Energy Efficiency and Conservation Authority
Te Tari Tiaki Pūngao

Technical Information Document

Indirect Electric Resistance Process Heating

Conduction, Convection & Radiation Electric Heaters

Technical Information Document 2019

New Zealand Government

Introduction

Indirect heating methods involve heating a medium (usually air) that surrounds or is adjacent to a product requiring heating. A domestic oven is a good example of an indirect heating method.

Direct heating methods, such as infra-red or microwave radiation, ohmic resistance or induction heating use a radiant or field-based energy source to generate heat in the product directly, without heating the air in between. Direct electric heating systems often offer higher efficiencies for applications at lower temperatures. However, indirect heaters provide more design flexibility and are a better fit with high temperature and high-pressure applications.

This information sheet focuses on indirect heating for medium and high temperature applications and outlines the key geometries of indirect heaters, their performance and application.

Most indirect heaters consist of electric elements surrounded by refractory materials and insulation generally formed to suit the medium being heated. High efficiency in indirect heaters is achieved by having a close fit between the heater and the product (see Figure 1).

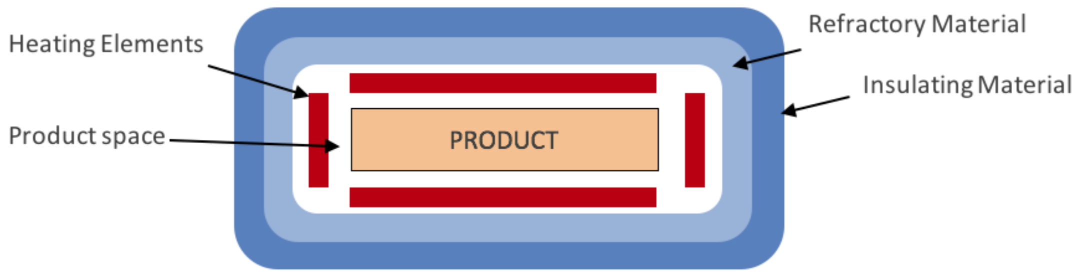

Figure 1. Elements and insulation in relation to product

EECA commissioned Strata Energy Consulting and Efficient Energy International to produce this document which is one of a series on electrical heating.

Technical features

Heat Transfer dynamics

Electrical current passes through an element to heat it. The heat at the element's surface is transferred through the medium surrounding the element (e.g. air) which is then transferred to the product by either, or a combination of, conduction, convection, and radiation.

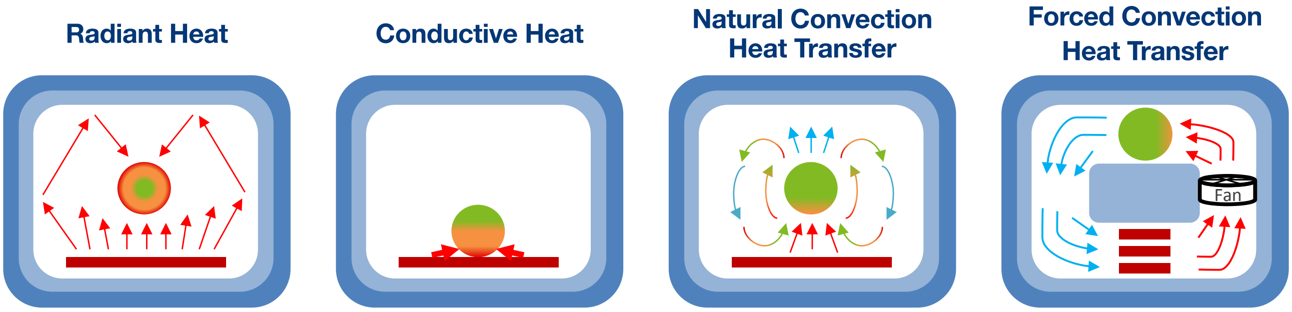

Figure 2. Conductive, Radiative and Convective heat transfer

Conduction

Is the transfer of heat through direct contact between the product and the element. The energy efficiency of conduction heating depends on the quality of the surface contact between the element and the product.

Convection

This is the circular movement of a heated medium (such as air or liquid) from the hot resistance elements to the product and back. Convection can occur naturally as hot liquids and gases rise, but it can also be forced by a mechanical fan, mixer or turbine, which is an ideal option for low temperature applications.

Radiant heat transfer

Most energy is transferred radiantly (as infra-red radiation) at temperatures of over 500°C (*see figure 3 below*). Efficiency and safety can be increased by using a low emissivity (reflective) surface to contain the chamber and reduce radiant heat loss.

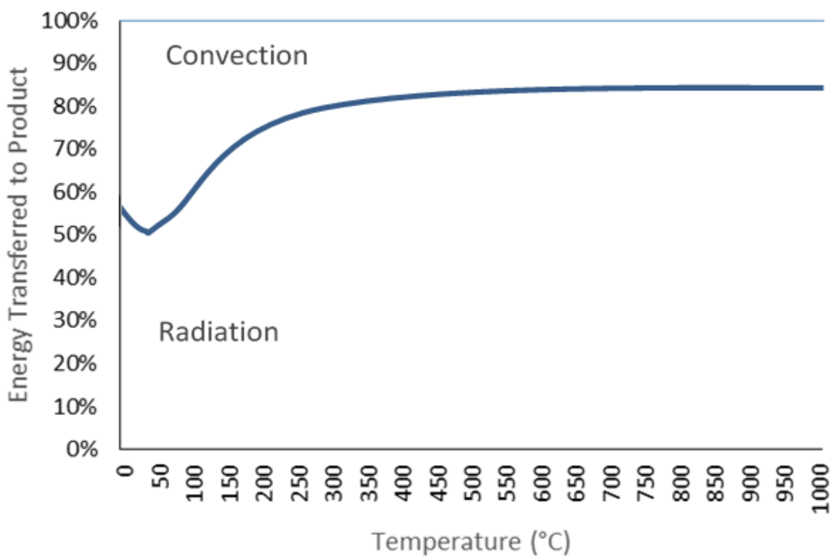

Figure 3. Convection and Radiation heat transfer relative to temperature

To optimise costs and maximise energy efficiency, a resistance heater should be designed to suit the specific needs of the application.

Design Features

For example consideration should be given to:

1. The type of elements

Heating elements should reflect the intended purpose, such as maximum required temperature, resistance to corrosion, frequency of heating-cooling cycles.

Type of Element	Example	Max Temp	Notes
Nickel Chromium Alloys	Nichrome, Chromel Kanthal, Iconel	1300°C	Lifespan is reduced by constant max temperature operation and rapid heating and cooling
Rare Earth Element Alloys	Molybdenum disilicide, Zirconia Graphite, Lanthanum chromite	1800°C	Longest lifespan when kept at 600°C, reduced lifespans when frequently cooled to room temperature

2. Precision Controls

Achieving accurate control of electric heaters is key to higher product quality and minimising costs. To achieve this, digital temperature controllers can be used to provide precise control of heating and cooling rates with instant operator or automatic feedback, analysis tools and diagnostics.

Variable functions can be programmed into the controllers. For example, such temperature adjustments can be pre-set to take advantage of time-of-use electricity prices or to avoid increasing peak time demand charges.

3. Power density

This is the rate at which the product is heated. Different factors will affect the product's maximum power density limit, such as its concentration, its starting temperature, its movement speed, and its physical and chemical properties.

Slow heating rates are important for products like oils (which can coke or carbonize) or in applications that heat products to near boiling (as vapour has a lower heat transfer rate). Power density should be kept as low as possible in corrosive applications to minimise the chance of damage to elements.

Consulting element suppliers and, if necessary, trialling elements with the product will be the best way to ensure a satisfactory design.

4. Shape of the resistance elements.

The choice of element shape will determine the heat distribution and affect the product heating rate. A heater that fits the shape of a product will produce faster, more uniform and efficient heating.

Most elements are made with resistance wire formed into linear or coiled structures, but solid, liquid, granular, sectional, ceramic or moulded elements can also be used.

5. Heat application

How heat is directed to the product will have a material impact on the efficiency of the heating process. Consider continuous flow mechanisms, such as conveyor belts or pipes which can control the speed of the product moving through the heater, or ovens with controllable heating and cooling rates.

6. Product handling

Cost, energy efficiency and element longevity can be increased by minimising frequent element cooling and re-heating. This may be achieved by reducing product handling requirements or by installing flow mechanisms to transport the product through the heater.

7. Heater shape and mobility

The shape of the heating space can have a large effect on heating rates and efficiencies. Typical shapes include plates, wells, crucibles, tunnels, elevators, drums and bells.

Modern process operations may require a level of mobility, so fixed or movable equipment options should be considered.

Examples of indirect resistance heaters

Radiative Electric Heaters

Furnaces & Kilns

These typically have high temperature elements fixed into grooves in the inside surface of a chamber that is lined with insulation refractory material.

Figure 4. Spiral elements embedded in kiln insulation
Source: http://www.argusheating.co.nz/kiln-spiral-elements-kiln-coil-elements

Convection resistance heaters

These heat air or fluid as it flows through the system and can be augmented with fans to increase heat transfer and flow rates.

A minimum of 1m/s face velocity is recommended for fan forced flow rates in air duct heaters.

When there is insufficient air flow, the coils in the heater can overheat. Fan forced systems should also be paired with a filter to keep the heater bank clean.

Immersion Water Heaters

These are typically a 8 mm to 10 mm diameter element consisting of an external sheath and an internal heating element. They are designed to be immersed in a gas or fluid to heat it from within.

These robust elements cope with demanding heating conditions, offer long-life reliability and can be used in pressure vessels.

For more detailed information on water heaters, see the Technical Information Sheet covering Electrode Boilers.

Conduction heaters

Conduction heaters are designed for close contact heating and need to be tightly clamped to the product. Air gaps between the heater and product reduce efficiency and heater lifespan.

Strip heaters, Band heaters and Drum heating Jackets

These are heating elements embedded in ceramic, insulating sleeve or sheath that can be clamped or bolted onto solid surfaces. Strip material, shape and size can be designed for specific applications.

They are tightened using clamps to ensure a high efficiency heat transfer, typically up to 9 W per cm^2. They can be easily removed for maintenance and access. Sizes range from 25 mm to over 800 mm in diameter and over 200 mm in length. Thermocouples may be included to provide accurate tracking of product heating.

Figure 5. Band heaters
Source: http://www.argusheating.co.nz/metal-band-drum-heaters

Ceramic Band heaters are high temperature versions of band heaters that can operate at up to 700°C with similar heating rates but are thicker as they contain ceramic elements.

Drum heating jackets are larger and offer controllable temperatures generally limited to below 90°C, but higher temperature versions are available that can reach up to 200°C.

Foil heaters, heat tracing cables and flexible silicone heaters

These have elements encased in a flexible pad or cable and can be attached with double sided adhesive tape or mechanical fastenings to irregularly shaped surfaces.

Heat tracing elements are fitted to the outside of pipes and run along the length of the pipe providing consistent heating.

PTFE (Teflon) insulation is used for high power applications while silicone is used for medium power applications up to 50 W/m, and PVC insulation is used for low power applications up to 10 W/m.

Benefits

Lower energy consumption

Resistance heater elements can easily be installed where heat is needed. Sources of heat loss through exhaust, ventilation and intermediary objects that also require heating are minimised or removed from the system entirely.

Efficient

Around 95% of the electrical energy is transferred into heating the product. Modern control systems can optimise power use and minimise overall energy consumption.

Low space requirements

Systems that use resistance heaters are smaller than systems that burn fuels and can be located at the point of use reducing or removing the need for a separate heat distribution system.

Emissions free

An electric furnace or heater does not give off the dangerous emissions that fossil fuel burners do, making them safer and more environmentally friendly.

Low cost and maintenance

Electric furnaces are among the cheapest furnaces to purchase and install. They also require less maintenance than fossil fuel furnaces.

Controllable

The accuracy with which the temperature of electric resistance heaters can be controlled makes them ideal for applications where specific temperatures are required. The high precision afforded by this level of control can provide significant product improvements.

Challenges

Energy costs

The running costs of electric heaters are composed almost entirely of the cost of input energy, which can be higher than the equivalent kWh cost of other fuels.

Inefficient in large spaces

Electric resistance heating is an inefficient solution for heating large commercial spaces. Heat pumps and infra-red heating offer high efficiencies in large low-temperature applications.

Network capacity requirements

Additional capacity may be required on the network to support resistance heaters with larger power consumption requirements, potentially increasing installation costs.

Manufacturers, suppliers and installers of electric heaters

Electric heaters are common in many applications, in New Zealand they tend to be used for small-scale applications and have yet to expand into process heat applications.

Immersion elements are available in corrosion resistant alloys and stainless steel.

Individual elements can be installed in groups of three to utilise 3 phase power and can supply several hundred kW of capacity with power densities up to 5kW per meter of element length.

New Zealand Suppliers

Avon Electric
http://www.cn-heating.com/products/induction-heating-furnace/

Argus Heating Ltd
http://argusheating.co.nz

BJC Elements
http://www.bjcelements.co.nz

Hislop & Barley
http://heatingelements.co.nz

Homershams
https://www.homershams.co.nz

Techspan
https://www.techspan.co.nz

International suppliers

Caloritech
http://www.caloritech.com/elements-specialty-heaters

Chromalox
http://www.chromalox.com

HQ Heating SDN. BHD.ltd
http://www.hqheating.com

NPH National Plastic Heater
https://www.nph-processheaters.com

Tempco
https://www.tempco.com

Wattco
https://www.wattco.com

Application notes

Indirect resistance heater range

Cartridge heaters

Provide localised heat in areas of restricted space and closely controlled process temperatures up to 750°C. Dyes and platens are efficiently heated using this technology.

Cartridge heaters are available in NZ from $44 per 400 W unit to $130 for a 1000 W unit

Immersion heaters and boiler

Applications include heating air, water heating, steam generation, ovens, platens, defrost elements in refrigerators, evaporators, load resistors and in oil heating.

Immersion heaters up to 6 kW are available in NZ

Electric furnace

Applications include heat treatment, ceramics, pottery kilns & glass furnaces up to 1400°C, high temperature ovens, metal melting, annealing and heat treatment furnaces.

High temperature duct heaters can operate up to 650°C while delivering power density as high as 140 W/m^2. Lower power designs between 40 and 70 W/m^2 are also available.

Band heater

Applications include plastic extrusion, injection moulding, blow moulding, pipe or tank heaters, fluidised bed heaters, food industry container heaters, pharmaceutical industry, processing equipment heaters.

Foil heater

Applications include heating inside bulk containers and tanks, pipes containing fats and oils, chemical containers, honey melting vats, propagation trays, food tray warmers, butter conditioners, incubators, and as panel heaters.

Heat tracing

Applications include offsetting heat loss in transport pipes, preventing condensation, door heaters in cool stores or freezers for preventing ice build-up or for de-icing, underfloor heating, frost protection for drains, heated towel rails, or for custom shaped heaters.

Indirect resistance heater applications

Metallurgical, mechanical and electrical industries

Applications include heat treatment, galvanising, metal forming, enamel baking and manufacturing silicon computer components such as semiconductors.

Ceramic Products

Applications are suitable for heating industrial materials like tiles, bricks, insulation and refractory material, and for domestic materials, like pottery or porcelain.

The small size and precise temperature control of an electric element offers significant advantages in heating ceramics that require stringent thermal cycles and temperature precision.

Glass products

Indirect heating is sometimes used in glass manufacturing, such as in mechanical glass making machines during glass blowing heat treating.

Baking and food preparation

Examples of applications include chamber ovens, rotary hearth trolley ovens, continuous ovens and procedures requiring temperatures between 100°C and 300°C such as baking of breads, pastries, biscuits, drying products and cooking hot meals.

Food Service

Electric food service heaters improve the operation, consistency, and reliability of food quality through lower operating and maintenance costs.

Applications include quick serve electric fryers, rotisseries, combi and convection ovens, thermal solutions for grills, griddles and toasters, tubular heaters used in sandwich and panini griddles, and dishwashing where electric tubular heaters heat only the water required.

Packaging

Electric heating can provide high levels of cleanliness and quality in packaging processes with good control of packing quality.

Petrochemicals

Many heating operations are undertaken in primary and secondary processing of oil products, where precise temperature control is important for product yield and quality. Electric process heating technologies can supply many of the process heat needs and improve temperature management.

Other applications

The variability, control, portability, safety and efficiency of heating using resistance heaters also makes them ideal for applications in laboratories and pharmaceuticals, for preparation of powders, pellets, dried plants and sterilisation operations. In the wood industry, they can be used for drying, and in the plastics industry for forming and drying.

Design of electric process heater systems

Because there is no requirement for combustion space, fuel/ash handling equipment, or central steam distribution systems, electric process heaters can compete on cost where end-uses have intermittent heating demand, small spaces and require high temperature quality control.

Step 1

Establish an accurate picture of your end-use process heat demand.

What temperatures and heat rates do you need? When, and for how long?

- What are the current marginal and long run costs of operating the existing heat system?
- What is the remaining economic life of the existing system?
- Can the system be rationalised? Can high temperature heat demand be separated from lower temperature heat demand and does this create opportunities to use heat pumps?
- If the end-use temperatures are below 60OC, could they be met by infra-red heaters or high temperature heat pumps instead? These options offer lower energy costs and higher efficiency heat production.

Step 2

Determine the load profile and capacity required by the electric heater and compare this to your energy costs and tariffs.

- Does this fit with available electrical capacity on the site?
- Will the heater operate at peak electric demand times, or can it be managed effectively to avoid them? Use the same measurement / metering time frames as your electricity tariffs to estimate the cost of installing and connecting the electric heaters.

Step 3

Identify and evaluate all opportunities to minimise heat losses and process inefficiencies and the economics of alternative heating options.

- Explore options to spread heating loads.
- Explore whether smaller distributed heaters are better than a central system.
- Explore options to recycle or reclaim heat.
- Explore options to change from steam to other direct or indirect process heat modes.

Step 4

If electric heaters make economic sense, identify suitable heater options, establish capital, installation and transaction costs, and establish the net present value of change using a life cycle cost-benefit analysis.

Work out if you should install the heaters to operate in parallel to existing heat sources as this may minimise transaction costs, improve system resilience, and allow peak load reductions.

Indicative Costs

Capital investment costs

Indirect resistance furnace, oven and heater design is almost infinitely variable to suit specific applications. This makes providing indicative price guides very difficult. In table 2 indicative costs for resistance heater elements have been provided. The capital cost of equipment will also need to include framework, refractory material, insulation, product handling equipment and the electrical installation and control gear.

Cartridge Heaters		Heat Bands		Air heating elements	
Power (W)	**Cost**	**Power (W)**	**Cost**	**Power (W)**	**Cost**
200	55	85	100	1,550	80
600	65	200	100	2,000	116
1,000	75	300	115	3,300	130
1,500	85	350	120	10,000	423

	Average Unit Price NZD 2018	Average Fuel Price NZD 2018 per kWh
Gas	3,360	0.03 - 0.06
Oil	7,900	0.05 to 0.1
Electric	2,660	0.11 - 0.25

All costs are indicative for element purchase only and exclude GST.

Real costs will vary with element dimensions, shapes and the degree of customisation required.

Fuel costs are estimated using average costs and conversion factors at the time of writing. They do not account for heat losses, and unit costs will vary based on installation, supplier and time.

Table 2. Indicative resistance heater element costs

Operating costs

Maintenance costs for electric indirect resistance equipment is relatively low. Occasional replacement of elements will be needed and, in the longer-term refractory linings and insulation may need replacement. As there are no burners of flues, maintenance costs for electric equipment will be much lower than for gas and other fossil fuel fired heating options.

Because the purchase cost for electricity is higher than gas the higher efficiency of electric indirect resistance heating options will need to be realised. Additional benefits such as improved temperature control, reduced ventilation losses and cleaner environment will also need to be considered.

In addition, electric indirect resistance heating will not directly produce any greenhouse gas (GHG) emissions, however, some of the electricity consumed may have been generated from non-renewable sources that produce greenhouse gases. Because the proportion of non-renewable generation in New Zealand is low, the GHG impact of indirect resistance heating will be much lower than for gas or other fossil fuel options.

Climate change gas rule of thumb comparison:

Electricity

CO_2 = kWh consumed x 0.1

For every 100 kWh of electricity used 10 kg of CO_2 is emitted

Gas

CO_2 = kWh of gas consumed x 0.216

For every 100 kWh of gas used 21 kg of CO_2 is emitted

In summary, electric indirect resistance heating is extremely flexible, has low capital cost and has several additional benefits to fossil fuelled heating options. Operating costs for electricity may be higher than for gas but other quantifiable benefits may improve the business case for investment in favour of the electric option. Because electricity emits approximately half the CO_2 of gas combustion, efficient electricity applications can reduce CO_2 emissions by more than 60%.

Remember, each potential indirect resistance application will have specific operating conditions, operational efficiency opportunities and duty cycles. Because of this, capital and operating costs, and the potential benefits, will vary considerably.

Case studies

Case Study: Improved electric preheater design

Pre-heating combustion gases improves combustion efficiency but can be challenging when a small footprint (250x25x25 mm) business operating in a harsh environment demands high thermal efficiency and low maintenance. Heaters needed to be replaced often due to exposure to corrosive materials and high power densities. The gas needed to be pre-heated to 300°C within a 10 minute ramp up time. The gas flow could not be exposed to any resistive material.

BCE SuperCirc cartridge heaters have a fin design that triples the heated surface area within the prescribed electrical and dimensional specifications. This decreased the power density from 5.6 W/cm2 to 2.2W/cm2, reducing surface temperatures on the heater and increasing heater life. The new heater was able to ramp to 300°C in less than 10 minutes; its robust 316 stainless steel construction prevents degradation with exposure to harsh chemicals. An embedded thermocouple provides accurate temperature monitoring, and the heater body inlet and outlet fit effortlessly into the existing ports.

Source:
https://belilove.com/section_252_Case-Studies.cfm

Case study: High quality bottle drying

Bottles are used for packaging a headache remedy which requires absolute absence of moisture. When the factory-sterilised bottles are brought from storage in sealed cartons, they are sometimes cool and moist. All moisture needs to be removed and the bottles left slightly pre-heated. It was also desirable to put the whole drying process on a production line basis. Four batch-type ovens involving rather cumbersome and superfluous handling needed to be replaced.

Removal of the moisture from the bottles is done by forcing compressed air at 200° F., 65 lb. per square inch into them. The air is heated by four Chromalox model GCH circulation heaters. Moisture is also removed from the air by a dehumidifying unit and silica gel before it reaches the heaters. The bottles are now consistently, absolutely dry. A cumbersome batch process with excess handling has been replaced with a faster drying process done in one minute compared with the previous eleven minutes, and with a faster heat-up time and no overheating.

Source:
http://www.chromalox.com/en/global/case-studies/circulation-heaters-remove-moisture-from-bottles-before-filling

Case study: Circulating electric oil replaces direct fired fryer

A conventional direct fuel fired fryer, while economical in operating cost, had important drawbacks. An inability to control temperature accelerated fat breakdown and made it difficult to achieve product uniformity. Maintenance was a problem. It was replaced by a circulating electric oil heater to ensure clean oil and an efficient system for the deep frying of fish. The cooking oil is heated by a 350-kW Chromalox heat transfer system. This pre-engineered and pre-wired package requires only piping and wiring connections. Using non-flammable Therminol® as the heat transfer medium, it circulates the latter at temperatures ranging from 430 to 500°F through coils in the fryer.

The new system offers cleaner frying with a more uniform quality than the old method, which is very important in food processing. The temperature control is accurate and the heat transfer method distributes heat evenly throughout the oil so that it lasts longer and saves money.

The process is much safer with no open flame. Higher volume production has been achieved in less space turning out as much as 3,000 kilograms of fried fish per hour with far fewer maintenance problems.

Source:
http://www.chromalox.com/en/global/case-studies/5,000-lbs,-d-,-of-fish-fried-per-hour-with-help-of-heat-transfer-system

Case Study: Replacing central high temperature fluid heater with individual heaters.

A company's existing system for heating reactors and stills with high temperature oils was limited in temperature range and could be troublesome. A growing diversity of products required a greater degree of flexibility in temperature range than the hot-oil system could provide.

Because of the wide range of heating requirements, individual heat sources were chosen. For one 1,325 litre vacuum still, 18 kW of heating capacity now provides temperatures of 290°C.

Chromalox Type TMO Immersion Heaters operate in the bottom of the vented vessel jacket which contains the heat transfer medium. Using 30 kW, a 1750 litre sealed jacket reactor can obtain temperatures up to 325°C.

In some cases, particularly where vessels were equipped with steam coil or for glass lined equipment, it was not practical to insert heaters directly into the vessel or jacket. In these cases, the heat transfer medium was heated adjacent to the vessel and circulated by means of a sump-type centrifugal pump.

Improved plant versatility resulted from the individual stage heating capability and close control of temperature in each vessel. With low operating costs and economical installation, the electric heaters eliminated the need for a central heating system and offered faster heat up. Immersion heaters are standard and immediately available from stock.

Source:
http://www.chromalox.com/en/global/case-studies/immersion-heaters-provide-high-temperature-heating-flexibility-on-various-processing-vessels

Case study: Electric autoclave avoids fossil fuel.

A manufacturer of specialty synthetic fibres required a custom autoclave for a drying application. Rather than utilise more expensive fossil fuel, the new autoclave used nitrogen as the heat transfer medium via forced convection, with temperatures ranging between 200°C and 260° C in the system's base heat load. In addition, nine individual zones within the system each required its own temperature and power control loop for precision quality control.

Baseline heating of the nitrogen loop was provided by a Chromalox 35kW circulation heater. Chromalox Fintube tubular heating elements with INCOLOY sheaths were used to heat the autoclave interior. Individual loops within the system were heated by nine 5kW circulation heaters. Each of these loops is controlled by Chromalox MaxPac SCR power controllers, part of the autoclave's main control panel. The MaxPac power control panels allow precision control of each loop, which use high temperatures and low gas flow. A similar system was designed and retrofitted to an existing autoclave.

Fuel cost savings and precision quality control led to duplication of the system on an existing unit. The system is simpler to maintain and provides better control than a fossil fuel system.

Source:
http://www.chromalox.com/en/global/case-studies/heat-and-control-system-provides-precision-needed-for-quality-control