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The use of induction heating in reaction apparatus small tonnage production

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Abstract. Currently, in the planning and further implementation of technological processes that require heating of products to operating temperatures of about 1300 C, the issue of selecting energy-efficient environmentally friendly reactors using various heating methods is an acute issue. This scientific article discusses the effective use of electric and non-electric heating methods. Recommendations on the practical application of these methods are given, based on the final product and the specific features of the technological cycle of a particular enterprise. The question of the compliance of both methods with modern international requirements for the small-tonnage chemistry devices under consideration is considered. On the example of the Scientific Production Association «Lakokraspokrytiye» the main advantages in the application of induction heating in reactors used in technological lines for the production of paints and varnishes and coatings are shown. Examples are given of devices that are currently being developed and implemented in the Scientific Production Association «Lakokraspokrytiye», their basic characteristics are described. The described small-tonnage chemistry devices are widely used in the Russian Federation, CIS countries and Eastern Europe.

Introduction

In modern conditions of industrial development and increasing prices for energy resources, one of the primary tasks of equipment design is the optimization of energy costs during the operation of industrial equipment. In the paint and varnish industry, the most energy-intensive equipment should be considered from the standpoint of optimizing energy consumption. The main methods for optimizing energy consumption for reactors with induction heating can be divided into two directions: structural (modernization of the ventilation system for purging the reactor shell, "stretching" the turns in the coil, i.e. winding each layer with a forced step) and automation (using modern measuring instruments, control and automation of the resin synthesis production process).

1 The problem of induction heating in reaction apparatus



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Currently, in the planning and further implementation of technological processes that require heating of products to operating temperatures of about 1300 °C, the issue of selecting energy-efficient environmentally friendly reactors using various heating methods is an acute issue. This scientific article discusses the effective use of electric and non-electric heating methods. Recommendations on the practical application of these methods are given, based on the final product and the specific features of the technological cycle of a particular enterprise. The question of the compliance of both methods with modern international requirements for the small-tonnage chemistry devices under consideration is considered. On the example of the Scientific Production Association «Lakokraspokrytiye» the main advantages in the application of induction heating in reactors used in technological lines for the production of paints and varnishes and coatings are shown. Examples are given of devices that are currently being developed and implemented in the Scientific Production Association «Lakokraspokrytiye», their basic characteristics are described. The described small-tonnage chemistry devices are widely used in the Russian Federation, CIS countries and Eastern Europe.

When carrying out technological processes associated with the need to heat chemical products to a temperature of 125-140 °C, it is necessary to make a decision on the choice of a method for heating a product located in a reaction apparatus (reactor) using electric and non-electric heating methods.

With the non-electric heating method, it is necessary to distinguish between devices with direct heating with an open flame and using intermediate heat carriers, which include flue gases, steam, hot water and high-temperature organic heat carriers, heated by heat obtained by burning gas, coal or fuel oil.

The direct use of an open flame has some disadvantages:

- uneven heating;
- large energy losses with exhaust gases;
- high capital costs;
- the need for preliminary heating of the linings due to their large thermal inertia;
- difficulty in adjusting the temperature regime;
- compliance with sanitary and hygienic and environmental requirements.

The use of intermediate coolants is effective only in cases where their heating occurs due to a more complete use of available energy resources, which include exhaust flue gases, steam or hot water from the cooling system.

2 The electrical types of heating apparatus

According to the method of converting electricity to heat and taking into account the nature of the transfer of heat to a heated apparatus, the following electrical types of apparatus heating are distinguished: indirect and direct (electrical) heating based on ohmic resistance and induction heating.

For indirect heating of resistance, tubular electric heaters (TEH) are used, made in the form of a wire, rod or tape made of special alloys (usually nichromes), which are distinguished by increased electrical, fire and explosion safety and are widely used in chemical industries. Indirect heating allows you to heat both the apparatus and intermediate heat transfer media directly. The disadvantage of indirect heating is a TEH small resource of work.

Direct heating involves passing an electric current through a heated metal product (wire, tape, pipe) using a step-down transformer. This method is very economical, since the heat is released directly in the heated object, and the equipment used is simple to implement. The disadvantages of a direct electric heater are the presence of electric potential on the equipment and the possibility of heating only certain types of apparatus, since the electrical resistance of the heated object must be higher than the resistance of the current leads to achieve a high efficiency.

In the apparatus with induction heating, the output to the working heating occurs directly in the wall of the reactor. Thus, when heated, only one temperature transition is overcome: between the wall of the apparatus and the product. The magnitude of the temperature difference depends primarily on the magnitude of the transmitted power and the heat transfer coefficient from the wall of the apparatus to

the product. Therefore, when using induction heating, a significantly higher specific heat load of the heating surface can be achieved with minimal heat loss. With a changing level of product loading, the induction heating power can change due to the sequential shutdown of the induction coils manually or in automatic mode.

When using induction heating in two or more stages of the technological process (for example, in the synthesis of alkyd resins), the process can easily be programmed with the necessary heating rates and temporary exposure times of the product at given points, which is quite difficult with other heating systems. Induction heating in comparison with other systems is inertia-free, which allows you to quickly and accurately adjust process parameters. Along with a sufficiently high efficiency, induction heating allows minimizing the need for production facilities and installing devices under a canopy in open areas. In addition, induction heating has high operational safety, a long service life, ease of maintenance, economy and environmental friendliness [1, 2].

3 The issue of cooling inductors

Due to the fact that the electrical resistivity and relative magnetic permeability of the material of the walls and bottom of the reactor (structural steel) depend on temperature (figure 1 and figure 2) [3], and electrical insulation is designed for a certain temperature, one of the main problems is the question cooling inductors.

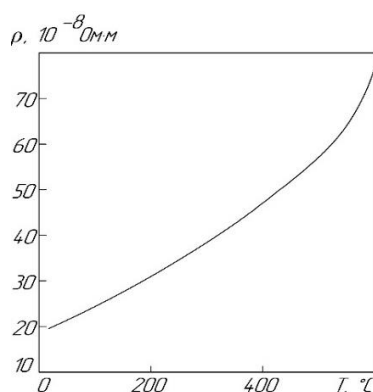


Figure 1. The dependence of the electrical resistivity ρ of structural steel on temperature T .

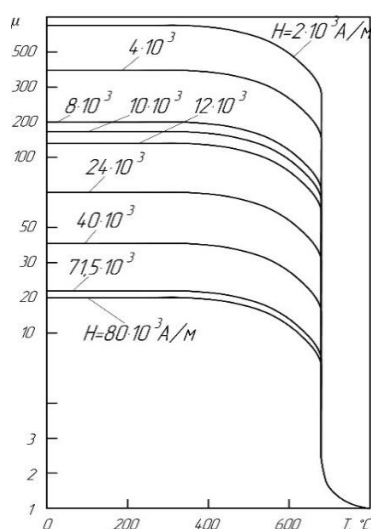


Figure 2. Dependence of the relative magnetic permeability μ of structural steel for various values of magnetic tension H on temperature T .

In practice, induction heating is widely used water cooling of inductors, and for large specific heating powers, also use forced (figure 3) [4] or natural air cooling, which simplifies the design and operation of the apparatus.

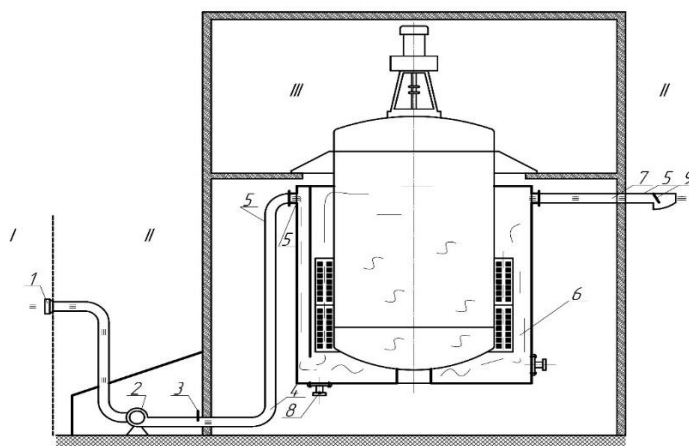


Figure 3. The scheme for providing the protective gas (air) of the inductor in the shell, blown under excess pressure, combined with the cooling circuit. (I - space in the non-explosive zone from which atmospheric air is taken for use as a protective gas; II - non-explosive zone; III - explosive zone. 1 - filter; 2 - fan supply of protective gas (air); 3 - shutter for regulating the amount of protective gas (air); 4 - inlet duct; 5 - fitting for connecting gauges for monitoring excess pressure in the shell of the inductor; 6 - inductor; 7 - exhaust duct; 8 - inductor input device).

Modernization of the ventilation system for purging the reactor shell (figure 4) [4, 5] using the latest heat and electrical insulation materials with high mechanical and thermal resistance in the structural elements of the inductor can reduce the power of the fans used. This leads to energy savings and reduced heat loss with the purged air.

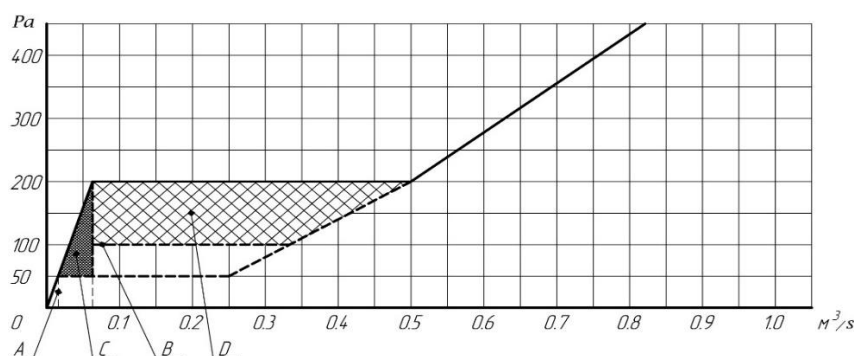


Figure 4. The dependence of the pressure of the protective gas (air) at the entrance to the shell in the shell of the inductor on its flow rate. (A - minimum permissible values of overpressure and flow rate of the protective gas (air) at which interlocks should operate; B - the minimum values of the overpressure and the flow rate of the protective gas (air) during normal operation of the inductor, taking into account the differential value of the overpressure control device; C - working area after modernization; D - working area before modernization).

In devices with induction heating, non-productive heat consumption is mainly associated with the flow rate of the shielded gas (air) blown through the casing to create explosion safety. These losses are estimated from 3.5 to 7.0% of the installed inductor power. For example, for a reactor with a capacity of 6.3 m³, they will amount to 16 kW/h in heating mode.

At the three largest paint and varnish factories (Yaroslavl PA Lakokraska, Lida PA Lakokraska and JSC Empils), the workshops were executed according to a single project and equipped with devices with

induction heating produced by the GDR. Initially, reactors with a capacity of 12 m³ had an installed power of 560 kW and a blowdown system based on a fan No. 6.3-7.5 kW, which was justified for the adopted design of the inductor. After replacing the impotent defective inductor with a domestic one with a closed magnetic system, the power decreased to 480 kW without deteriorating performance. For reactors of 6.3 m³, this figure changed from 310 to 240 kW. At the same time, it became possible to reduce the volume of air blown through the casings of the modernized inductors by 2 times. For example, at OOO Kraski KVIL, a fan No. 3 with a 1.5 kW motor is used for a 16 m³ reactor.

For induction-heated reactors, magnetic shielding of induction coils can provide significant economic benefits. Magnetic shielding reduces operating currents and Joule losses in each induction coil. The main purpose of the magnetic system is to localize electromagnetic energy in the boiler wall, eliminate the influence of adjacent phases on each other and, as a result, increase the electrical efficiency. and the natural power factor of the reactor as a whole.

The most important advantage of such magnetic shielding is the independence of the geometric dimensions and placement of the induction coils relative to the case, a sharp decrease in the air gap, the ability to comply with the "Electrical Installation Rules" and "Rules for the manufacture of explosion-proof and mine electrical equipment" in relation to the permissible minimum distances between the turns. "Stretching" the turns in the coil - winding each layer with a forced pitch ensures the following effects are achieved: allows you to make the coil removable, i.e. to reduce the repair time by more than 30 times, significantly reduce the cost of it, ensure the possibility of repairs without interrupting production, and also eliminate transportation costs; facilitates the working conditions of the insulation of each inductor and increases its operational reliability; improves heat dissipation during ventilation; reduces electrodynamic forces (shock loads when switching on and vibration during operation) by increasing the distance between the turns.

Automation of the production process also plays an important role in reducing energy costs. Depending on the requirements for a particular production, our enterprise has identified various economically justified directions in the automation of both the entire line and a single reactor. To classify these areas, we have introduced the concept of "Small automation" and "Integrated automation". Both automation options have a three-level structure: the lower level is the periphery (sensors, converters); middle level - hardware (for complex automation - these are controllers from SIEMENS of the S7-300 family, for small automation - this is a microprocessor-based measuring regulator from Aries); upper level - control and data input - SCADA (personal computer with installed SCADA visualization system GTI Procon).

The introduction of an automatic control system of each of the two types will ensure the achievement of the following goals: increasing the efficiency of the resin synthesis process control; archiving data and process history; setpoint control of the values of technological parameters and timely warning alarms, allowing to avoid emergency situations or to shutdown equipment as a result of triggering the emergency protection alarm; processing and analysis of information with subsequent optimization of operating modes; formation and issuance of reporting and archival documentation.

In addition, complex automation ensures the achievement of a number of additional goals: coordination of the operation of technological systems and coordination of the operation of all technological equipment; reducing the influence of the human factor in the preparation and decision-making.

Conclusion

Based on the experience gained, we proposed to introduce into the automation system, which maintains the blowdown parameters, the ability to change and regulate the temperature and flow rate of air outgoing from the casing during the modernization of reactors with induction heating. Optimization consists in choosing the specified parameters, determining various options for their influence on each other, outputting these parameters to a personal computer for monitoring the process and the possibility of developing an individual program for controlling the process or its individual stages.

Correct optimization of energy losses guarantees their reduction by 50%. To determine the readiness of the product, graphs of the dependence of the degree of readiness on viscosity, acidity and electrical conductivity are used.

Chemical apparatuses with induction heating with a capacity from 1.0 to 12.5 m³ that are being developed and manufactured by Scientific Production Association «Lakokraspokrytiye» fully meet modern requirements. These devices are made of stainless steel, equipped with mixers and coils for cooling or preheating the reaction mass. The use of domestic reactors with induction heating made it possible to completely abandon the purchase of similar equipment abroad, and the re-equipment of existing imported apparatus eliminated the cost of acquiring spare parts. Long-term operation in an industrial environment showed that the technical solutions made it possible to develop devices that were not inferior in their characteristics to Siemens (Germany), but even surpassed them in some respects. The use of a number of technical solutions protected by copyright certificates has made it possible to increase the efficiency, durability, safety of operation of the reactors, reduce the duration and improve the quality of repair work. Equally important are the use of high-quality materials, operational control, the use of specially designed equipment, acceptance tests at a special stand with certified devices, and highly qualified designers and manufacturers.

It should be noted that the explosion safety of the reactor is ensured by connecting induction coils to power cables through a cable entry placed in a casing blown with protective gas (air) under excessive pressure through an open ventilation cycle, as a result of which access to the casing of combustible gases and vapors and the formation of explosive mixtures there with by air. The inductor casing has a degree of protection IP54 according to GOST 14254-80.

The purge of the inductor casing is carried out using fans. Two fans are installed in the system, one of which is redundant, automatically turning on when the excess static pressure in the inductor shell decreases, as well as air ducts within the explosive zone below 50 Pa.

During the operation of devices with induction heating, there were no stops due to breakdowns of the inductor. These devices are used not only in Russia, but also in countries such as Ukraine, Belarus, Poland, Latvia. Since the beginning of the development of production, more than 500 devices of this type have been manufactured and implemented.

Currently, based on original developments, apparatuses with a wall temperature of up to 500 °C are manufactured instead of the usual 300 (for example, evaporators made of cast iron with a wall thickness of 75 mm for the production of resorcinol). The accumulated experience allows us to design and manufacture inductors for devices from various materials and ferrous metal, clad and enameled containers with a volume of up to 32 m³.

All designs of inductors according to individual customer requirements are developed and have a great advantage over foreign ones - the ability to mount and dismantle on site without the use of hot work. Devices with induction heating are environmentally friendly and do not have electromagnetic radiation outside the protective casing, even if it is partially destroyed.

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