The authors explain why it is advisable to consider and specify the enclosure - the so-called 'hot box' - and the heating equipment as an interrelated system.

High temperature heating in hazardous areas

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The elements of an interrelated system provide an overview of key points to consider when specifying or building heating equipment for process instrumentation.

For instrumentation in chemical and petrochemical plants, and especially in sample conditioning systems for analysers, the maintenance of an elevated temperature is often essential in order to prevent the condensation and/or crystallisation of media.

Complete insulation of the measurement and analysis station is rarely possible due to the requirement for maintenance and calibration.

Some users create ad hoc solutions in the form of a 'hot air shower' where a fan (or compressed air) warms the local environment. These can be very energy-intensive and can be difficult to build for hazardous areas (and are not usually suitable for applications demanding closely regulated temperatures).

The optimal solution is a so-called 'hot box' consisting of an enclosure for the equipment in question, fitted with a heating element and controller. For best results when building a hot box, care needs to be taken with the design: choosing and considering the elements as an inter-related system, rather than simply assembling the box from a collection of discrete components.

Heaters for hazardous areas

Most media in chemical and petrochemical plants are explosive; consequently, heaters must be certified for use in hazardous areas according to the standards and laws of the country. Today, the rules that apply in most countries around the world are based on the IEC 60 079 standard, which has been developed from the European ATEX standard, EN 50 014 ff. Heaters for use in the USA and Canada must be certified according to different standards: NEC or CEC. Most African countries accept IEC or ATEX approvals. South Africa follows IEC standards, for mining applications. The certificates of imported equipment have to be formally re-certified by a local testing house. (According to the new ARP 0108 it is anticipated that re-certification will be also necessary for above-surface applications from July 2009.)

Regardless of what standards apply, explosionproof heaters are something of a paradox: they must heat to high temperatures, but they may not get hot. Surface temperatures may not exceed the temperature class. Internal temperatures may not exceed the rated material temperatures.

Fig. 1: A typical hot box - a well-insulated enclosure made from glass reinforced polyester with a smart conduction heater (behind substrate). In this case housing an analytical sample conditioning system built using a Parker Hannifin Intraflow SP76-compatible modular substrate.

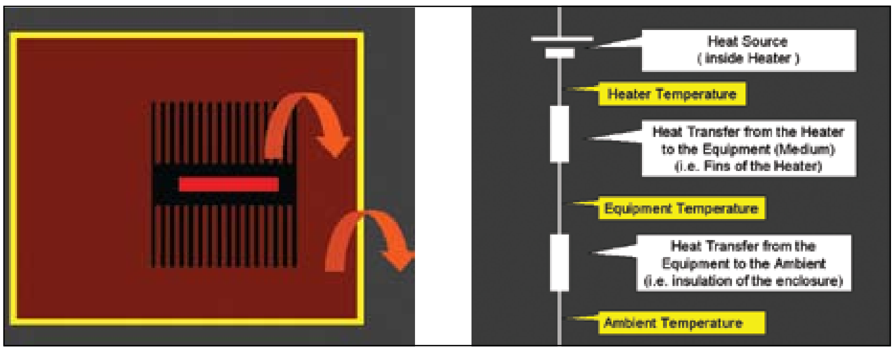

Fig. 2: Left: Thermal energy in a hot box flows from source through the space to be heated, and on to the ambient. Right: Thermal flow can be usefully considered as an electrical model, with a serial connection and two temperature drops - with the heat output divided as if by a potentiometer.

Fig. 3: Left: The sandwich construction principle using GRP sheeting and an insulation layer. Right: Typical finished hot box with 100 mm of PUR foam insulation, for use in extreme climates such as the Arctic.

With the exception of self-limiting heaters – which in practice are limited to low power applications - every explosion proof heater must be fitted with a temperature limiter that may not be reset. For safety, there is a margin between the temperature class and the switching temperature of the limiter, and there has to be a margin between the peak maximum temperature of the heater and the switching temperature.

If the heating system is not controlled well and/ or laid out appropriately (i.e. too much power at too low 'delta T' - the difference between heater temperature and temperature inside the cabinet), there is a risk that the heater's internal temperature limiter will switch and the heater fails and must be replaced. (It used to be the case that fusible links were field-replaceable, but the new ATEX rules demand that units are sealed and maintainable only at the factory.)

A little about the physics involved

With any heating process, there is a constant flow of thermal energy from the heat source to the room that shall be heated, and from there to the ambient (Fig. 2). In the steady state (constant temperature) flow rates are constant.

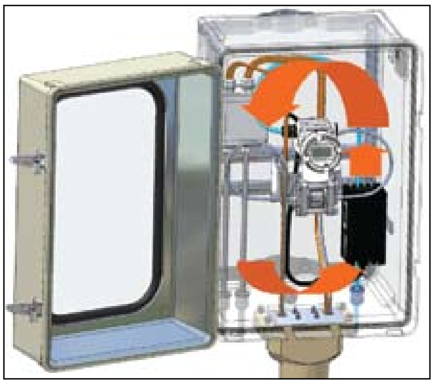

Fig. 4: Convection heating demands care over layout to aid the flow cycle, as in this transmitter enclosure.

The maximum temperature of the heater is determined by the temperature limit required, and the ambient temperature - which depends on the plant's location. The heater needs to be specified for the worst case (the minimum ambient temperature the plant will ever see). Thermal flow can be usefully considered as an electrical model, in a serial configuration with two temperature drops - with the heat output divided between them in the same way as a potentiometer divides a voltage. Equipment temperature (the temperature inside the enclosure) depends on the relation of:

- Heat transfer resistance between the heating element and the equipment that has to be maintained at temperature (usually the tubing and devices such as regulators that contain the medium),
- Heat transfer resistance between the equipment and the ambient (temperature of the air surrounding the enclosure).
- The heat transfer ratios are what matter. If the enclosure is well insulated (with no large heat losses) then the heater output needs only to be in a certain power range to make precise temperature control easy. Over-specifying the heater power can cause problems.

Enclosure insulation quality

Achieving a stable and well-managed thermal environment depends on a well-insulated enclosure with no large heat losses. The usual way of achieving this is to improve the insulation by adding a thick layer of material such as PUR foam ($\lambda \approx 0{,}02 – 0{,}05$ W/m°K). But, the better the insulation of the walls, the more important the effect of any heat sinks.

When designing a hot box, the construction materials and processes of an enclosure become very important. Steel enclosures (galvanized or stainless) ($\lambda \approx 15 – 50$ W/m°K) are made of materials with high thermal conductivity (up to 250 times higher than that of glass-reinforced polyester or GRP for example: $\lambda \approx 0{,}2$ W/m°K - of which more later). Any metal connection between outer and inner shell provides a thermal shortcut. And with metal constructions, it is almost impossible to avoid metal parts in some design elements (such as the door frame, door leaf, window, wall penetrations for cables and tubing etc.) because the stability of this type of housing is based on bent sheet metal, and insulation materials are typically soft.

An interesting solution to manufacturing enclosures without thermal sinks is a sandwich construction housing based on glass-reinforced polyester (GRP) sheeting surrounding an inner layer of insulation (Fig. 3). The use of long fibre reinforced GRP sheeting provides great structural strength, combined with high resistance to weather and the corrosive effects of aggressive chemicals. All

Programmable explosion-proof heaters

Compared with today's common approach of building explosion-proof heating systems from components such as trace heating cables, controllers, and terminations, Intertec's 'smart' programmable heaters provide a compact and versatile solution for the precise regulation of temperature inside enclosures. Approved for worldwide Zone 1 use, by IEC, ATEX, GOST and CSA, Intertec's smart heater consists of a heating element (conduction or convection) plus a networkable digital PID controller with encapsulated electronic circuitry. Dual temperature sensors (one intrinsically safe sensor that can be freely positioned in the enclosure or cabinet, another in the heater body) allow the system to control air temperature precisely while also ensuring safety in hazardous areas by limiting the heating element's maximum surface temperature to the required 'T' rating. The precision control allows smart heaters to control temperatures up to 150 °C.

Fig. 5: Sometimes a combination of conduction and convection heating is required.

the construction materials have a low thermal conductivity, and the sandwich construction means that enclosures can be made using bonding techniques, avoiding heat short cuts between inside and outside shells. The overall thermal insulation of GRP sandwich shelter is typically more than twice as good as a steel shelter with the same insulation thickness.

Choice of heating technique

Heat transfer efficiency from the heater to the equipment should be as good as possible. The choices available are conduction, convection, or a combination.

Conduction is a very effective heat transfer method. As air surrounds the equipment inside the enclosure, it acts as a good insulator. As a rule of thumb, conduction is roughly five times as effective as convection, so conduction is usually the preferred method if it is possible to use it. Conduction heaters have a flat surface for good heat transfer. Therefore the equipment to which they are fastened must have good flat surfaces for proper heat transfer. Other equipment gets its heat by conduction through the fittings and tubing. Fig.1 illustrates conduction heating, the block heater is attached to the rear of the substrate, the controller is at the bottom of the cabinet.

When positioning the conduction heating element(s) it is very important to get most heat to the equipment in the cabinet that acts as a heat sink, such as a regulator (which acts as a constant heat sink due to Guy-Lussac's law, because of the pressure drop in flowing media). For the effective heating of gas cylinders (i.e. sample probes) special conduction heaters with a cylindrical surface, called Cylindertherm, are available.

Often, the equipment that has to be heated has no flat surface, and is not suitable for conduction heating. Another problem can arise when a cabinet contains numerous items of equipment that need heating. In this case, the air

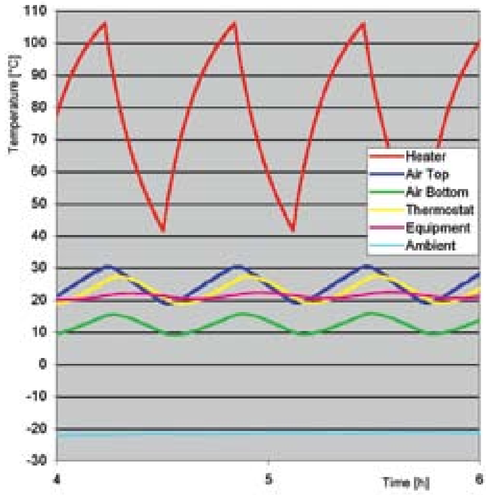

Fig. 6: A switching thermostat causes temperature oscillations.

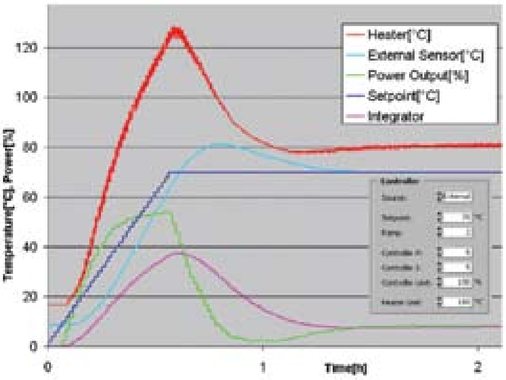

Fig. 7: Cold start up of a smart conduction heater with continuous action for the sample conditioning system seen in Fig. 1.

has to be used as the transport medium for heat.

Natural convection is powered by difference in density: hot air is lighter than cold air, and therefore floats upwards. Care needs to be taken when using convection heating, to position the convection heater for optimum performance (Fig. 4). Key factors include:

- Installing the heater below the critical equipment
- Aligning heater fins vertically to optimise the convection process
- Choosing a cabinet with enough space, and positioning the heater and equipment to aid air flow (leaving space below the heater, and a path for cooler air to descend).

Combining conduction and convection

In some situations, especially when equipment needs to be maintained at a temperature close to the level of the temperature limiter, it makes sense to combine both heating principles to provide an efficient heating cycle (Fig. 5).

Temperature control

The temperature difference between the heater temperature and the temperature inside the cabinet - known as delta T - is finite and limited. The higher the temperature that needs be maintained in the enclosure, the closer that temperature is to the shutdown limiter level, and in these situations the efficiency of the controller becomes very important.

Thermostats are commonly used as a temperature control mechanism for lower temperatures, and where precise temperature control is not required. However, the way they operate imposes limitations when control at higher temperatures is required (as it might be with difficult media in hazardous oil and gas, petrochemical or chemical processing areas such as artificial rubber or ethylene plants).

Fig. 6 illustrates this: the swinging operating action of the thermostat (the red line) 'eats' up the valuable delta T headroom, wasting some 60°C of the margin up to the temperature limit. The swinging action also causes the equipment temperature to oscillate around the ideal value.

Speaking generally, thermostats are adequate for controlling temperatures up to around 40°C. For higher temperature applications, a controller with a continuous action is the preferred solution. A 'smart heater' combines a PID controller with an electronic limiter for the heater temperature.

Fig. 7 illustrates the control precision of a smart heater. The PID control action keeps the temperature of the fluid and the metal equipment precisely at the setpoint temperature (the light blue line, which is controlled to $\pm$0,5°). Even more important than the accuracy is safe operation under all possible circumstances, in this case ensuring the reliable operation of an analyser.

However, as discussed, such precise control also relies on the overall efficiency of the other elements of the complete hot box system: a well-insulated enclosure without heat sinks, and a heater with good heat transfer. Considering these three elements - controller, enclosure and heat transfer - as an inter-related system will yield great benefits when specifying and building hot box systems for high temperature hazardous area applications.

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