	23	23	20
	Fe	Balance	Balance	Balance	Balance	0
Max continuous operating temperature	°C	1420	1400	1300	1200	1200
Melting point	°C	1500	1500	1500	1500	1400
Electric resistivity at 20°C	μΩ-m	1.45±5%	1.45±5%	1.39±5%	1.42±5%	1.08±5%
Density	g/cm^3	7.1	7.1	7.2	7.2	8.4
Thermal expansion factor 20°C~1,000°C	°C-1	14.8X10-6	13.6X10-6	13.6X10-6	14.8X10-6	17.6X10-6
Tensile strength	N/mm^2	650 ~900	650 ~900	650 ~900	630 ~850	700 ~900
Elongation	%	15 ~25	15 ~25	15 ~30	10 ~30	20 or more
Hardness	Hv	220 ~ 240	220~240	220~240	220~240	150 ~190
Repeat bending frequency	F/R	⩾5	⩾5	⩾5	⩾5	
Continuous service time	Hours/°C	⩾300/1300	⩾300/1300	⩾300/1300	⩾100/1300	⩾300/1200
Magnetic properties		Magnetic	Magnetic	Magnetic	Magnetic	Non-Magnetic

For these two metallic alloys, the resistance remains relatively constant with temperature and time. But for silicon carbide as a heating element, the resistance increases with time. It is called as ageing. Its resistance also changes with temperature. Silicon carbide has the higher operating temperature than Mara FeCrAl.

Molybdenum disilicide resistance does not change that much with time. It does not age, but it exhibits a drastic increase in resistance with temperature. Its operating temperature is higher than that of silicon carbide.

Chapter - 18

Heat Requirement Calculations

18.1 General Heat Requirement

There are two basic heat energy requirements in the sizing of heaters for a particular application. These are Start-up heat and Operating heat, respectively.

(1) Start up Heat

It is the heat energy required to bring a process fluid's temperature up to operating temperature. Let's assume that we have to heat the fluid from temperature T_1 to T_2. So the heat required to reach the temperature of the process fluid up to T_2 is the startup heat. After reaching the desired temperature, the T_2 pump is turned on, which circulates the fluid.

Calculation of Start-up Heat :

Case I Without Phase Change : First let us assume that there is no phase change of the fluid that is being heated from temperature T_1 to T_2

Power required for heat-up : In order to heat certain mass (m) of working fluid from temperature T_1 to T_2 in given time t (sec), the required heater power (in Watt) can be calculated by :

$$= \frac{mc_p\Delta T}{\text{heating time (s)}}$$

$$= \frac{mc_p(T_2 - T_1)}{t(s)}$$

Power required to compensate losses During the heat transfer from Heater to the process fluid (T1 → T2), some amount of heat will be lost in the surrounding atmosphere. To compensate this heat loss, heater require some extra power.

$$\frac{\text{Wattage loss}}{m^2} \times \text{Heater Surface Area } (m^2)$$

Now Total power of the heater required is the sum of Power required for heat-up & the power required to compensate losses.

Case II with Phase Change: Now let's assume that we have to heat the working fluid from temperature T_1 to T_2 which undergoes phase change at temperature Tphase. Whenever any material changes its phase from liquid to gas or solid to liquid, it requires some additional thermal energy for the phase change process. This additional energy is called latent heat. The heat needed to melt a solid material is known as the latent heat of fusion while the heat needed to vaporize the liquid is known as the latent heat of vaporization. Latent heat of fusion & vaporization depends on the pressure. Higher the pressure lower is the latent heat. hfg is the latent heat of vaporization. The power required for the heater can be calculated by

$$\frac{mc_p(T_{phase} - T_1) + mh_{fg} + mc_p(T_2 - T_{phase})}{\text{heating time (s)}}$$

Power required to compensate losses : During the heat transfer from Heater to the process fluid ($T_1 \rightarrow T_{2)}$, some amount of heat will be lost in the surrounding atmosphere. To compensate this heat loss, heater require some extra power.

$$\frac{\text{Wattage loss}}{m^2} \text{ x Heater Surface Area } (m^2)$$

Now Total start up power of the heater required is the sum of Power required for heat-up & the power required to compensate losses.

(2) Operating Heat

The heat energy required to circulate the fluid from the inlet temperature to outlet temperature is called operating heat. To maintain the desired temperature at the outlet, heater power should be sufficient to heat the fluid up to that temperature. When calculating the required KW of the heater, the maximum mass flow rate ($\dot{m}$) of the fluid, the minimum temperature at the heater inlet, and the maximum desired outlet temperature are used. If during the flow, the fluid is undergoing phase change, then the extra heat, i.e., latent heat, must be added along with sensible heat.

The power of the heater can be calculated by

$$P = \dot{m}\, c_p \Delta T$$

Power required to compensate losses : During the heat transfer from Heater to the process fluid, some amount of heat will be lost in the surrounding atmosphere. To compensate this heat loss, heater require some extra power.

$$\frac{\text{Wattage loss}}{m^2} \text{ x Heater Surface Area } (m^2)$$

The total required operating power of the heater is now the sum of the required operating power and the power required to compensate for losses. The larger the start-up and operating heat values, the larger the wattage required for the application. The wattage of the heater is calculated by both the start-up and operating thermal loads. Then the heater is designed according to the maximum wattage. If start up power is greater (including losses), then the heater is designed according to this value of wattage. Assume that if the operating power (including losses) is greater than this value of wattage, the heater is designed accordingly. A good design is one in which start-up power and operating power are almost the same.

The two equations are used to quickly calculate the heater power required for the given air flow rate. Once the volume of airflow (CFM – in cubic feet per minute) and the required temperature rise, ΔT (in °C) through the heater are known, the required kilowatt rating (KW) of the heater can be determined from the formula:

$$KW = \frac{\text{Volume of air flow (CFM) x temperature rise}}{3193}$$

$$KW = \frac{\text{Volume of air flow (Liters/Sec) x temperature rise}}{837}$$

18.2 Heat Requirement calculation in a Chemical Reaction

In a chemical reaction, the reactants react with each other to form the product. The reaction can be initiated with the help of catalysts. The catalysts do not take part in the chemical reaction, but they increase the rate of reaction. The majority of the reaction occurs under constant pressure. So the heat absorbed or released can be expressed as the change in enthalpy of the product and the reactant.

Standard Enthalpy of Formation: The heat of formation, also called the standard heat of formation or the standard enthalpy of formation, is the amount of heat absorbed or evolved when one mole of a compound is formed from its constituent elements, each substance being in its normal physical state (solid, liquid, or gas). A pure element in its standard state has a standard enthalpy of formation of zero. For example, the standard enthalpy of formation of CO2 would be the enthalpy of the following reaction under the standard pressure (1 bar) and standard temperature (25 °C). In this reaction, carbon and oxygen are in their normal physical states. As a result, whatever heat is released or absorbed represents the standard enthalpy of CO2 formation.

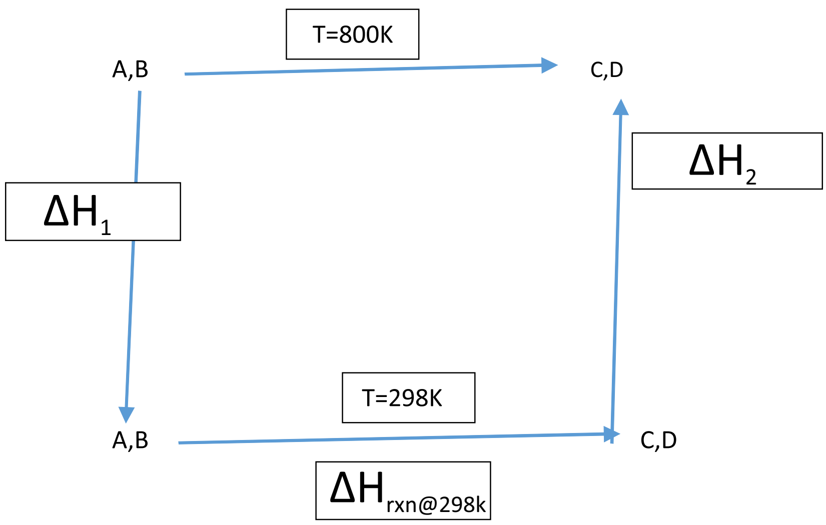
$$C(s,graphite) + O_2(g) \rightarrow CO_2(g)$$

Heat of Reaction: It is the amount of heat that must be added or removed during a chemical reaction in order to keep all the substances present at the same temperature. Those reactions in which net heat is released is known as Exothermic Reaction. Endothermic reactions, on the other hand, are those in which net heat is supplied. In an endothermic reaction, heat is supplied from an external heating source, such as an electric heater. This electric heater must have sufficient wattage for the endothermic reaction to take place within a given time. As a result, the amount of heat required in an endothermic reaction is a critical design parameter for the heater. We shall calculate the heat requirement in the reaction with an example.

Consider a general endothermic chemical reaction occurring at temperature T (800K). We have to determine the net heat (Joule) required in this reaction.

$$3A + 2B \xrightarrow{T=800K,\ P=1bar} 4C + D;\ \Delta H_{Rxn@T}$$

We determine the change in enthalpy in the reaction through an alternative path, as shown in the figure. This is possible because enthalpy is the state function.



$$\Delta H_1 = \int_{800k}^{298k} (3c_{p_A} + 2c_{p_B})dT$$

$$\Delta H_{rxn@298k} = \Delta H_{f,product} - \Delta H_{f,reactant}$$

$$\Delta H_{rxn@298k} = [4\Delta H_f(C) + 1\Delta H_f(D)] - [3\Delta H_f(A) + 2\Delta H_f(B)]$$

$$\Delta H_2 = \int_{298k}^{800k} (4c_{p_C} + 1c_{p_D})dT$$

Net heat in the reaction,

$$\Delta H_{Rxn@T} = \Delta H_1 + \Delta H_{rxn@298k} + \Delta H_2$$

In this analysis it is assumed that reaction is happening at constant pressure.

Chapter - 19

Wiring practices for heaters

In a 3-phase supply, heaters are either connected to a delta connection or a star (Wye) connection, as shown in the figure. If the resistance in each arm of star/delta are same then it is called balanced star/delta.

19.1 Delta Connection

In a 3-phase supply, heaters are either connected to a delta connection or a star (Wye) connection, as shown in the figure.

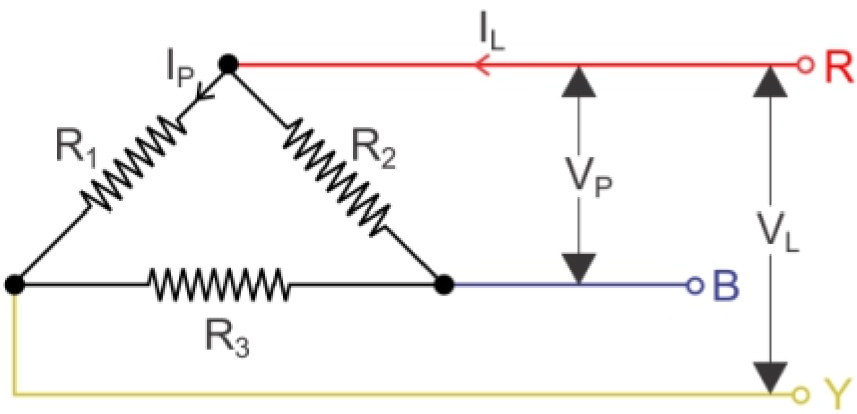


Fig.: 29 Delta Connection

$$I_P = \frac{I_L}{\sqrt{3}}$$

$$V_P = V_L$$

$$P = 3 \times \frac{V_P^2}{R}$$

$$\Rightarrow \quad P = 3 \times \frac{V_L^2}{R}$$

$$P = 3 \times V_P I_P$$

$$\Rightarrow \quad P = 3 \times V_L \times \frac{I_L}{\sqrt{3}}$$

$$\Rightarrow \quad P = \sqrt{3} \times V_L \times I_L$$

19.2 Star (Wye) connection

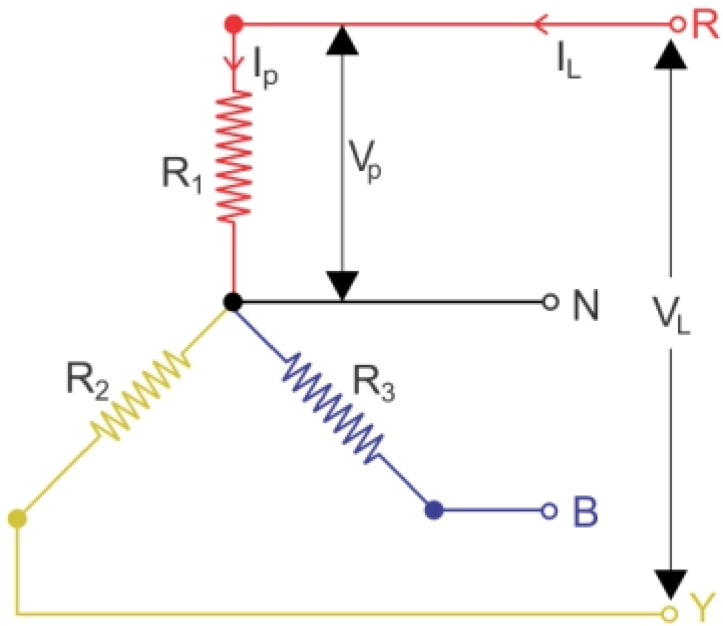


Fig.: 30 Star Connection

$$I_P = I_L$$

$$V_P = \frac{V_L}{\sqrt{3}}$$

$$P = 3 \text{ x } \frac{V_P^2}{R}$$

$$P = 3 \text{ x } V_P I_P$$

$$\Rightarrow \quad P = 3 \text{ x } \left(\frac{V_L}{\sqrt{3}}\right) \text{ x } I_L \qquad (I_P = I_L)$$

$$\Rightarrow \quad P = \sqrt{3} \text{ x } V_L \text{ x } I_L$$

Where

V_P: Phase Voltage (V)

V_L: Line Voltage (V)

I_P: Phase Current (Amp)

I_L: Line Current (Amp)

W: Wattage (Watt)

19.3 Relation Between Phase Voltage & Line voltage, Phase Current & Line Current

The following table shows the relationships between phase voltage and line voltage, phase current and line current for the balanced star/delta:

Connection	Phase Voltage	Line Voltage	Phase Current	Line Current
Delta	$V_P = V_L$	$V_L = V_P$	$I_P = I_L/\sqrt{3}$	$I_L = \sqrt{3} I_P$
Star	$V_P = V_L/\sqrt{3}$	$V_L = \sqrt{3} V_P$	$I_P = I_L$	$I_L = I_P$

The terminal box contains connections for instruments and elements. The elements are connected by connections. The R, Y, and B wires are connected to the appropriate bus bar. Three phase power cables are connected to the bus bar. Spare elements are not connected.

19.4 Current requirement calculation

On a single phase (two-wire) power supply, the amperage per line is calculated by:

$$I_L = \frac{P}{V_L}$$

On three phase power circuits with balanced Delta or Wye heating loads, line current is calculated by:

$$\text{3 Phase line current} = \frac{\text{Total Wattage}}{\text{Line Voltage} \times \sqrt{3}}$$

$$I_L = \frac{P}{\sqrt{3} V_L}$$

Chapter - 20

Calculation Related to Heating Wire (resistance wire)

Austenitic alloys or Ferritic alloys are used to make wires that are the main heating elements of the heater. The wire parameters are as follows:

20.1 Resistance

The resistance of a conductor is directly proportional to its length, l and inversely proportional to its cross sectional area, A. The formula for calculating resistance is

$$R \propto L$$

$$R \propto \frac{1}{A}$$

$$R \propto \frac{L}{A}$$

$$R = \frac{\rho L}{A}$$

The proportional constant is the resistivity (ρ) of the material which is the property of the material and it is temperature dependent.

20.2 Dimensions of the wire

The following two formulae will help us to calculate the diameter and length of wire under certain Capacity and Voltage.

$$d = \sqrt[3]{\frac{4 \times 10^5 \rho P^2}{\pi^2 U^2 W}}$$

$$L = \frac{U^2 \pi d^2}{4 \rho P \times 10^3}$$

Where:

d — Diameter of heating wire, mm

ρ — Resistivity of heating wire in $\Omega mm^2/m$

P — Power per phase, KW

U — Voltage, Volts

W — Watt Density, W/cm^2

L — Length of heating wire, m

With the help of these formulas, the wire size can be known. However, for specific applications and temperatures, wire diameter and watt density differs according to the alloy used. Considerations must be made.

20.3 How to make the Cold End in the Heater

The heater tube consists of a cold length and a hot length. The actual heat is generated in the hot part, while the cold part remains relatively cooler than the hot part. The resistance and the power dissipated in the cold part should be very low as compared to those in the hot part, so that the heat generated in the cold part would be very low. That is why the cold section is sometimes referred to as the "no heat zone." Cold part length is very short as compared to hot part length, and sometimes cold part length is kept as per customer requirement.

Low resistivity materials like nickel, copper, and nickel-plated mild steel are the preferred materials for the cold part. Since the resistivity of these materials is low, so is the resistance. Another way to decrease the resistance of the cold part is made by making the cross sectional area larger at the cold end. Since the resistance is inversely proportional to the area, more cross sectional area means less resistance and low power dissipation at the cold end. Current is supplied to the lead wire by the heater. The current flows from the cold-end wire to the heating wire. The cold end wire remains electrically connected to the hot end wire.

Chapter - 21

Closed Loop System of Heater Cycle

In a closed loop control system, there is constant feedback from the heater through the temperature sensor, which in turn adjusts the temperature through a controller to maintain the set point. It is also called a "feedback control." A closed-loop temperature process control system consists of four basic components:

The temperature sensor detects the temperature in the heating system and passes this information to a temperature controller, which compares the current temperature with the set point temperature and triggers the power controller devices to control the power delivered to the heater. Power control devices can be any of the solid state relays (SSR), silicone controlled rectifiers (SCR), or electromechanical relays.

21.1 Heaters

1. Process Heaters (Heating Skid, Circulation Heaters, Immersion Heaters, Flanged Immersion Heaters, Over the Side Immersion Heaters, Screw Plug Heaters, Tubular Heaters, Finned Tubular Heaters)
2. Component Heater (Cartridge Heater, Ceramic Band Heater, Mica Band Heater, Strip Heater, Finned Strip Heater, Silicon Rubber Heater)
3. Furnace Heater (Bundle Rod Heater, Bobbin Heater, Edge Bound Heater, Open Coil Heater, Mineral Insulated Heater Cables, Radiant Tubes, Infrared Radiant Heater)

Temperature Sensor : They can be classified as:

1. Contact temperature sensors such as thermocouples, RTDs, and thermistors
2. Non-contact temperature sensors such as pyrometers

Temperature Controller : The temperature controller also comes in a range of configurations. The main groups are:

1. Thermostats
2. PID Controller (microprocessor-based)

Power Controllers

1. Solid State Relay System
2. SCR Control System
3. Integrated Control Panel System

21.2 Temperature Sensors

All temperature sensors operate on the same basic principle; all of them provide temperature in the output in response to changes in their physical characteristics in the input.

Contact Temperature Sensors : The sensors remain in physical contact with the body whose temperature is to be measured. The measuring point is typically far from the indicating equipment in industrial and lab processes. So it senses the temperature in terms of electrical quantities like voltage, resistance, etc. It is of three types:

a) Thermocouples : It is the temperature measuring device which works on the principle of Seebeck effect. In a thermocouple, there are two junctions: one is the hot junction (whose temperature is to be measured) and another is the cold or reference junction. It works on the principle of the Seebeck effect, which states that when two dissimilar metals are joined end-to-end and these ends are kept at different temperatures, then some voltage (which is usually small (in mV)) is generated across the hot and cold junctions, which increases with an increase in the temperature of the hot junction. The voltage that is generated is calibrated in terms of temperature. There are various types of thermocouples. Type J and K thermocouples are very commonly used.

b) Resistance Temperature Detector (RTD) : It utilizes a precision resistor, the resistance (Ohms) value of which increases with temperature. The change in resistance value of the resistor is calibrated in terms of temperature. RTD has a positive temperature coefficient. Platinum is used as the most common RTD material (precision resistor) because the change in resistance of the metal with temperature is linear. As a result, calibration becomes simple.

c) Thermistors : Thermistor is a semiconductor used as a temperature sensor. It has a distinct non-linear resistance versus temperature relationship. The resistance of a thermistor decreases with an increase in temperature. So it has a negative temperature coefficient. It shows an extremely large resistance change for minor temperature variations. They are highly sensitive and small in size, which makes them suitable for use in medical equipment.

Non-Contact Temperature Sensors:

A non-contact temperature sensor measures the temperature of the body without making physical contact. When sensors are not allowed to remain in physical contact with the body whose temperature is to be measured, then a non-contact temperature sensor is the perfect choice. The pyrometer is the most common type. These sensors operate using the concept of heated object emission. Radiation is produced by every object whose temperature is greater than absolute zero. Temperature affects the wavelength and frequency of these heat radiations. The radiations are captured by detecting devices and transformed into electric signals, and these electric signals are calibrated in terms of temperature.

21.3 Temperature Controllers

An output action is generated by a temperature controller dependant on the input signal from a temperature sensor. Thermostats (on/off controls) or PID controllers are the two types of temperature controllers.

1. Thermostat (On/Off Control) :

A thermostat is a component that senses the temperature of the system and controls it so that the temperature of the system remains close to a desired value known as the set point. It achieves this by turning on and off the heaters. Sensors are used in thermostats to measure temperature and control the heater's output When the temperature reaches a certain limit, the output tends to be either high or low. This constant on/off around the set point reduces heater life cycle, increases thermal losses, and increases the oxidation rate of heating elements. To resolve this issue, a power controlling device can be used in combination with the thermostat or a PID controller can be used. This not only improves heater performance but also adds resistivity to reduce stress on the heater and prevent contactor damage.

2. PID (Proportional-Integral-Derivative) Temperature Control :

This type of controller is used to optimize thermal system performance. It detects the rate of temperature increase or decrease and alters the output actions that are necessary. It provides a proportional control or a proportional combined integral and derivative temperature control, as the name implies. Proportioning implies operating heat closer to the set point, which would need less power. This can be accomplished by employing derivative and integral operating modes. The controller is available in a variety of sizes; inputs must be determined in advance, and output action necessarily requires the use of a power controller to resist rapid switching cycles. Most PID controllers come with four different control functions for various applications.

- P control Only
- Pi Control (no Offset= Higher Overshoot)
- Pd Control (steady State In The Shortest Time)
- Pid Control. It combines the advantages of PI and PD control. Also called fuzzy logic control.

21.4 Power Controllers

The heating element's electric power is applied to or interrupted by power controllers in response to input from the temperature controller. Power controllers change the flow of electricity through solid state devices.

Semiconductors, which are used in solid state devices, can be electronically turned ON or OFF to provide precise power control. The benefits include having a nearly endless life expectancy and being able to provide the quick switching cycles needed by PID temperature controllers. Solid state relays (SSRs) and SCRs are popular solid state power controllers (silicon controlled rectifiers).

Solid State Relay (SSR): A transistor in a solid state relay (SSR) is turned on by a tiny AC or DC control current transmitted by the temperature controller. In less than a second, this kind of relay can switch between 10 and 75A at up to 480V AC. They are primarily used in radiant heaters and air heaters, which require very frequent power switching, as they are well-suited to provide the rapid switching cycles required by PID controllers. In order to reduce the electrical noise produced by midcycle switching, the majority of SSR switch at zero electrical potential. Benefits include faster response times, longer heater lifespans, and no arcing while switching.

Silicon Controlled Rectifier (SCR): These solid state contactors provide power switching advantages that SSR lacks. This device provides three-phase and single-phase electrical load switching abilities from 10 to 1000A and up to 575V AC. An SCR power controller consists of:

- Semiconductor power devices
- Control circuit called firing circuit
- Protective circuits (fuses and transient suppressors)

SCRs can control the amount of power applied through burst firing or phase angle firing:

At zero voltage, burst-firing switches complete the ON and OFF phases of an AC cycle. In comparison to infrared heating applications, burst firing is ideal for applications requiring time proportional power control, high temperatures, and high watt densities.

Inside the AC sine wave, phase angle firing switches the power ON or OFF. Electrical loads which need "soft starting" because their resistance values vary with temperature and time, such as radiant heaters, are best suited for phase angle firing.

Benefits of SCR power controllers:

- High reliability
- Infinite resolution
- Extremely fast response
- Selectable power control parameters
- Minimum maintenance

To create a complete control panel, these power controllers can be combined with temperature controllers and input power supplies. Process temperatures may be precisely controlled with this integrated control panel system. A customized control panel is made for a particular application.

Chapter - 22

Safety Factor Guidelines

When the power of the heater is calculated using the process parameter, some safety margin is added to the actual requirement for power. To meet out the power during some adverse conditions, the safety factor is considered. The safety factor is dependent on how small or large the system is. For small systems with closely calculated power, a 10% safety factor is considered. 20% is a commonly used safety factor. For large systems, the safety factor is taken as 20% to 35%.

Some general guidelines:

- 10% safety factor for small systems with closely calculated power requirements
- The average safety factor is 20%.
- 20% to 35% safety factor for large systems

Chapter - 23

Important Aspects of Heater Design & Operating Condition

- The heater should be selected according to the application, the temperature of the ambient environment, and the nature of the material to be heated.
- Watt density, sheath material, heating alloy material, and insulation material should be chosen according to the application.
- The hot length of the heater should not come out of the material to be heated.
- The heater power must be compatible with the thermal load.
- Flange size and rating should be chosen carefully as per application.
- Contamination and deposits on the metal sheath must be prevented. If deposits occur on the tube surface, they must be removed to increase the heater's life. Contamination or deposits on the heater surface are one of the causes of heater failure.
- Lead wire must be protected from high temperatures.
- A temperature sensor, temperature controller, and power controller should be used to maintain the desired temperature.
- Prevent excessive thermal cycling.
- The heater must be operated at its rated voltage.
- The heater should be grounded for safety reasons.

We offer a customized solution for every problem, be it large or small, simple or complex. Our team is dedicated to research and development, using the latest technologies while being motivated to meet every customer's needs by manufacturing high-quality industrial heating products. Some of the standard industrial heaters offered by us are listed below.

Chapter - 24

Process Heaters

24.1 Tubular Heaters

The basic part of the process heater is the heating element. The process heater is basically an assembly of several tubular heating elements. Generally, the heating elements are bent into a U shape. Process heaters are used to heat up the process fluids like water, oil, etc. They are widely used in the oil and chemical industries. Process heaters are used to heat not only the liquid phase but also the gaseous phase. Process fluid can be heated in the tank with the help of a heater, or it can be heated during flow by a circulation heater.

Manufacturing of Heating Element

First of all, the appropriate gauge wire is selected based on watt density and power. The gauge wire material is typically nichrome 80/20. This wire is converted into a coil by a coil winding machine. The cold rod terminal pin is spot welded to the coil. Magnesium oxide is used as the insulation in the tubular heating element, which ensures sufficient dielectric strength and better heat transfer characteristics. Granular MgO is filled in the tube by the MgO filling tower. On this tower, the heating wire with the terminal pin is centered first, and then MgO is filled in the tube by the gravity filling method. Simultaneously, during the filling, vibration is imparted to the tube to increase its compactness.

After the filling of MgO in tubes, it is compacted in a roll-reducing mill. The diameter of the tube decreases, the length of the tube increases, and the compact density of the insulation increases during rolling. The main aim of rolling is to fill the void/gap between granular MgO particles. Increased compactness ensures better heat transfer and high dielectric strength. After rolling, the hardening process takes place. So before bending the element, annealing is done in the furnace at an appropriate temperature. The annealing process softens the material, making bending easier. The bending of elements into the required configuration is regarded as the forming process in manufacturing. Forming is the plastic deformation process by applying the force or stress. Forming also work hardens the material. So bending should be done at an appropriate radius so that no cracks develop on the tube surface.

At the end of the tube, very little MgO is removed. This is known as the "digging process." This is done to make room for the sealant. MgO is hygroscopic in nature, so it will absorb moisture from the air. Atmospheric air contains dry air and water vapor. The amount of water vapor present in 1 kg of dry air is expressed as specific humidity. The greater the amount of water vapor, the greater the chance of moisture penetration into the tube. The chance of moisture penetration increases in a humid atmosphere. Sealant is applied at the exposed end of the tube to ensure that no moisture will enter the tube.

The schematic diagram of a straight tube heating element is shown in the figure. The bending of this straight tube heating element is done. The bending radius should be chosen appropriately. Generally, the heating elements are bent into a U shape, but customized bending can be done in Marathon. The electrical connections are made at the end of the terminal pin.

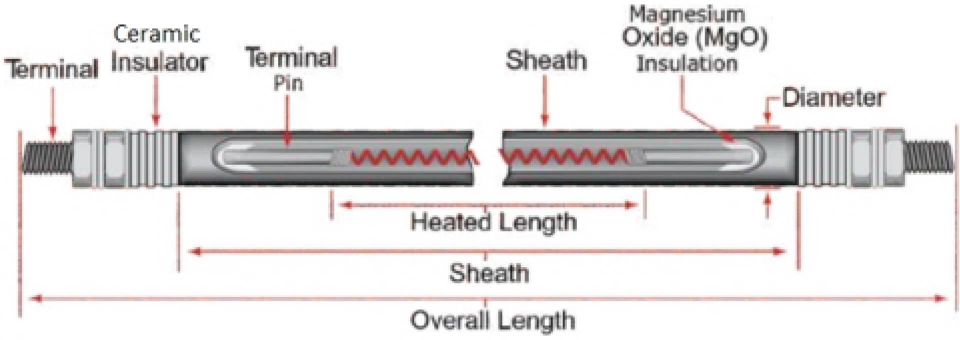


Fig. : 31 Straight Tube Heating Element

Technical Specifications

Sheath Material	SS grades, Inconel 600, Copper, Titanium
Sheath OD	8mm,11mm,12.5mm,16mm
Sheath Tube manufacturing	ERW or Seamless
Insulation	Granular MgO powder
Heating Coil	Nichrome 80/20
Terminal Pin	Ni or Ni plated mild steel
Sealing	Epoxy, RTV
Porcelain Insulator	Ceramic

Watt density depends on several parameters, like total wattage, fluid flow velocity, and the type of fluid to be heated. The sheath material selection depends on the fluid to be heated because some fluids may attack the sheath material chemically. For example, steel is not suitable as a sheath material for water heating because it will be corroded. So stainless steel is preferred for corrosive fluids because it does not corrode.

The below table lists the use of sheath material for different application:

Material	**Application**
Copper	Water, Oil, Grease
Steel	Alkaline cleaning solutions, Tars, Asphalt or air heating
Stainless Steel	Corrosive liquids, food processing equipment, Radiant heating
Incoloy	Cleaning and degreasing solutions, Corrosive liquids
Inconel	Plating and pickling solutions, acid
Titanium	Corrosive liquids

Moisture Resistant Seals

It should be ensured that the moisture does not enter the tube, as explained above. If moisture enters the tube, it will reduce the insulation properties of MgO and increase leakage current, which is undesirable. So the tube is sealed with an adhesive like epoxy or RTV at the end, which is exposed to the atmosphere. These materials are resistant to moisture penetration in the tube.

Sealing Material Properties:

A good sealant should have a high adhesion tendency, high temperature durability, and a high moisture resistance tendency. Materials like polyurethane, RTV, silicone plugs, and epoxy are the most popular sealing materials in the heating industry.

The total wattage of the heater depends on the amount of fluid to be heated per unit time, the specific heat of the fluid, and the initial and final temperature difference. The total wattage is distributed according to the number of tubes.

While selecting the ideal tubular elements for your application, please consider the following factors:

- Heating element watt density
- Sheath material (corrosive or non-corrosive)
- Temperature of the product
- Ambient temperature

Heater Bundle Construction

A heater bundle is made up of several heating elements, a heater flange, a baffle, a tie rod, a terminal box, and a temperature sensor device such as an RTD or thermocouple. There is a restriction on the length of the heating element. For example, a heater bundle installed in the tank horizontally cannot have the tube length greater than the tank diameter. So to meet the thermal load, we have to increase the number of heating elements. The number of heating elements depends on the total wattage and the watt density of the element when the length is fixed.

These heating elements are fixed to the heater flange. There are several ways to fix the elements on the heater flange. These are discussed below.

Heating Element to Heater Flange Connection Types

The heating elements are connected to the heater flange in various ways. The selection of the best fixing method depends on the application.

The heating elements are connected to the heater flange by several methods. A few highly recommended methods are illustrated below. It is important to select the most desired method of connection based on the design recommendation and process requirements.

a) Stand Pipe fixing with Welding or Brazing

This is the traditional way in which tubular heaters are passed through seamless pipes welded to the main heater flange and terminal box end plate, as shown in figure. The pressure sealing is done by means of brazing or welding between Sleeve pipe and heating elements. This method of fixing is also known as the "sleeve fixing method." It is appropriate for non-critical applications requiring low pressure and temperature. This method is not recommended for hazardous-area applications.

Attributes

- Suitable for pressures up to 50 bar.
- Flange repairable
- Recommended by licensors
- Liquid may leak up to the terminal enclosure

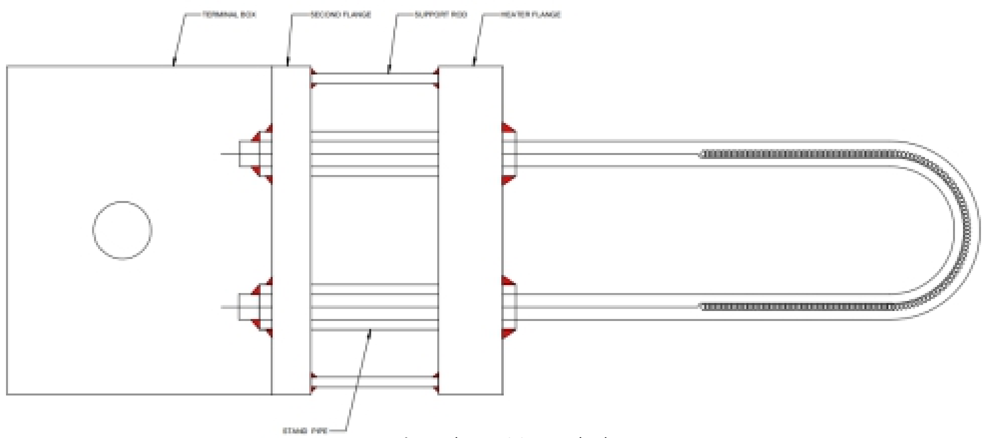


Fig:32 Sleeve Fixing Method

b) Direct Welding of Heating Elements to Heater Flange

In this method, the heating element is directly welded to the heater flange, as shown in figure. The weld joint is designed as per ASME standards. The highly precise weld was carried out by qualified welders and evaluated by third parties and consultants. This fixing method is highly recommended for process heaters and hazardous gas heaters such as hydrogen, etc.

Attributes

- Suitable for pressures up to 350 bar
- Recommended by UOP / AXENS Licensors
- Non-replaceable type
- Must for hydrocarbons, H2 Gas etc.

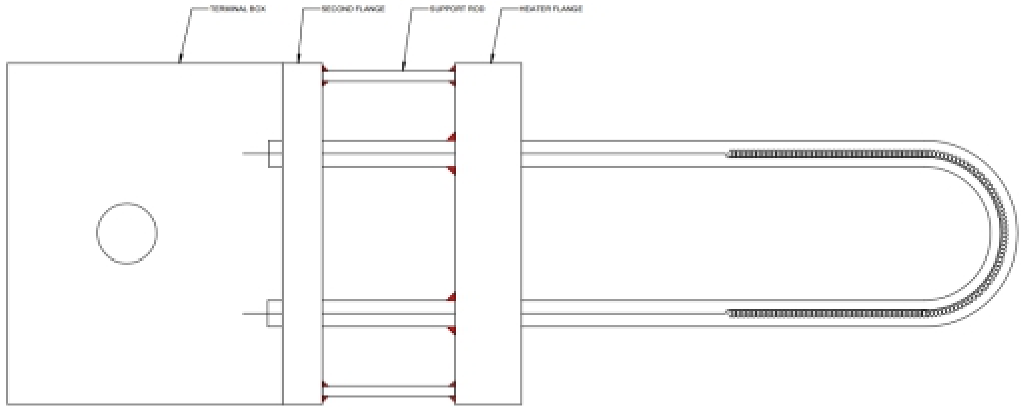


Fig:33 Direct Welding Method

c) Bite Coupling of Heating Elements to Heater Flange

This is the specialized design in which tubular heaters are connected to the heater flange by means of metallic ferrules and nuts. The pressure sealing is done by means of a SS ferrule, followed by nuts tightened as per the recommended torque. This method is widely used for heater constructions in which hot work such as welding or brazing is not allowed.

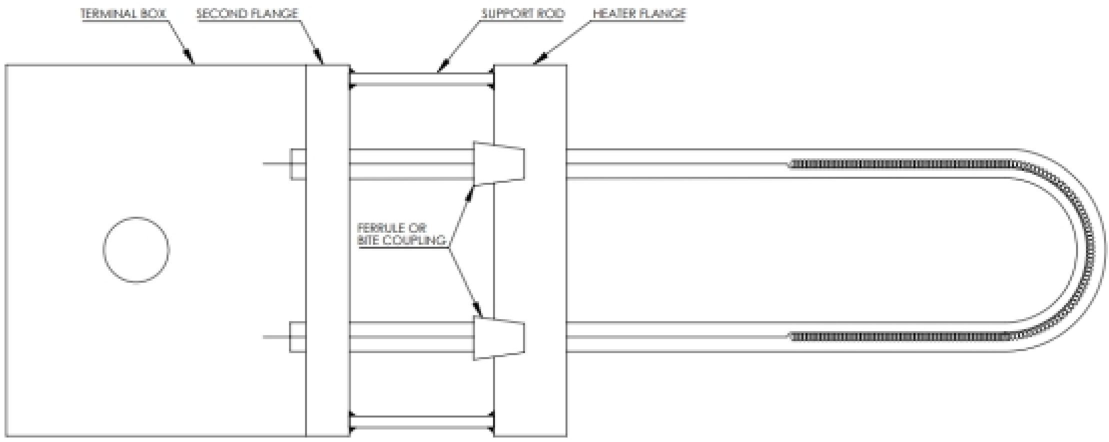


Fig:34 Ferrule Fitting Method

Attributes

- Suitable for pressures up to 150 bar
- Simple element replacement
- No welding stress on the flange

d) Threaded Nut

In this method, the heating elements are inserted into the hole in the hex nut. In this fixing method, elements are passed through the hex nut and welded thereon, as shown in figure. The hex nut is tightened on the counter threads in the heater flange as shown in the figure.

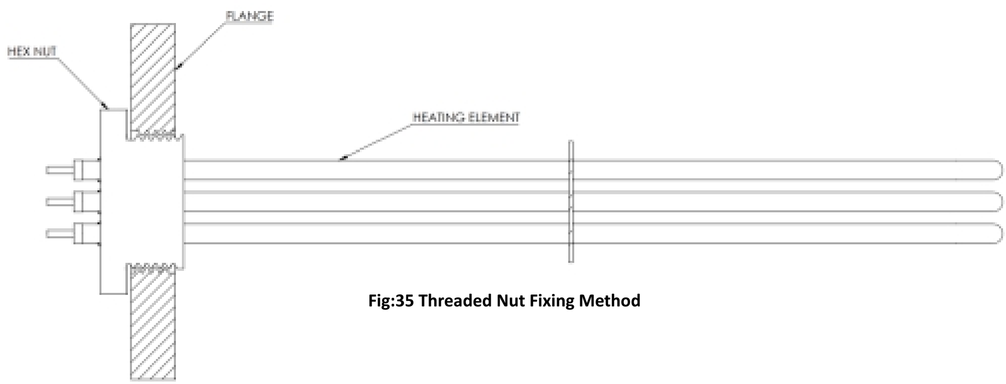


Fig:35 Threaded Nut Fixing Method

e) Indirect Heating

In this fixing method, elements are passed through the hex nut and welded thereon, as shown in figure. The casing pipe is welded to the heater flange as shown in figure. There are threads on the inside of the casing pipe. The hex nut is tightened on the counter threads in the casing pipe by applying the appropriate torque. In this type of fix, the heating element is not in direct contact with the fluid being heated. Heat is transferred from the elements to the casing pipe mainly by radiation. Then, from the casing pipe, the heat is transferred to the surrounding fluid by convection. It is known as indirect heating because the fluid is not in direct contact with the heating element.

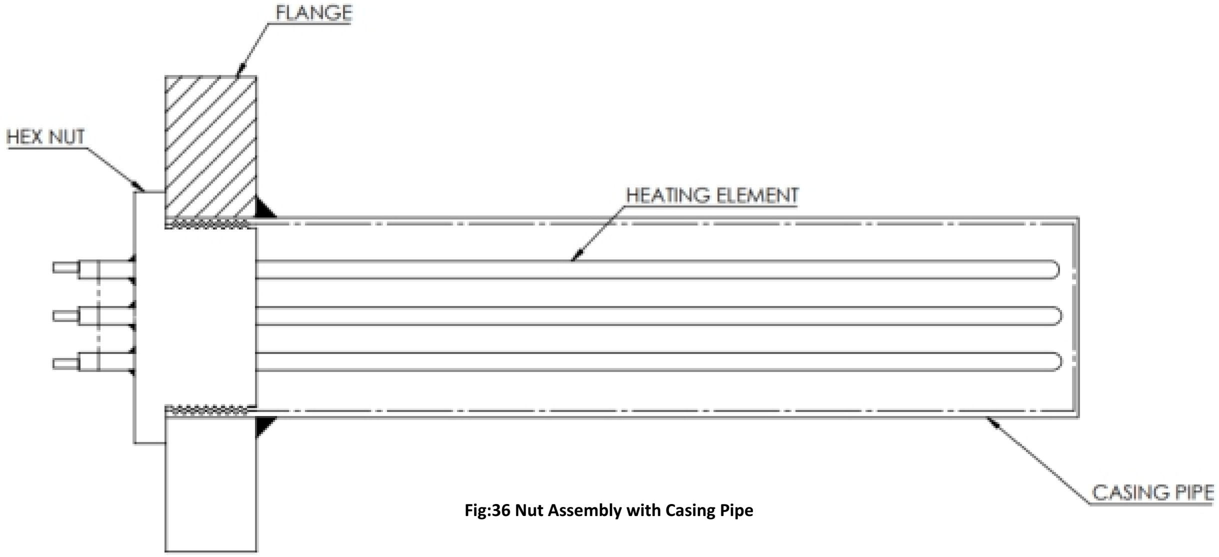


Fig:36 Nut Assembly with Casing Pipe

Attributes

- Recommended for Tank Immersion Heating
- Can replace elements without draining the tank
- Larger size/low density
- For corrosive fluids

Baffle Assembly

The main purpose of the baffle assembly in a heater bundle is to ensure smooth heat transfer from the heating element to the process fluid within the allowable pressure drop. At the same time, the baffle cage also protects the heating elements from sagging and other mechanical damages.

Marathon provides several varieties of baffle plate designs from which to choose the best baffle as per application & requirement. The best model will be chosen based on a variety of factors such as allowable pressure drop, element skin temperature, and so on.

There are two types of baffle assemblies: Segmental type and Rod type. Segmental-type baffles are most often used.

There is one disadvantage of baffles: when the fluid flows into the heater, it suffers a pressure drop because of the obstruction and friction. When the number of baffles is increased, the pressure drop increases. When the pressure drop for the same number of rod baffles and segmental baffles is compared, the pressure drop for segmental baffles is greater.

Rod Type Baffles

Segmental Baffle Assembly.

Fig:37 Rod Type and Segmental Type Baffle

Tie rods are used to hold the baffle in place.

Cooling Baffle is provided between the terminal box and the heater flange. It acts as the fin. The cooling baffle's purpose is to reduce the temperature of the sheath that is exposed to the environment. A second flange is used to hold the terminal box. It is fixed to the heater flange with the help of a support rod. All the safety instruments and element connections are done in the terminal box.

For temperature control, an element skin sensor, heater flange sensor, or process temperature sensor can be installed in the heater bundle. As a temperature sensing device, an RTD or a thermocouple can be used. The temperature sensor's output can be used to control the heater's operation. Temperature can be controlled by a thermostat, a Thyristor-based control panel, or a contactor-based control panel.

A complete heater bundle design and construction depends on various factors, such as operation data, process condition, installation site condition, standards and specifications, governing laws and regulations, certifications, etc.

Marathon Heaters gives high priority to ensuring the proper design and selection of heater flange size and material by using proven design software. The results are also often verified and approved by independent consultants, notified bodies, etc.

In general, a heater bundle consists of

- Heater flange
- Heating Elements
- Assembly of Baffle Plates and Tie Rods
- Terminal Enclosure
- Temperature sensors

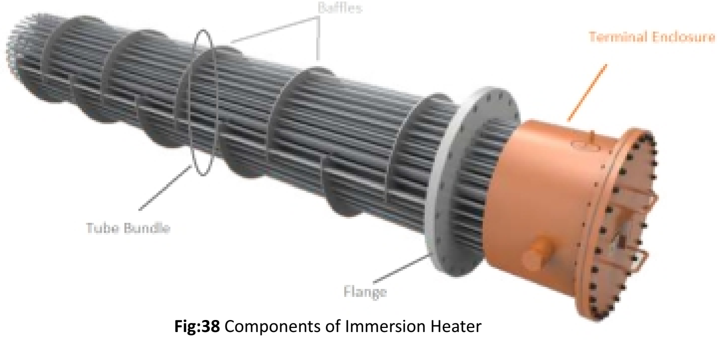


Fig:38 Components of Immersion Heater

24.2 Flanged Immersion Heaters

Flanged immersion heaters are manufactured by welding or brazing the several tubular elements on the flange. The immersion heater is fitted in the tank through a counter flange on the side wall, as shown in the figure. It is used to heat up the process fluid in the tank before pumping it out. If the single immersion heater cannot meet the demand, another heater can be installed in the tank through the wall. These are used for heating chemical, petroleum, and water-based applications, especially heat transfer fluids, medium- and lightweight oils, and water in tanks and pressure vessels.

Baffles intensify flow mixing and increase the heat transfer rate. For horizontal mounting of the heater, baffles also reduce the sagging of the heating element. Tie rods are used to hold the baffle in place.

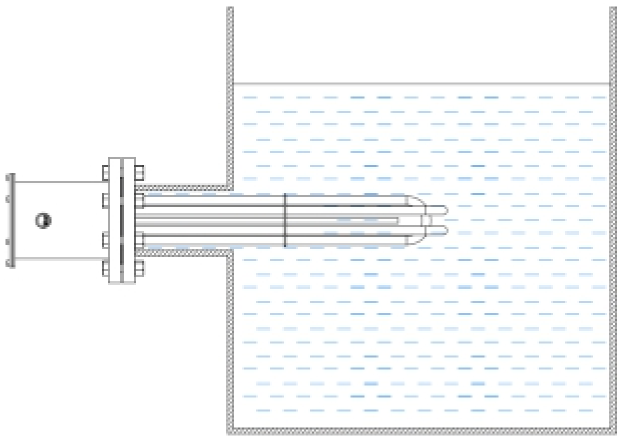


Fig. : 39 Direct Immersion Heater

All electrical connections are done in the terminal box. To maintain the set point temperature, a temperature sensor like an RTD or thermocouple is used to measure the temperature. This temperature information can be transferred to the temperature controller device, which is used to maintain the set point temperature. To protect the thermocouple, it can be installed in the thermowell. A sheath safety temperature sensor is used to measure the temperature of the outer sheath. Temperature readings are then transmitted to a control unit that regulates power. It can be designed to heat the process fluid in the tank, which requires very high wattage.

Different alloys and materials can be used for specific applications. For instance, steel flanges are used for deionized water, lubricant oils, heavy and light oils, and waxes, as well as mildly corrosive liquids and low flow gas and water tank heating. Stainless steel flanged heating elements are used with mild and severe corrosive solutions and in military applications. The sheath materials used can be steel, stainless steel, copper, and incoloy.

Immersion heaters are designed and constructed in various forms based on the application and mounting requirements. Some of the common types of immersion heaters are:

Direct Immersion Heater: The heater bundle will be directly mounted inside the tanks, and the process fluid will be directly in contact with the heating element as shown in figure.

Indirect Immersion Heater

The heating elements will be mounted inside the pockets and welded to the tube sheet. The heat from the elements is transferred to the pocket tubes, which is then transferred to the fluid. These kinds of heaters are used in large storage tank heaters, in which heater replacement can be done without draining the complete system. In an indirect immersion heater, the heating element is not in direct contact with the fluid to be heated.

Technical Specifications

Sheath Material	Copper, Steel, 304 Stainless steel, INCOLOY
Flange Material	Carbon steel, Stainless steel , Alloy 800/625 , Hastelloy
Flange size	2 to 42 inches
Flange Rating	150, 300, 600 or 900 lb pressure class ANSI
Design Temperature	-40°C to 650°C
Design Pressure	Upto 350 bar(g)
Heating Elements:	Mineral filled insulated Heating Elements or Tubular heating Elements with Ni-Cr (80-20) as heating Coil and suitable outer sheaths.
Terminal Enclosure	As required (Weather proof or Flameproof).
Control System	Thyristor control Panel + Local control Stations for effective temperature control & safe operation. (Safe area or Hazardous area) Smaller Heaters : Thermostatic control
Protections & control	Element Skin Temperature controls process temperature control Earth leakage protection. Overload current protection.
Installation:	Mostly Horizontal For vertical installation, please refer L shape Immersion Heater.
Immersion Length	Up to 240inch
Diameter	0.260”, 0.315”, 0.375”, 0.430” or 0.475”, 0.625”
Control	Thermocouple, RTD, Thermostat, Digitally controlled
Voltage	Up to 600 V
Wattage	Customized

The below table list down the use of different sheath and flange material which are used in different fluid applications.

APPLICATIONS	SHEATH MATERIAL	FLANGE MATERIAL
Clean water, hot water storage, portable water, freeze protection of liquid	Copper	Steel
Hot water, steam boilers, mildly corrosive solutions (in rinse tanks, spray washers), vapor degreasers	Incoloy	Steel
Oils (light or medium), Gases, hydraulic oil, stagnant or heavy oils, lubricating oil, crude asphalt	Steel	Steel
Process water, soap and detergent solutions, Boiler and water heaters, deionized water, chemical baths	Stainless Steel	Stainless Steel
Severe corrosive solutions, demineralized water	Incoloy	Stainless Steel

Method to Reduce the Skin Temperature with an Immersion Heater

- Use a heater with a low watt density.
- Make the fluid flow at a higher velocity.
- Make the flow turbulent.
- Use baffles.

Features

Terminal Enclosures

Apart from general purpose terminal enclosures, other types are also readily available.

- Moisture resistant
- Corrosion resistant
- Explosion resistant
- Combination of Explosion/Moisture Resistance

Temperature Control

- Thermostats: They provide process temperature control and are generally mounted inside the terminal enclosure.
- Thermocouple: Type J or K thermocouple offers precise temperature control and sensing. It can be mounted inside the thermowell and attached to the heater's sheath.
- RTDs: If precision greater than that of a thermocouple is desired, an RTD is the right solution to the problem.

Gaskets: Rubber, asbestos-free, and spiral wound gaskets are available for all flange sizes.

Baffles: It's also known as "Element spacers." Standard supports are provided for open tank or convection heating applications. In order to enhance or modify fluid or gas flow for better heat transfer, 316 stainless steel baffles can be provided

Benefits of a flanged immersion heater

- 100% efficient and versatile
- Easy installation, control, and maintenance
- Designed and built for safety
- Perfect for higher kW output applications
- Provide a uniform temperature.
- Moisture resistant
- Corrosion resistant
- Durable

Before buying flanged immersion heaters, these things should be considered.

- Supply voltage: single-phase or three phase
- Heat Capacity
- Terminal box
- Sheath Materials
- Heating element materials
- Temperature controls

L-Shaped Immersion Heater

In some applications where the heater is required to be mounted vertically but also expected to cover the maximum tank area horizontally or at the bottom of the tank, the "L"-shaped immersion heater is the best preferred design. An L-shaped heater is shown in the figure.

Fig:40 L Shape Immersion Heater

24.3 Pipe Heaters

In pipe heaters the heater is installed inside the pipe. In such heaters, the fluid is not in direct contact with the heating element. Rather, fluid is in direct contact with the pipe surface. The heat energy is transferred from the heating element to the pipe mainly via radiation. The pipe gets heated because of the radiant heat from the heater. The pipe transfers this heat to the working fluid, which is in the tank, either by natural convection or forced convection.

Natural convection, or free convection, will take place when there is no bulk fluid flow, while forced convection will occur when there is fluid flow involved. The fluid flow is caused by an external device like pump. In a steady state, the heat energy received by the pipe is equal to the heat taken by the fluid. Since the heating element is not in direct contact with the fluid, the chance of corrosion, fouling, and chemical scaling is reduced. But in pipe heaters, the skin temperature of the heating element is high as compared to an immersion heater of the same power and watt density.

A temperature sensor like an RTD or thermocouple can be used to measure the temperature and control it with a temperature controller.

The tank does not need to be emptied out if the heater needs to be replaced. Pipe heaters can be used for heating hazardous fluids.

24.4 Circulation Heaters

A complete circulation heating system consists of a heater bundle, vessel, terminal box, mounting brackets, saddle, and inlet and outlet connections for fluid flow. When the pressurized fluid or gas needs to be heated during the flow, it is heated by the circulation heater. A circulation heater is also known as an inline heater.

A circulation heater consists of a heater bundle and vessel. The heater bundle has a number of heating elements, which are mounted on the flange by various heating element fixing methods as discussed above. The heater bundle is inserted into the pressure vessel, and the heater flange is bolted to the counter flange of the shell. The shell thickness is chosen according to the design pressure. The flange class is selected according to design pressure and design temperature. There are inlet and outlet nozzles on the vessel.

The fluids enter the vessel from the inlet nozzle. It is heated in the vessel by heating elements and flows out of the pressure vessel through an outlet nozzle at the desired temperature. Drain valves are also provided at the bottom of the vessel. The purpose of a drain valve is to remove leftover fluids or residues. The element's skin temperature sensor and process temperature sensor are provided for the control of the temperature. The control mechanism can be provided by a Thyristor-based control panel, a contactor-based control panel, or a thermostat.

Instruments and elements are connected into the housing, which is known as the terminal box. In the terminal box, the elements are connected in a three phase star or delta connection. The circulation heater can be used for liquid or gas heating during the flow. Saddles are provided for the support of the pressure vessel. The vessel can be mounted horizontally or vertically as per application. A horizontally mounted vessel with a heater bundle is shown in the figure.

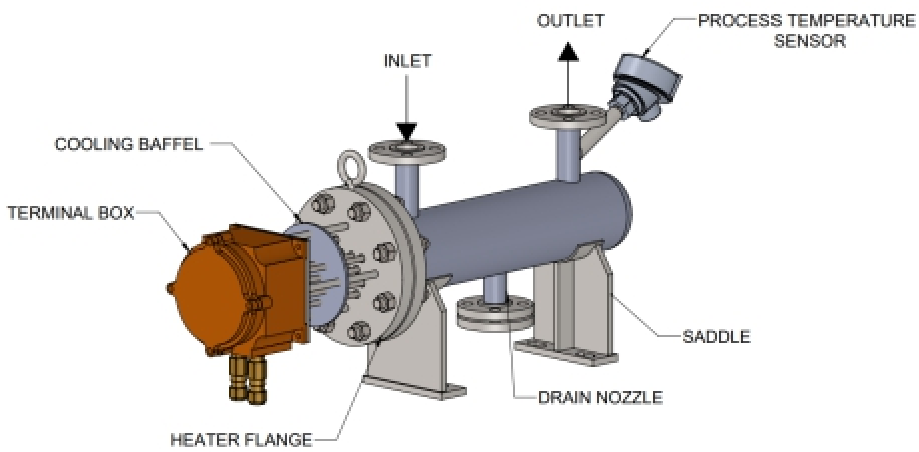


Fig:41 Circulation Heater

An insulation layer of low thermal conductivity material, such as glass wool, can be wrapped around the pressure vessel to reduce heat loss. Such heaters are ideal for processing fluids, including hazardous liquids that require intermediate heating while maintaining viscosity and flow rate.

Technical Specifications

Sheath Material	Copper, Steel, 316 Stainless steel, INCOLOY
Kilowatt Ratings	500 KW or higher
Wearing Watt density	6.5 W/in^2,15 W/in^2, 23 W/in^2, 45 W/in2, 65W/in^2
Flange & Vessel Material	Carbon steel, Stainless steel
Flange size	Up to 42 inches
Flange Rating	Up to 2500 lb pressure class ANSI
Terminal Enclosure	IP 23 Standard Terminal Box IP 66 Water Proof Terminal Box ATEX Certified
Control	Thermocouple, RTD, Thermostat, Digitally controlled
Terminal Enclosure Standoff	4 or 6 inches
Terminal Seals	RTV, epoxy
Standard Size	1.25” NPT Screw Plug size to 14” diameter
Flange Gasket	Standard, Spiral wound or any other
Thermal Insulation	Standard, High temperature or weather proof jacket
Mounting position	Horizontal or Vertical

Features & Benefits

- Thermal insulation is provided to prevent heat loss.
- Mounting lugs are provided for support.
- Different terminal enclosures are available for easy wiring.
- Digitally controlled for precision
- It is easy to install, compact, clean, and durable.
- It can work in conjunction with the control panel.
- It can be custom designed to meet any specifications & requirements
- It is highly energy-efficient and provides maximum dielectric strength.
- It is compatible with standard industry piping and safety standards.
- Gaskets and mounting lugs are provided as per specifications.

24.5 Screw Plug Heaters

Screw-plug heaters replace the flange in the heater with a screw or threaded hex. A U-shaped heating element passes through a number of holes in threaded hex. These U-shaped heating elements are welded or brazed to the hex. Screw plug heaters can be used for direct heating as well as indirect heating. In direct heating, the heating element is in direct contact with the fluid to be heated, while in indirect heating, a screw plug heater is fitted into a pipe, as in the case of a pipe heater. The pipe has counter internal threads. The heater is threaded on the internal thread in the pipe.

When a screw plug heater is used with the pipe, the heater can be replaced without emptying the tank. In indirect heating, the screw plug heater can be fitted to the side of the tank through a threaded opening. Depending upon the customer requirement, thermowells, thermostats, or control panels can be used with these heaters to meet the objective of precise temperature control. The electrical connections are done in a terminal box. A screw plug heater is shown in the figure.

Fig:42 Screw Plug Heater

Technical Specifications

Sheath Material	Copper, Steel, 304 Stainless steel, INCOLOY
Watt Density	Up to 120 W/square inch
Screw Plug Material	Stainless steel, Brass, Steel, Titanium
Screw Plug NPT fittings	1 to 4 inches
Diameter	0.260”, 0.315”, 0.375”, 0.430” and 0.475”
Voltage	120 to 480 V AC Single phase or three phase
Terminal Enclosure	IP 23 Standard Terminal Box IP 66 Water Proof Terminal Box
Control	Thermocouple, RTD, Thermostat, Digitally controlled

Screw plug heaters are widely used for various purposes in many industries, including the food and beverage industry. They are ideal for heating gases and liquids in tanks or vessels, processing water heating, heating oils, and heat transfer processes, including heating up flammable liquids or gases that require explosion proof housing.

The different sheath materials used in these heaters have different watt densities and operating temperatures. While choosing the sheath material, the following points should be looked at:

- **Stainless Steel :** Maximum operating temperature is 650°C, and the maximum watt density is 120 W/in^2.
- **Steel :** Maximum operating temperature is 400 °C, and the maximum watt density is 120 W/in^2.
- **INCOLOY :** Maximum operating temperature is 870 °C, and the maximum watt density is 120 W/in^2.

The table below lists the different sheath and flange materials that are used in different fluid applications.

APPLICATIONS	SHEATH MATERIAL	FLANGE MATERIAL
Clean water, hot water storage, portable water, freeze protection of liquid	Copper	Steel
Hot water, steam boilers, mildly corrosive solutions (in rinse tanks, spray washers), vapor degreasers	Incoloy	Steel
Oils (light or medium), Gases, hydraulic oil, stagnant or heavy oils, lubricating oil, crude asphalt	Steel	Steel
Process water, soap and detergent solutions, Boiler and water heaters, deionized water, chemical baths, mildly corrosive solutions	Stainless Steel	Stainless Steel
Severe corrosive solutions, demineralized water, food equipment	Incoloy	Stainless Steel

24.6 Over the Side Immersion Heaters

When there is no access to insert the heater through side wall and there is only option to install the heater from the top of the tank, over the side immersion heater is the best choice. They are installed from the top of the tank. In these heaters the hot length should be calculated very carefully such that the hot length is always immersed in the fluid.

Hot length must be below the minimum water level in the tank. If due to any reason water level falls below the minimum water level and hot length projects out of the free surface of water then heater may fail because of overheating. Heater can be removed from the top without empty of the tank. Various shapes and sizes are provided as per customer requirement such as L shaped and O shaped. The heated part can be horizontal or towards the bottom of the tank.

Over the side immersion heater can be designed in such a way that it covers the maximum area in the tank. It is commonly used in petroleum and chemical industries. It can be used for heating oils of varying viscosities, degreasing solutions, heat transfer oils and caustic solutions, plating baths, salts and acids

24.7 Finned Tubular Heater

In a finned tubular heater, corrugated steel or aluminium fins are brazed to the heating element as shown in the figure. In all modes of heat transfer, heat transfer rate is directly proportional to surface area. So these are superior to tubular heaters since fins greatly increase surface area and permit faster heat transfer to the air and permits putting more power in tighter spaces—like forced air ducts, dryers, ovens, and load bank resistors—resulting in lower element surface temperatures. As the surface area is increased and heat transfer is improved due to the fins, it results in a lower sheath temperature and increases the heating element's life.

These industrial heating solutions are among the most common and are best suited for a large number of applications such as conduction, convection, and radiation for stoves, industrial ovens, drying cabinets, air conditioners, etc. They can be used in virtually every industrial environment up to about 750 °C and can be moulded into many unique and complex shapes.

Finned tubes are generally used for air. They are most often used in duct heaters. The convection heat transfer rate is given by

$$Q = hA\Delta T$$

When air is flowing over a surface, its heat transfer coefficient is lower. So to increase the heat transfer rate with air, we prefer to attach fins to the surface to increase the surface area for the heat transfer. So heat transfer is enhanced by attaching fins to the outer surface of the heating surface. This is why we employ fins in the case of air.

Fins on tubular heating element are shown in the figure.

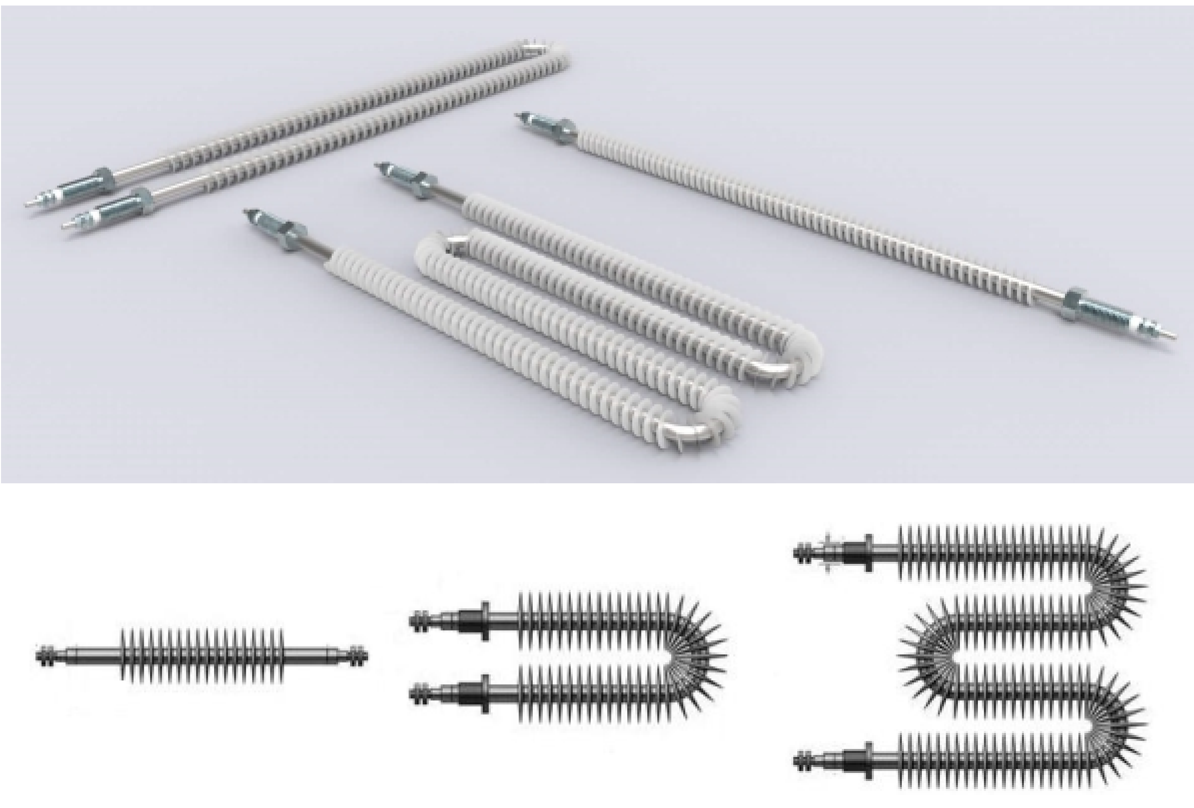


Fig:43 Finned Tubular Heating Elements

Features

- A variety of custom bends are available.
- Various types of terminations are available.
- Cold section is customized.
- Stainless steel mounting bracket, welded to the terminal end.
- RTV and Epoxy seals, which ensure moisture resistance in humid environments.

Applications

- Comfort Air Heating
- Heating, Ventilation and Air Conditioning (HVAC)
- Drying
- Industrial Hot Air Generation

24.8 Duct Heaters

Duct heaters are used to heat the pressurized and non-pressurized air systems. A duct heater is an assembly of several tubular heating elements mounted in a frame or duct. There are three types of duct heaters available: open coil, tubular, and finned tubular heating elements that are either flanged or inserted in the duct.
A duct heater with tubular heating elements and another with finned tubular heating elements are shown in the figure. When the element needs to be replaced, the individual heating element can be removed through the housing of the assembly without removing the complete duct heater. Duct heaters can be equipped with a temperature control system like a thermostat and wired in various power configurations.
The duct heaters are designed according to the air flow rate and temperature required at the outlet of the heater. They can be manufactured for a wide variety of applications that can meet the temperature requirements at the outlet at different flow rates.
In a finned tubular heater, corrugated steel or aluminium fins are brazed to the heating element. These are superior to tubular heaters since fins increase the surface area, permit faster heat transfer to the air, and lower the element's surface temperature. As the surface area is increased and heat transfer is improved due to the fins, it results in a lower sheath temperature and increases the heating element's life.
Duct heaters are used to heat the air in various industrial applications. It is used for air-drying purposes. They are used in heating, ventilation, and air-conditioning systems (HVAC) in residential and industrial complexes, as well as in hotels, airports, and stadiums, etc., for the purpose of maintaining temperatures. These are used in industrial applications such as power plants, and paint is used for air-drying purposes.

Fig:44 Duct Heater without fins

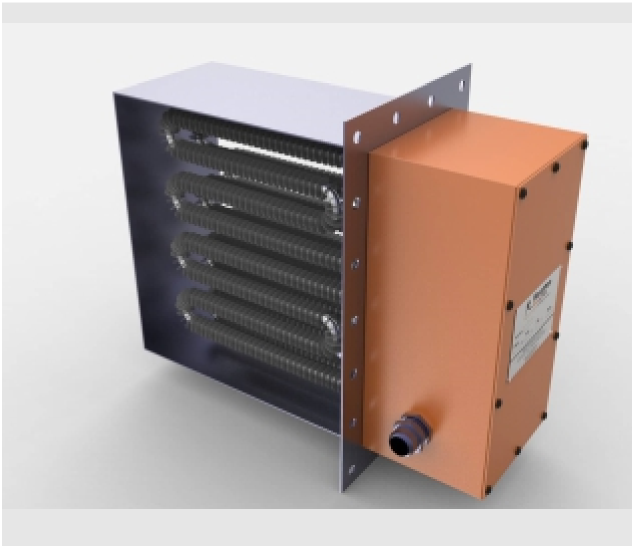


Fig:45 Duct Heater with fins

Technical Specifications

Sheath Material	Steel, Copper, Stainless Steel, INCOLOY
Fin Material	Steel or Aluminium fins
Watt Density	Up to 40 W/in^2
Wattage	Up to 2 MW
Controls	SSR/ SCR/ Digitally Controlled
Diameter of Tube	0.260, 0.315, 0.375, 0.430, 0.475 inch
Voltage	120, 240, 300, 480, 600
Sheath Length	11 – 240 inches
Process temperatures	-29 to 650 ° C

Features

Terminal Enclosures

In addition to the standard, general purpose terminal enclosure, the following optional terminal enclosures are available to meet specific application requirements:

- Moisture resistant
- Explosion resistant
- High-temperature stand-off enclosures

Control

Type J or K thermocouples, inserted in the thermowell, accurately sense element sheath temperature. Using a thermocouple requires appropriate temperature and power controller.

Applications

- Heat Treating
- Air Drying Operations
- Air handling equipment
- Forced Air Comfort Heating
- Core Drying
- Fan Coils
- Booster Air
- Air Preheating
- Terminal Reheating
- Multi-Zone Reheating
- Resistor load banks
- Annealing

Chapter - 25

Component Heaters

Component heaters are used in the component heating of various machinery in industries such as plastic packaging, plastic extrusion, and plastic forming, through the processes of conduction or convection.

25.1 Cartridge Heaters

The basic design of the cartridge heater consists of a ceramic core, heating wire, insulation, a metal sheath, a terminal pin, and lead wire. In the cartridge heater, the heating wire is wrapped around the solid MgO core. This core is called a winding core. The heating wire is wound at an appropriate pitch such that there is no shorting of the wire. The terminal pins are inserted in the central hole in the core and connected to the heating wire. The sheath and the solid core are separated by a small gap. This gap is filled with granular MgO to prevent contact between the heating wire and the sheath. To minimize the air gap in the MgO powder, vibration is imparted to the tube while filling. To further increase the compactness of MgO, the heater's diameter is reduced by swaging. In the swaging operation, the MgO core is crushed to increase compactness. Heat transfer rate and dielectric strength increase as MgO compactness increases. So the temperature of the heating wire decreases because of the rapid heat transfer rate due to the increased compactness of MgO, and the life of the heater increases. A terminal pin is connected with the lead wire to give an electrical connection. A single-phase or three-phase supply is given to the lead wire. Lead wire can be terminated in any position as needed. Cartridge heaters are often placed in the blind hole as shown in figure 3. The lead wire should be placed outside the hole, and the heated length should be placed inside the hole where the part is to be heated; this means that the heated length part must dissipate heat to the workload. If some of the heated length is outside the hole, the heating wire may fail, break, or melt due to overheating.

One end of the metal sheath is welded to the circular disc at the end, while at the other end, lead wires are taken out for connection. This end is sealed with epoxy to prevent moisture penetration into the magnesium oxide. If it is not sealed, then moisture will enter the heater because MgO is hygroscopic in nature and will absorb the moisture from the atmosphere. If somehow the moisture goes into the heater, then the insulation characteristics of MgO drops. So sealing is required at the end.

If temperature control is required inside the heater, a thermocouple wire can be inserted into the core hole, and the thermocouple's temperature output can be used to control the temperature via a temperature controller. A single-phase or three-phase power supply is given to the lead wire. The watt density of the cartridge heater depends upon the number of turns of the heating wire per unit length. Low pitch is used when producing high-wattage cartridge heaters. The outer sheath comes into contact with the surface, which needs to be heated as shown in figure. The leads that come out of the heater terminal have metal conduit or silicon sleeves to protect them from high temperatures. Lead wires are often made of fibreglass or silicon rubber.

The cartridge heater is often placed in the blind hole to heat the workload by conduction. The schematic diagram of the cartridge heater that is inserted in the hole to heat the mould is shown in the figure 3. The hole size is slightly bigger than the outer diameter of the cartridge heater. The length of the hole is slightly longer than the length of the cartridge heater. If the hole size is too large, the heater may fail because of overheating. The cartridge heaters are used to heat the mold, metal blocks, and dies for die casting. For the placement of the cartridge heater, a hole must be drilled in the work piece. Among all the heaters, the cartridge heater is the best choice when localized heating is required. The cartridge heater has a heated length and a cold length. The "heating length" is the length from where the heating wire winding starts, and actual heat is generated in the "heated length." Watt density is calculated based on the surface area of the sheath over the heated length.

The life of the cartridge heater depends upon the watt density, type of fit in the hole, and thermal conductivity of the material to be heated. A high-wattage cartridge heater operates at maximum temperature, so the life of the heater will decrease. A loose fit of the cartridge heater will decrease the heater's life because it will operate at a high temperature. If the thermal conductivity of the workload is low, heat will transfer to the workload at a slower rate, raising the temperature of the heater and shortening its life. When it comes to the life of the cartridge heater, these factors should be carefully considered.

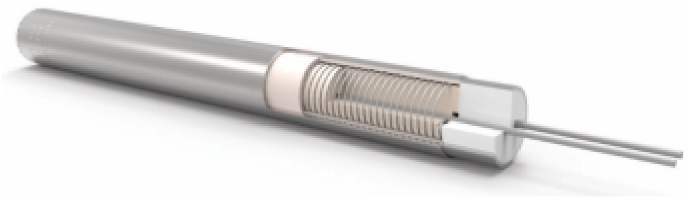


Fig:46 Cartridge Heater [1]

Watt density is calculated by

$$\text{Watt Density} = \frac{\text{Wattage}}{\pi \times \text{Diameter} \times \text{Heated Length}}$$

The various components of cartridge heaters are shown in the figure

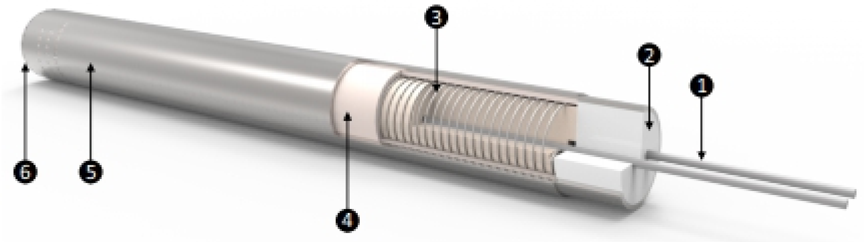


Fig:47 Cartridge Heater [2]

- High temperature lead wires for temperatures up to 550° C.
- High impact ceramic cap retards contamination and is suitable for high vibration applications. Deep holes in cap prevent fraying of leads when bent.
- Nickel-chromium resistance wire for maximum heater life, evenly wound for even heat distribution
- High purity magnesium oxide fill selected for maximum dielectric strength and thermal conductivity, highly compacted for maximum heat transfer.
- Stainless steel sheath / Inconel sheath for oxidation resistance in wide variety of environment.
- TIG welded end disc to prevent contamination and moisture absorption.

Technical Specifications

Sheath Material	Stainless steel, INCOLOY
Watt Density	Up to 400 W/in^2
Voltage	Up to 480V AC
Length	Up to 72 inches
Leads	Stranded/ Swaged in/ Pin leads/ Customized
Diameter	Customized
Controls	Thermocouple/ RTD

Operating Temperatures and Watt Density

Material	Maximum Operating Temperatures		Maximum Watt Density	
	°F	°C	W/in^2	W/cm^2
INCOLOY	1400	760	400	62
Stainless Steel	1000	538	400	62

Applications

- Mould Heating
- Die Casting
- Metal block heating from inside

25.2 Band Heater

Band heaters are mostly used to heat cylindrical surfaces. Marathon make band heaters are available in a variety of construction styles to meet the demands of various operating environments. Band heaters are of two types: mica band heaters and ceramic band heaters.

25.2.1 Mica Band Heaters

Mica band heaters are used to heat cylindrical surfaces like pipes and drums. Mica band heaters are an example of an indirect type of heater.

In mica band heaters, mica is used as the insulation. It consists of an outer sheath and mica layers. Mica is in the form of thin sheets. Actually, there are three sheets of mica, and the thickness of each is chosen suitably to give adequate dielectric strength and insulation characteristics: top mica sheet, winding mica sheet, and bottom mica sheet. The heating wire (made up of nichrome) is wrapped on the winding mica sheet, which is placed between the top and bottom mica sheets as shown in figure 49. These three mica sheets are encapsulated in the outer sheath. Generally, stainless steel is used as the sheath material because it is corrosion-resistant and provides physical strength to the heater.

When current is applied to the heater via lead wire, heat is generated in the resistance wire, which is then transferred to the sheath via the mica core. Mica core ensures sufficient dielectric strength and better thermal conductivity. The sheath is in contact with the external cylindrical surface. The heat is transferred from the sheath to the cylindrical surface, and then from the cylindrical surface to the fluid inside the pipe.

It can accommodate a thermocouple for measuring the internal temperature of the heater. The mica heaters are designed to prevent moisture penetration and contamination. The maximum sheath temperature is 450°C. It is widely used in the plastics industry. Terminal boxes can be provided that protect terminations and also have the option to install a temperature controller device like a thermostat that regulates the temperature.

Mica band heaters with cut view is shown in the figure 49.

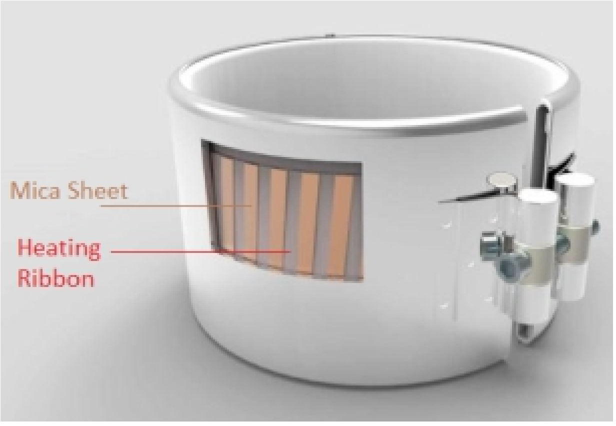


Fig:48 Mica Band Heater [1]

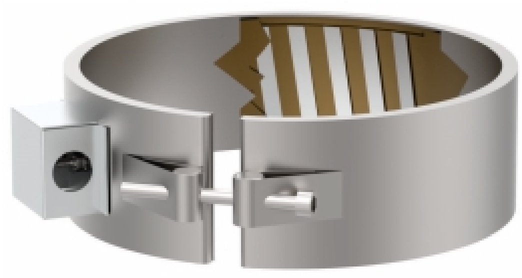


Fig:49 Mica Band Heater [2]

Fig:50 Mica Band Heater [3]

Technical Specifications

Max. Sheath Temperature	450°C
Voltage	120 & 240V
Watt Density	Up to 45 W/in^2
Minimum Diameter	2”
Minimum width	1”
Regular gap	3/8”
Terminal Enclosure	Regular or moisture resistant terminal box
Control	Thermostat

Features and benefits

- Various shape options for mica strip heaters
- Reasonably high temperature
- Good efficiency
- Good lifetime
- Low cost
- Less in thickness

Applications

- Injection, extrusion, and moulding processes
- Plastic Processing Industry,
- Chemical Industries
- Food Processing Industries
- Oil Lubricating Unit
- External Tank and Vessel Heating
- Blown Film Dies

25.2.2 Ceramic Band Heater

Ceramic band heaters are used to heat the barrel or any external cylindrical surface. Band heaters are manufactured in such a way that they could fit over a barrel or cylindrical surface, like a pipe. However, a tight fit is not required in the case of a ceramic band heater because the heater not only heats the barrel by conduction but also by radiation.

It consists of ceramic knuckles that have holes. In these holes, heating coils are inserted. The heating coil is made of nichrome.

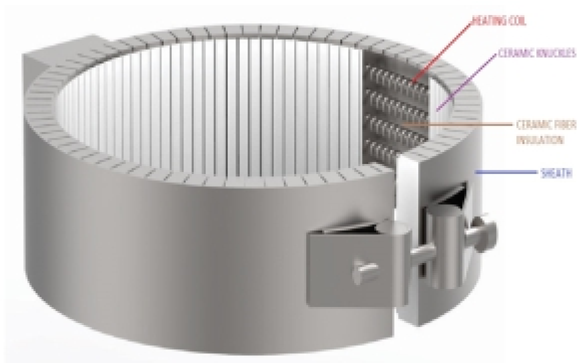


Fig:51 Ceramic Band Heater [1]

Thus, a mat of ceramic tiles with a heating coil is formed, which is flexible and can easily be housed in a stainless steel sheath. The housing has serrated edges that hold the mat in place. The inner face of the mat makes contact with the external cylindrical surface, which needs to be heated, while on the other face, fibre insulation is provided. Fiberglass insulation is between the knuckles and outer sheath, as shown in figure. It prevents heat loss to the surrounding air, resulting in lower electricity costs.

As we supply power through lead wire, heat is generated in the coil, one face of the mat heats up the barrel by conduction and radiation, and from the other face of the mat, heat is not transferred to the outer sheath because of thermal insulation. Fiberglass insulation of superior quality and appropriate thickness is provided. Either single phase or three phase power can be given to the heater by the lead wire. Two lead wires terminate the heater in a single-phase power supply, while three lead wires terminate in a three-phase power supply.

Technical Specifications

Sheath Material	Aluminium coated or Stainless Steel
Insulation Material	Ceramic Fibre Blanket
Watt Density	Up to 45 W/in^2
Watt Ratings	500 – 5000 W
Voltage	120 V & 240 V, single phase, 2 phase and 3 phase
Width	25mm – 250mm
Diameter	40mm minimum, expandable up to 1200mm in 3 parts.
Operating temperature	650°C

Applications

Ceramic band heaters are widely used for the heating of molds, dies, nozzles, and barrels on all types of plastic processing machinery.

25.3 Strip Heaters

25.3.1 Mica Strip Heater

Mica strip heaters consist of mica sheets, a metal sheath, and a heating ribbon. The heating ribbon is the flat heating element, which is very thin and has a rectangular cross section as shown in the figure. There are three sheets of mica: the winding mica, the top mica, and the bottom mica sheet.

A heating ribbon made up of Nichrome is wound on the winding mica sheet. A winding of mica sheet with a heating ribbon is positioned between top and bottom mica sheets, and this assembly of mica sheets with a heating ribbon is encapsulated in the metal sheath. Top and bottom mica sheets act as insulation, which ensures sufficient dielectric strength and conducts the heat to the surface because of the good thermal conductivity of mica. Top and bottom mica sheets restrict the leakage current from flowing to the metal sheath because of the high dielectric strength of the mica. The metal sheath provides physical strength to the heater.

The strip heater is in the form of a flat strip with a rectangular cross section. Mica strip heaters are often used to heat the plate or any curved surface by conduction. The heater can be fitted to the plate with the help of a bolt. The heater must be fitted in such a way that there is no gap between the plate and the heater.

If there is a gap between the heater sheath and the plate or surface, then the ribbon may overheat and melt or break. Threaded terminals with nuts and bolts are provided for the easy connection of the power supply. The sheath material should be chosen so that it will not corrode in the environment in which it operates. It is an inexpensive way of heating the surface.

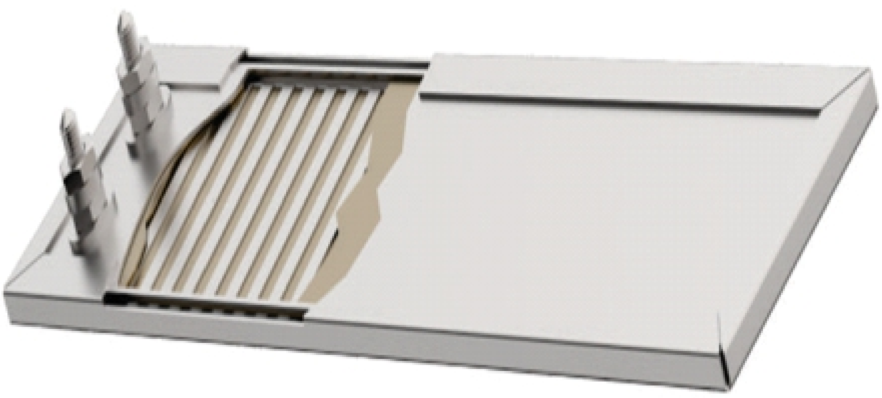


Fig:52 Mica Strip Heater

25.3.2 Ceramic Strip Heater

It's the same as mica strip heater. The difference is that in ceramic strip heaters, ceramic is used as the insulation. The heating coil is inserted in the ceramic knuckles. Thus, a ceramic mat with a heating coil inserted in the knuckles is formed, and the mat is encapsulated in the sheath. This ceramic acts as insulation between the metal sheath and heating coil. Ceramic knuckles provide sufficient dielectric strength to restrict the leakage current and allow heat transfer from the coil to the metal sheath.

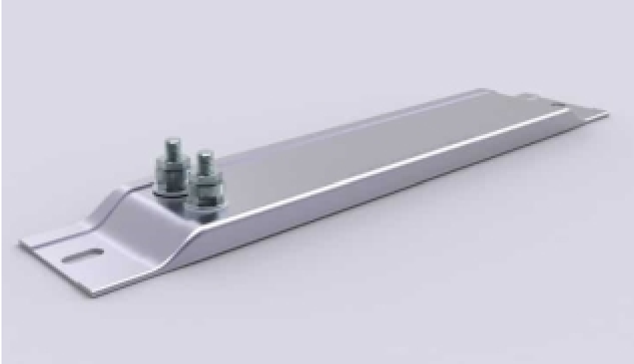


Fig:53 Ceramic Strip Heater

Technical Specifications

Options:	
Sheath Material	Iron, Steel, 304 Stainless steel, Aluminum, Zinc coated steel
Watt Density	Up to 45 W/in^2
Voltage	Up to 480 V AC
Operating temperature	Up to 650°C
Length	5 ½ to 48 inches
Width	1 ½ inch

Applications

- Surface Heating
- Plate Heating

25.4 Finned Strip Heaters

Finned strip heater is same as strip heater. The difference is that in a finned strip heater, fins are attached to the metal sheath. Ideally, the fin material should have high thermal conductivity. A high thermal conductivity of the fin material increases the fin's efficiency.

A finned strip heater is used for heating the air by forced convection or free convection. In forced convection, air flows over the fins with the help of an external device like a fan or blower. In free convection, there is no external device. Air flows because of the density difference created by the temperature difference.

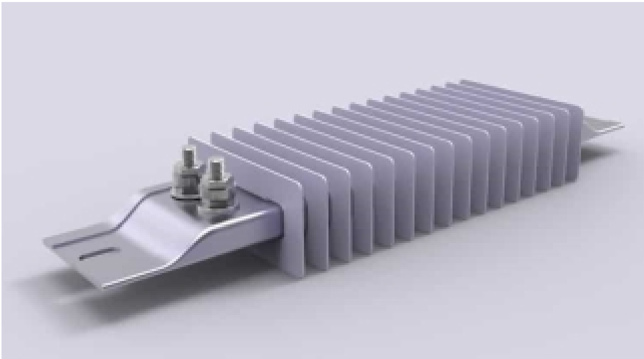


Fig:54 Finned Strip Heater

For example, as the air comes in contact with the heater, its temperature increases and density decreases, so this heated air rises because of buoyancy, and the gap that is created by moving air is filled by surrounding air.

A finned strip heater consists of a metal sheath, ceramic insulation, a heating coil, and fins. First, the strip heater is manufactured, as discussed in the previous section, and later, the steel fins are attached to the metal sheath. Fins increase the heat transfer area, and so the heat transfer rate from the heater increases. Hence, the internal temperature of the heating coil decreases, which increases the life of the heater. Air heats up at a faster rate when using the fins.

The operating temperature of the finned strip heater may increase substantially without a temperature controller because of the poor heat transfer coefficient of air. The heat transfer coefficient is lower in natural convection than in forced convection at low velocity. So the temperature of the heater can be regulated by a thermostat or heating control panel. The finned strip heater can be shaped into a rectangular, spiral, or round shape as per the application. A rectangular finned strip heater is shown in the figure.

Sheath Material	Steel, 304 Stainless steel, Iron, Aluminum, Zinc coated Steel
Watt Density	Up to 38 W/inch^2
Length	Up to 48 inches
Fins Material	Aluminum, Steel

25.5 Silicone Rubber Heaters

It is an extremely thin and flexible heater. It can be converted into a complex shape for easy mounting. It can be installed over any complex contoured surface. It is made up of a heating wire sandwiched between two sheets of silicon rubber, as shown in figure 55. Silicone rubber acts as both insulation and a sheath. These heaters are mounted over the drums to heat the content in the drum. There are different mounting methods available, like spring and boot hooks, laces and grommets, Velcro, etc. Heat concentration can be easily varied at different locations by creating low and high watt densities at those locations.

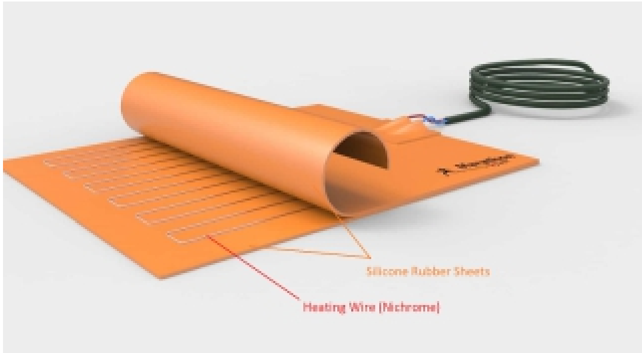


Fig:55 Silicone Rubber Heater

The high dielectric strength, better heat transfer ability, and flexible nature of silicon rubber give the heater a unique feature. Thermostats can be used for precise temperature control. An RTD or thermocouple can be attached to measure the temperature in the heater at some particular location. According to the requirements, lead wire can exit at any point. Teflon is used as the lead wire material. Depending on the application & requirement, either single-phase or three-phase current can be supplied to the lead wire. For single-phase supply, two lead wires exit out of the heater, while for three-phase supply, three lead wires exit. Silicon rubber heaters can withstand vibration or mechanical shock. They can be used for temperature applications up to 250°C.

Silicone Rubber Heaters are available in two types-

- Wire wound
- Etched foil

Resistance wire is wound on a fibreglass cord for support and stability in wire-wound elements. For all sizes of heaters, wire wound is suggested and chosen.

Etched foil heaters are made with a thin metal foil (0.001") as the resistance element. When compared to wire-wound elements, the etched foil heater provides superior heat transfer due to its large flat surface area. It can deliver more uniform heat profiles with higher watt densities, providing longer heater life.

A wire-wound circuit or etched foil circuit can be positioned between two wafers of silicone, which provides flexibility and strength as shown in the figure. Etched-foil elements are usually recommended for applications requiring high temperature and watt density. A wire-wound design and an etched foil design are shown in figure.

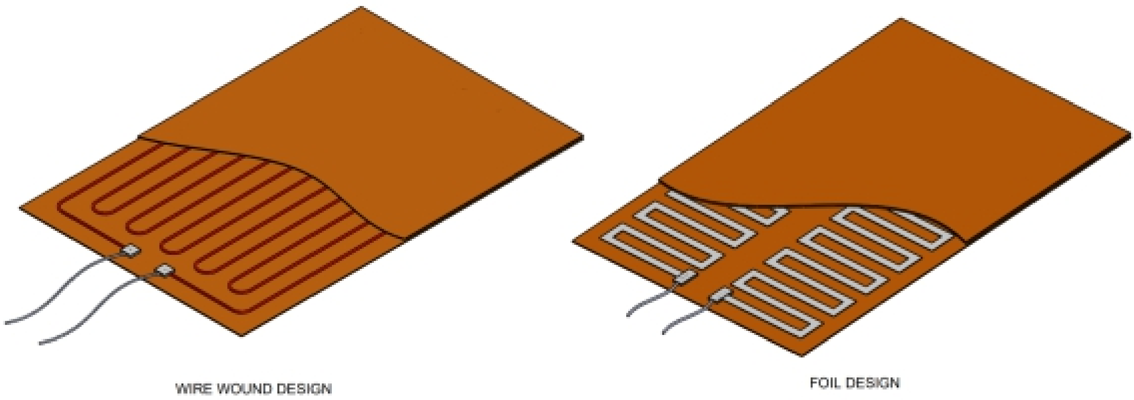


Fig:56 Wire wound & Etched Foil Design in Silicone Rubber Heater

Technical Specifications

Length	1 to 120 inches
Width	1 to 36 inches
Thickness	0.056" standard, other thicknesses available
Watt Density	80 W/in^2
Wattage Tolerance	+5, -10%
Operating Temperature	-70 to 450°F
Maximum Temperature	500 °F (230°C)
Voltage	12V to 600V AC or DC
Lead wire	12 inch Teflon insulated, other types available

Applications

- Freeze protection and condensation prevention
- Drum Heaters
- Medical equipment
- Computer Peripherals
- Photo processing equipment
- Semiconductor processing equipment
- Shelving

25.6 Blower Assembly

In a blower heater, the number of ceramic band heaters is fixed in the housing. The housing is made from sheets of stainless steel or mild steel. The sheet thickness is 1.2 mm or 1.6 mm. The two housings are closed by the hinge joint. The heater is connected in either single phase or triple phase depending on the customer's requirement. The fins are attached to the heater projected in the housing, as shown in figure 57. The fins are made up of high thermal conductivity material like copper. The blower heater is fitted over the pipe in which the working fluid flows, which needs to be heated. During the flow, the working fluid temperature increases because of the heat gained by the heater. The heat is gained by the working fluid through convection.

When there is no fluid flow, the pipe is still hot, which decreases the life of the pipe. The rate of heat transfer depends on the surface area. Fins increase the heat transfer rate by increasing the surface area. So attaching the fins to the heater can reduce the temperature of the pipe faster due to which the life of the pipe will be increased. Air is made to flow by an external device like a fan or blower over the fins, which pick up the heat from the pipe and cool the pipe faster because of the fins.

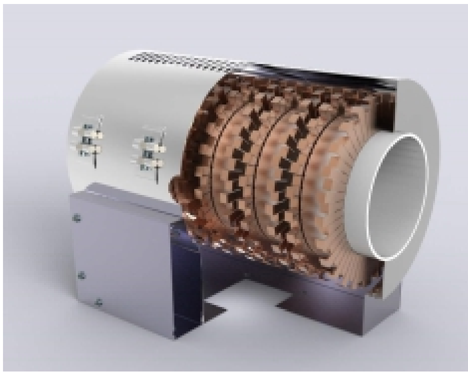


Fig:57 Blower Assembly [1]

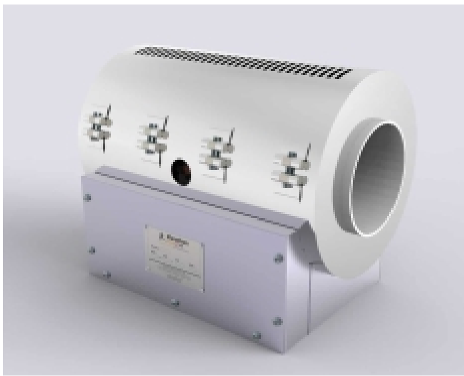


Fig:58 Blower Assembly [2]

25.7 Air Heater

Marathon air heaters have an open coil of high-resistance wire, such as Nichrome 80/20, wrapped around the mica sheets. Mica sheets have slots to accommodate the coil in place. Mica sheet acts as the insulation. The coil is wrapped in such a way that it can occupy the maximum possible volume, allowing heating to take place in the limited available space.

Fig:59 Air Heater

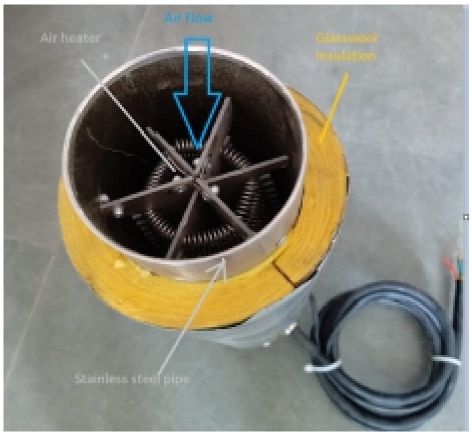


Fig:60 Air Heater installed in Pipe

This air heater, as shown above, is fitted inside the pipe (stainless steel pipe) in which air flows, which gets heated up when it passes over the coiled resistance element as shown in figure 60. Superior quality glass wool insulation is installed on the pipe to prevent heat loss to the environment. As a result of the insulation, the maximum amount of heat is present inside the pipe. Maximum heat transfer efficiency is achieved because the heated air passes directly over the resistance wire. Its design is small and lightweight, and it is also the most cost-effective of any type of heater.

Technical Specifications

Sheath Material	SS304
Sheath Outer Diameter	63.5 mm, 101.6 mm
Wattage	Various Wattage available ranging from 2kW to 30 kW
Watt Density	Up to 77 W/inch^2
Glass wool Insulation	Up to 1200°C
Wattage tolerance	+5%, -10%
Resistance Tolerance	-5%, +10%

Features and Benefits

- Heats up quickly
- High Efficiency
- Low maintenance
- Simple Installation
- Easy and low-cost alternative

Applications:

- Hot air dryer system
- Hand dryers
- Laminating
- Sealing
- Plastic welding

25.8 Coil Heater

The coil heater is in the shape of a coil, as shown in the figure. First of all, the appropriate gauge wire is selected based on watt density and power. Heating wire is made of Nichrome 80/20. The spring is made from this heating wire by the coil winding machine. The spring is welded to the cold terminal pin at its end. The terminal pin is made of low-resistance material like nickel. The spring terminal pin assembly is inserted into the MgO core. Usually, the core consists of 4 holes in which the spring is inserted in two holes, and the remaining two holes can be used to insert the thermocouple, which measures the internal temperature at that location. This core spring assembly is inserted into the sheath. The remaining gap in filled by granular MgO powder by gravity filling tower. Then it is drawn on a drawing machine using an appropriate die to increase the compactness. If we need to further draw it, then annealing is done to make the material soft. If annealing is not done before the second drawing, then the material may crack during the drawing. So after each drawing and before the next drawing, annealing is performed. Annealing is done in the furnace, and the temperature of the furnace is set according to the annealing temperature required for the material.

If a square-shaped cross section is required by the customer, then after the final drawing, swaging is done on a square swaging machine, which makes the round cross section of the heating element into a square shape. Finally, the heating element is converted into the coil form according to the mandrel diameter required. A coil heater having a square cross section is shown in the figure.

High-wattage coil heaters can be made. A coil heater can be used to heat the precise location that is not accessible by a cartridge heater because the coil is flexible, so its bending is easy, and we can heat the typical part of the component. A coil heater can be used up to a temperature of 750 °C.

Technical Specifications

Sheath material	Chrome Nickel Steel
Insulation material	High purity MgO
Heating element	NiCr 80:20
Thermocouple	'J' type (Fe K), 'K' type (Cr Al) grounded or ungrounded
Connection Wires	Stranded Nickel wires with PTFE coating
Voltage Range	24 to 250 volts
Power rating	Depending on application
Power tolerance	±10%
H. V Testing	800 V (Bent heater),500 V between T/C and heating element
Insulation Resistance	>5 MW
Current Leakage	<0.5 mA
Sheath Temperature	750°C max
Adapter Temperature	150°C max
Length Tolerance	Heated length ± 2%
Unheated Length	5-10 mm on bottom end, 50 mm at the adapter end. Larger lengths available on request.

Types of Termination exit

Different termination styles are available in coil heaters. We can terminate the lead wire according to our application. There are three types of termination exit in a coil heater, which are shown in the figure.

- Tangential
- Axial
- Radial

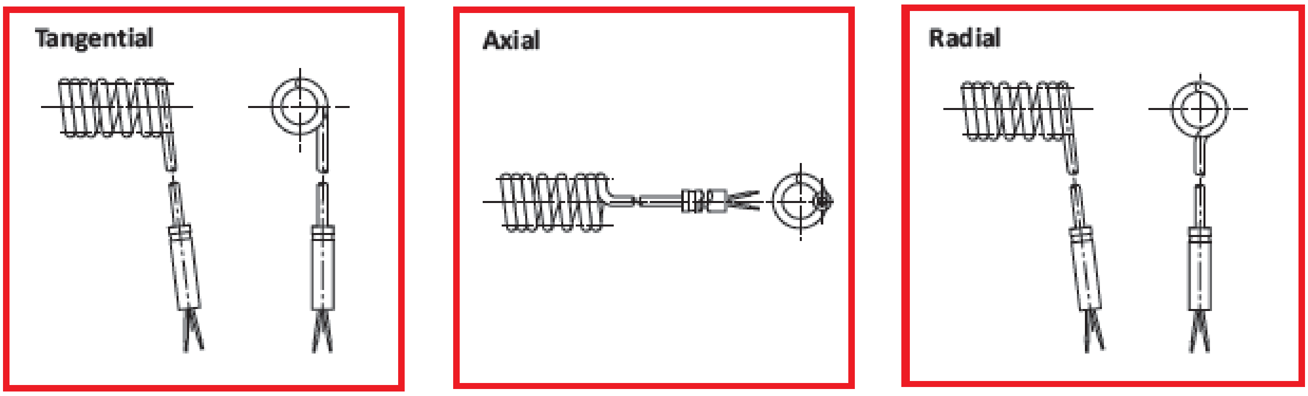


Fig:62 Different Termination Style in Coil Heater

Chapter - 26

Furnace Heaters

In the furnace, the workload is heated by radiation. In these heaters, there is no fluid flow, and heating is predominantly caused by radiation. In furnace heaters, direct heating of the workload is used.

High-temperature bundle rod heaters and metallic heating elements are used for different furnace applications, including annealing furnaces, galvanizing furnaces, etc.

26.1 Bundle Rod Heater

This heater is used in the furnace in which rod-shaped heating elements are used. Bundle rod heaters consist of a round ceramic disc that holds the heating element. In place of a round ceramic disc, a flower-type disc can also be used. Sometimes the cup-shaped disc can also be used according to requirements. A round ceramic disc and a flower-type ceramic disc are shown in the figure. Ceramic discs have holes through which the heating element goes, and these discs are used to hold the heating element and can sustain very high temperatures.

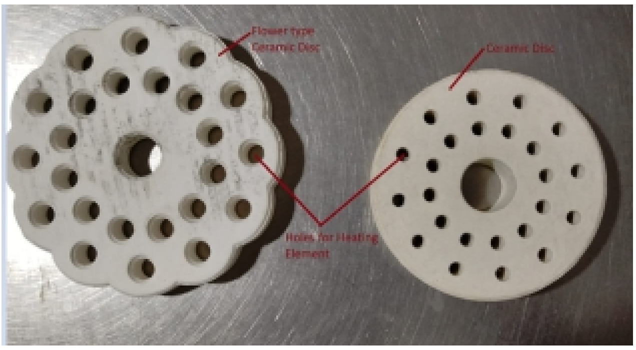


Fig:63 Ceramic Disc

These heaters are designed for long life and maintenance-free operation. The heating elements are available in nearly any length, but the standard dimensions are 68 to 170 mm. The bundle rod heater can be used either alone or inside the radiant tube. When they are used with radiant tubes, the elements are isolated from the furnace, so they are protected from the harmful atmosphere of the furnace. Bundle rod heater without radiant tube having round ceramic type disc is shown in the figure

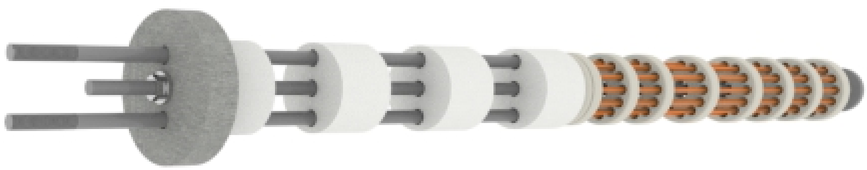


Fig:64 Bundle Rod Heater with round ceramic disc [1]

When the heater is turned on then its temperature increases. As the temperature increases the length of the heating element increases because of thermal expansion which is given by

$$\Delta L = L_0 \times \alpha \times \Delta T$$

Where α is the thermal expansion coefficient. ΔT is the rise in temperature of the heating rod when power supply is given to the heater & l_0 is the initial length when there is no power supply.

So some margin should be kept to accommodate the extra length increased due to thermal expansion

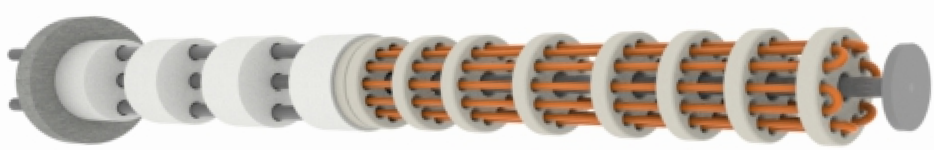


Fig:65 Bundle Rod Heater with round ceramic disc [2]

Bundle rod heater without radiant tube having flower type disc is shown in the figure

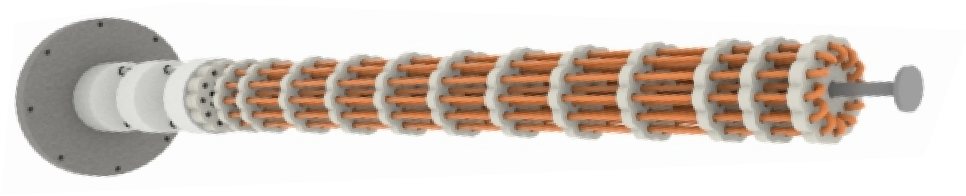


Fig:66 Bundle Rod Heater with flower disc [1]

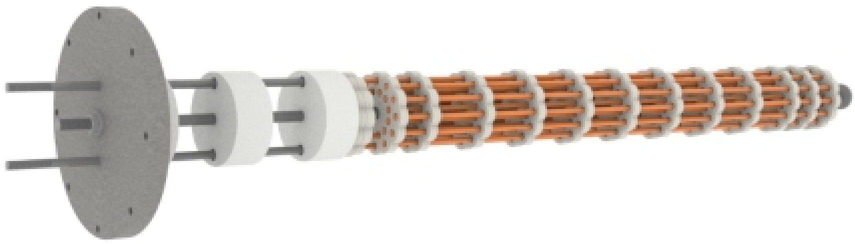


Fig:67 Bundle Rod Heater with flower disc [2]

Cut view of Bundle rod heater with radiant tube is shown in the figure.

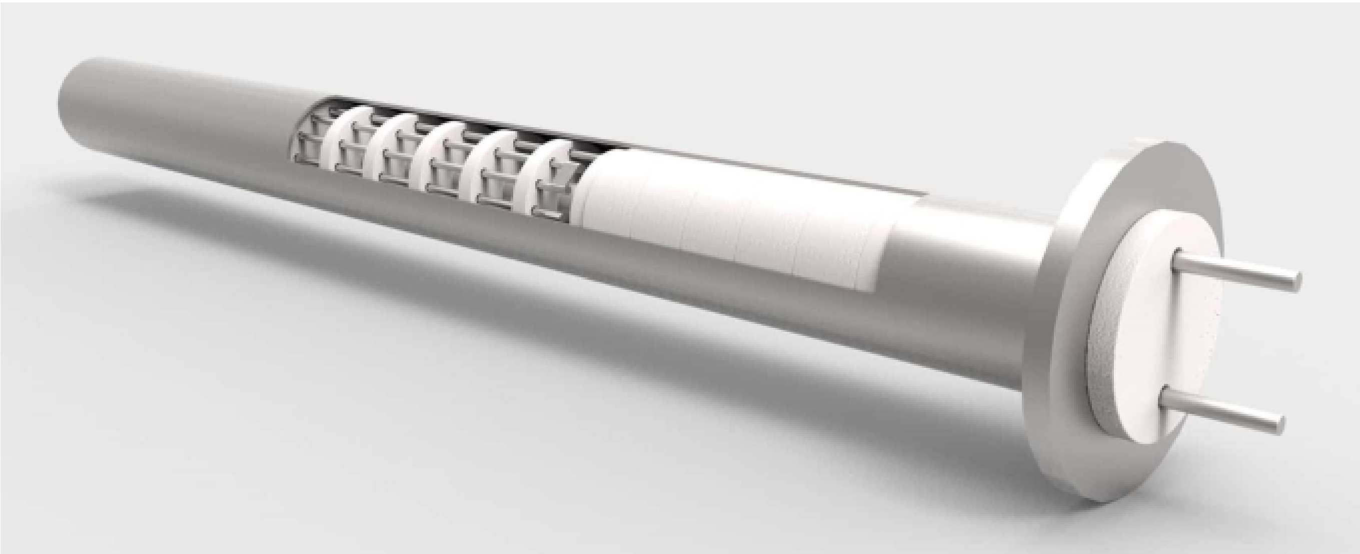


Fig:68 Bundle Rod Heater inside Radiant Tube

Superior Power Output

Bundle rod elements, with a higher power output, lead to major savings in cost and maintenance. Also, when it is combined with radiant tubes, it gives the highest power rating (up to 100 KW) as compared to any other heater.

Components of Bundle Rod Heater

Terminal rod: It carries the power supply wiring. usually made of SS 310 or INCOLOY.

The number of rods depends on the supply connection.

Center Rod: It is used to provide central support to the heater. Usually made of SS 310 or

INCOLOY. It is longer than the terminal rods.

Ceramic Disc: It is used to encompass all the heating elements to form a bundle. It is made up of alumina. It is usually in a flower shape or a round shape.

Fiber Disc: It is used to hold the terminal rods and central rod together. It is inserted in the cold zone of the heater. It is made up of ceramic fiber.

Technical Specifications:

Heating Element Material	Mara FeCrAl, NiCr 80/20
Power	1 KW to 75 KW
Cold Resistance Tolerance	$\leqslant$3%
Max. Temperature	upto 1250°C
Heater Parameter	Customized Power Rating,Voltage,Resistance, Length, Diameter
Fiber Disc	Customized
Voltage	240 or 480 VAC

Advantages

- Reduces CO_2 emissions by eliminating flue gases. Minimized environmental impact
- It can be used with or without a radiant tube.
- Higher output with fewer assemblies
- Lower cost
- Reliable production
- Uninterrupted operation

Applications

- Primary aluminium holding and melting furnace
- Galvanizing furnace in steel industries
- Heat treatment furnace in automotive industries
- Annealing furnace
- Carburizing furnace

26.2 Bobbin Heaters

Bobbin heaters consist of ceramic bobbins, heating coils, terminal rods, and center rods. Ceramic bobbins are made of an insulating material that has a recess at its periphery and a hole at the center. The heating coil is supported in the recess, and the center rod is passed through the center hole in the bobbin. A heating coil is a high-resistance element that is generally made up of Nichrome 80/20. A center rod is used to hold all the bobbins. The heating coil is connected to the terminal rod for power supply. Bobbin heaters can be designed for single-phase or three-phase power supplies.

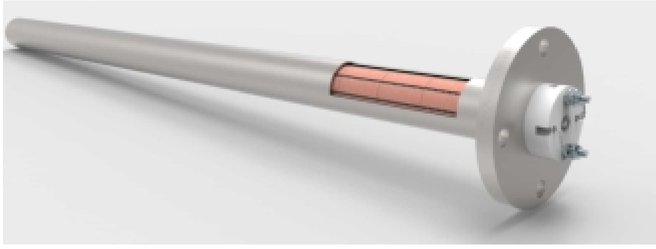


Fig:69 Bobbin Heater inside Radiant Tube

The bobbin heater can be used alone (without the radiant tube) for direct heating of the air, but to heat the liquids, it is inserted into the radiant tube as shown in the figure.

For indirect heating of liquids and gases, the bobbin heater is inserted into the radiant tube, and it is mounted on the flange. The heat is transferred from the bobbin heater to the radiant tube and then from the radiant tube to the surrounding fluid, which needs to be heated. The heater can be replaced without emptying the tank or vessel.

A temperature sensor can be provided for accurate temperature sensing, or other controls can be provided as well. The element allows for easy installation and handling. They are normally manufactured for horizontal mounting but may be specially designed and constructed for vertical installation. It is designed for any voltage or wattage within manufacturing limits. Bobbin heaters are typically used for low-wattage, low-density heating with a limited temperature range. It is known to be one of the most common and versatile heaters in the vast range; they are inexpensive, simple, and require little maintenance.

Sheath Material	Copper, Steel, 304 Stainless steel, INCOLOY
Power	Up to 12KW
Watt density	1 to 10 W/cm^2
Temperature range	Upto 600°C
Heating element	Ferritic alloys wire Mara FeCrAl and Non Ferritic wire NiCr 80-20 or NiCr 70-30
Bobbin size	Standard: 25,30,36,42,45,57,93 other customize size available
Heater parameters	Customized – power rating, voltage, resistance, length, diameter and other dimensions
Radiant tube/immersion tube	Stainless steel SS grade, incoloy, cast alloys
Thickness of tube	1.5 to 3mm
Length of tube	300 to 2800mm, customizable

Advantages:

- Heating water, chemicals etc.
- used for semi-solid materials like wax, fats, oil, and bitumen.

Benefits

- Suitable for furnace heating at low temperatures up to 600 °C.
- A wide range of lengths, voltages, and powers is available to meet customer's specific requirements.
- Simple and low-cost installation
- Ease of maintenance and repair
- Versatile and non-polluting
- Energy efficient, as 100% of the heat generated is within the solution.

26.3 Radiant Tubes

Radiant tubes are seamless tubes that are made up of heat-resistant materials like iron-chromium-aluminium alloys, nickel-based alloys, etc. They are widely used in the furnace. They can be designed straight (as shown in the figure), U-shaped, or W-shaped as per the required length. An electric heater is inserted into the radiant tube.

It prevents the heater from coming into direct contact with the furnace atmosphere. A radiant tube must have good mechanical properties at high temperatures. When power is supplied to the heater, heat is generated because of Joule's heating.

Fig:70 Radiant Tubes

This heat is transferred from the electric heater to the radiant tube by radiation, and then from the radiant tube to the material being heated. The material gets heated up by irradiation from the radiant tube. Radiant tube must be corrosion-resistant, leak-proof, and temperature-resistant. Some of the straight radiant tubes are shown in the figure. A bundle rod heater can be inserted in the radiant tube as shown in the figure. It can be used for temperatures up to 1400 °C.

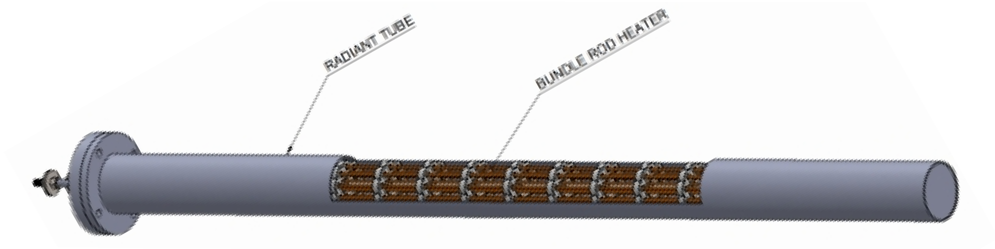


Fig:71 Bundle Rod Heater in Radiant Tube

Advantages

- Trouble free, long service life, and provides uninterrupted furnace operation.
- Cost effective solutions for maximized customer productivity and higher power output.
- Installation and replacement are relatively easy.

Applications

- Heat treatment furnaces (carburizing furnaces and galvanizing furnaces)
- Melting, dosing, and holding furnaces
- Dental furnaces
- Diffusion furnaces
- Laboratory furnace

26.4 Open Coil Heaters

Open-coil heaters consist of high-resistance wire, usually Nichrome or Mara FeCrAl, in the form of a coil, as shown in figure. These coil heaters are fixed to some supports. Open coil heaters heat up the medium directly. Heat is generated when power is supplied to the heating coil, which is then transferred to the medium, such as air, that needs to be heated. Since the medium is heated directly from the coil, heating efficiency is high.

Fig:72 Open Coil Heater [1]

Fig:73 Open Coil Heater [2]

Technical Specifications

Options:	
Wire	Nichrome or Mara FeCrAl
Rating	4 - 20 kW
Watt Density	Up to 3W/cm²
Operating Temperature	Up to 1100 °C
Length	Customized
Outside diameters	Customized
Voltage	240 or 480V AC
Controls	SSR/ SCR/ Relays/ RTD
Terminations	Customized

Typical Applications

- Plastic injection moulding nozzles
- Semiconductor manufacturing and wafer processing
- Hot metal forming dies and punches
- Sealing and cutting bars
- Medical, analytical, and scientific instruments
- Restaurant and food processing equipment
- Cast-in heaters
- Laminating and printing presses
- Air heating
- Textile manufacturing

26.5 Mineral Insulated Heater Cables

The MI heater consists of 3 parts: the heating wire, insulation, and outer sheath, as shown in the figure. Heating wire is made up of Nichrome 80/20, Inconel 600, Inconel 800, etc., as per the requirement.

A solid MgO core is used as the insulation between the heating wire and metal sheath. There are holes in this core where the heating wire can be inserted. The heating wire can be straight or helically coiled. If the internal temperature in MI has to be measured, then a thermocouple can be inserted in another hole. So the number of holes to be drilled in the core depends on the number of conductors to be inserted and the thermocouple wire.

This solid MgO bead is surrounded by a tube called the outer sheath. The outer sheath is made up of metal like stainless steel or Inconel, depending on the requirement and application.

Manufacturing of MI:

The heating wire is fitted inside the hole of the core or bead, and this conductor bead assembly is inserted into the tube. Then this assembly is drawn using a suitable die in a drawing operation. In this drawing operation, the compactness of the insulation increases. due to which pore size reduces and compactness increases. As a result, effective thermal conductivity & dielectric strength increases. If the diameter needs to be reduced further, it is annealed prior to the next drawing. After annealing, the material softens, making it easier to draw it to a smaller diameter. The cycle of drawing and annealing is repeated until the required diameter is achieved. Highly compacted MgO ensures rapid heat transfer from the heating element to the outer sheath, as well as high dielectric strength to limit the leakage current to the sheath. MI cable is cleaned before dispatch once the required diameter is obtained.

MI heating cables are used where high wattage is required.

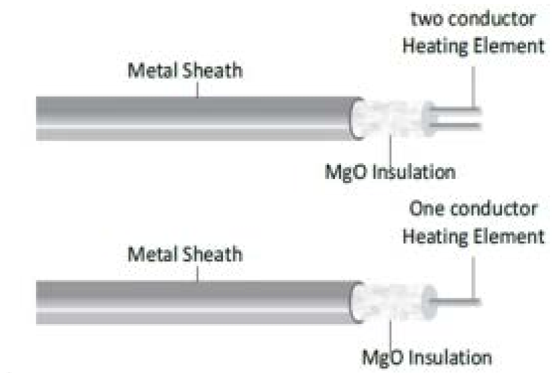


Fig:74 Mineral Insulated Heater Element

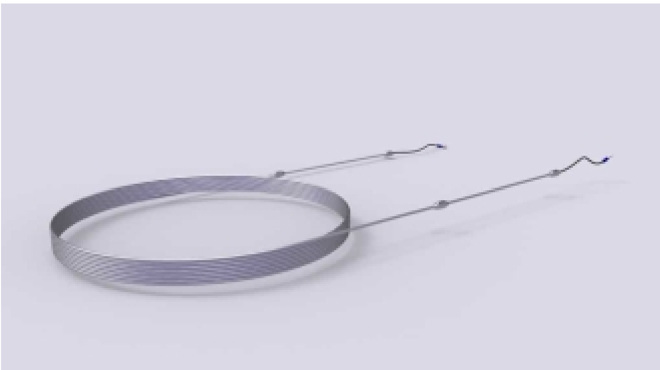


Fig:75 Mineral Insulated Heater Cable

They include a heating section and a non-heating cold lead section. They are supplied in fixed lengths, so determining and ordering the correct cable length is essential. The cold lead cable is connected to a junction box, which is connected to the power supply.

Advantages of MI cables are:

- High power output due to the perfect thermal conductivity of the metallic sheath.
- Reduced size due to the high dielectric strength of the magnesium oxide while maintaining good thermal conductivity.
- Easy installation due to its reduced size and annealed state of the outer sheath.
- High flexibility during the design phase is due to the wide range of available resistances.
- Cable sets have been factory assembled and are ready for installation.
- A fully annealed sheath allows field bending.
- Corrosion-resistant sheath

26.6 Infrared Radiant Heaters

These heaters are specially designed to heat the workload with infrared radiation. A special coating with a higher emissivity is applied to the heating element. By applying a coating, the radiation heat transfer increases because of the increase in emissivity. The heating element is in the form of flat strips of a certain length, as shown in the figure. The insulation is provided between the heating strip and bottom plate, which prevents heat loss to the other side. Generally, glass wool insulation of superior quality is provided. The bottom plate is used to hold the heating strip and insulation with the help of an allen bolt. It also gives strength to the heater. The maximum amount of radiation should be absorbed by the workload. To achieve this, the view factor between the heater and the workload should be close to 1. The power is supplied by the two legs. Infrared heaters are widely used in the glass industry.

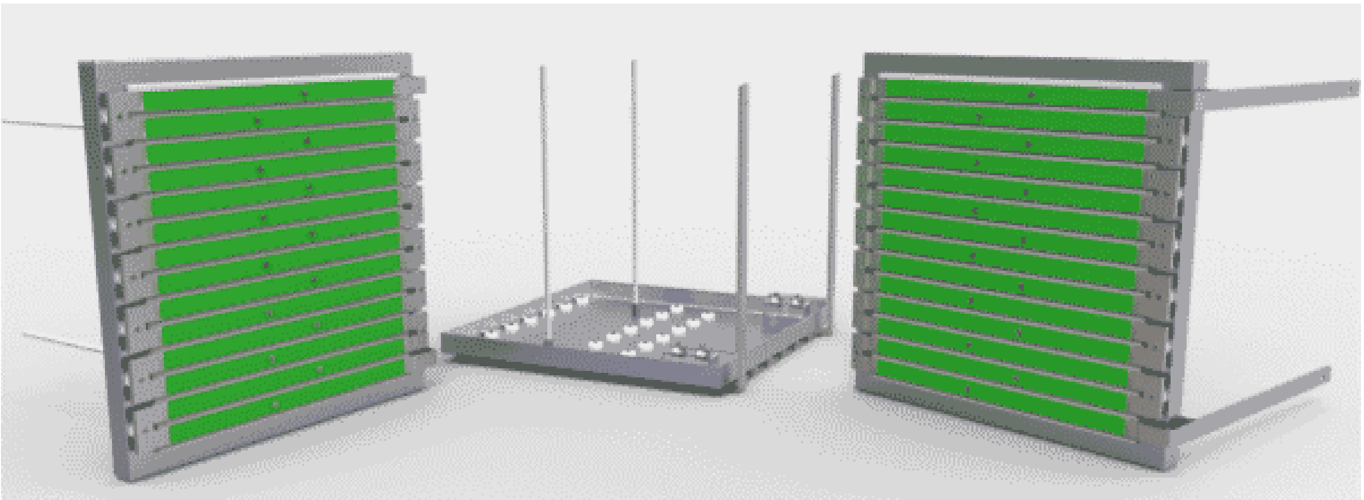


Fig:76 Infrared Radiant Heater

How to Calculate Heat Transfer Rate by Infrared Radiant Heater

Let heat be transferred from the heater (1) to the workload (2) with no heat loss to the surrounding medium.

It is the case when two surfaces are involved in radiation heat transfer, i.e., surface 1 and surface 2. Surface 1 is the heater surface, and surface 2 is the workload surface.

The radiation network is shown in the figure:

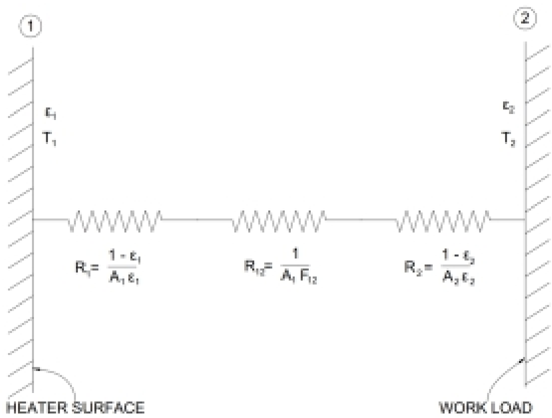


Fig:77 Radiation Network

There are two types of resistance: Surface Resistance & Space Resistance. R_1 & R_2 are surface resistance and R_{12} is space resistance. These resistances are in series.

$$Q_{rad} = \frac{\sigma \times (T_1^4 - T_2^4)}{\frac{1-\varepsilon_1}{A_1\varepsilon_1} + \frac{1}{A_1 F_{12}} + \frac{1-\varepsilon_2}{A_2\varepsilon_2}}$$

Applications

- Floating glass heating
- Movable mould preheating
- Industrial applications with medium-intensity infrared heat include paint spraying, booths, curing, drying, and softening resins

26.7 Edge Wound Heaters

This is used as the furnace heater. In an edge-wound heater, the heating elements are in the form of circular flat strips, as shown in figure 78. These strips are made up of high-resistance elements like Nichrome 80/20. The circular strips are wound in the clearance made in the ceramic spacer, as shown in figure 78 & 79. The heating elements are not in the form of rods, as in the case of a bundle rod heater. Since the heating elements are flat, having a rectangular cross-sectional area, they have more heat transfer area than a rod heating element, so the skin temperature reduces. In other words, for the same available area, an edge wound heater can provide more power than a bundle rod heater. When high power is required in a limited space, an edge-wound heater is the perfect choice.

Fig:78 Ceramic Spacer (left) & Circular flat Heating Element (right) [1]

Fig:79 Ceramic Spacer & Circular flat Heating Element [2]

The edge-wound heater can be used either alone or with a radiant tube. An edge-wound heater with a radiant tube is shown in the figure 81:

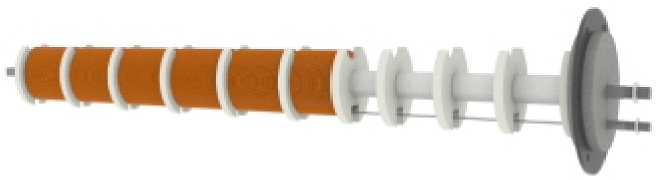


Fig:80 Edge Wound Heater

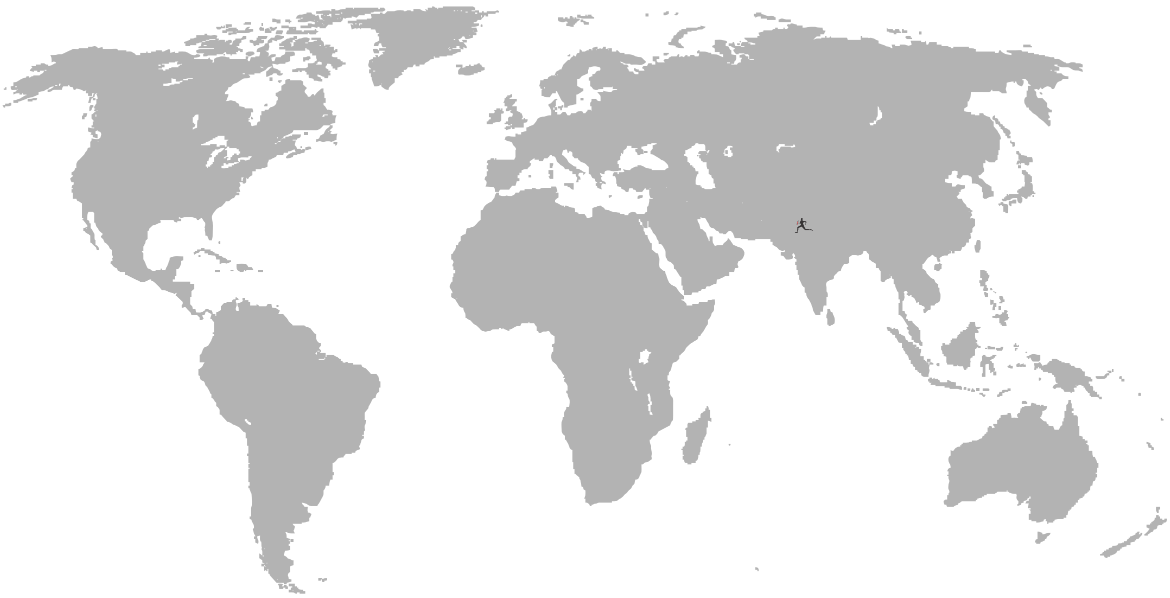
Fig:81 Edge Wound Heater in Radiant Tube

Technical Specifications

Heating Element Material	NiCr alloy (80/20 or 70/30)
Wattage	65 kW
Max. Temperature	1950 F (1050˚C)
Length	Customized

Features and Benefits

- Higher power density
- Easy to install, replace, and install
- Long service life at all temperatures
- Horizontal or vertical mounting
- Repairable to extend service life



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