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**Vitreous and porcelain enamels —  
Regenerative, enamelled and packed  
panels for air-gas and gas-gas heat  
exchangers — Specifications**

*Émaux vitrifiés — Échangeurs thermiques pour réchauffeurs air-  
gaz et gaz-gaz à empilement de panneaux émaillés remplaçables et  
démontables — Spécifications*

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 107, *Metallic and other inorganic coatings*.

This second edition cancels and replaces the first edition (ISO 28763:2008), which has been technically revised. The main changes compared with previous edition are as follows:

- the normative references have been updated;
- the terms and definitions have been updated;
- references to normative documents and respective clauses have been updated;
- references and requirements for hydrogen permeability of steel have been updated in [Clause 4](#);
- requirements for visual examinations have been amended in [Clause 6](#).

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

# Vitreous and porcelain enamels — Regenerative, enamelled and packed panels for air-gas and gas-gas heat exchangers — Specifications

## 1 Scope

This document specifies the minimum requirements and the functional characteristics of enamel coatings applied by any process, such as wet dipping, wet flow-coating, wet spraying, wet electrostatic spraying, wet electrodeposition or dry-powder electrostatic spraying, to profiled steel heat exchanger panels in regenerative heat exchangers, before and after packing in baskets.

For very severe service conditions, or to obtain extended operational life, more stringent limits can be agreed between customer and supplier.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 105-J03, *Textiles — Tests for colour fastness — Part J03: Calculation of colour differences*

ISO 2178, *Non-magnetic coatings on magnetic substrates — Measurement of coating thickness — Magnetic method*

ISO 4534, *Vitreous and porcelain enamels — Determination of fluidity behaviour — Fusion flow test*

ISO 7991, *Glass — Determination of coefficient of mean linear thermal expansion*

ISO 8289:2000, *Vitreous and porcelain enamels — Low voltage test for detecting and locating defects*

ISO 19496-1, *Vitreous and porcelain enamels — Terminology — Part 1: Terms and definitions*

ISO 28706-2:2017, *Vitreous and porcelain enamels — Determination of resistance to chemical corrosion — Part 2: Determination of resistance to chemical corrosion by boiling acids, boiling neutral liquids, alkaline liquids and/or their vapours*

ISO 28723, *Vitreous and porcelain enamels — Determination of the edge covering on enamelled steel plate to be used in heat exchangers*

ISO 28764, *Vitreous and porcelain enamels — Production of specimens for testing enamels on sheet steel, sheet aluminium and cast iron*

EN 10204:2004, *Metallic products — Types of inspection documents*

EN 10209:2013, *Cold rolled low carbon steel flat products for vitreous enamelling — Technical delivery conditions*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19496-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at <https://www.iso.org/obp>

— IEC Electropedia: available at <http://www.electropedia.org/>

**3.1**  
**air-gas heater**  
heat exchanger used to heat up the air needed for combustion in the boiler, using the combustion gases from the boiler as the hot fluid

Note 1 to entry: The maximum temperature of the hot gases entering the heat exchanger is 450 °C with a normal operating temperature from 380 °C to 320 °C.

Note 2 to entry: Air-gas heat exchangers through which gases from DeNO<sub>x</sub> installations pass are considered as gas-gas heaters for the purposes of this document.

**3.2**  
**gas-gas heater**  
heat exchanger used in desulfuration plants to reheat the gases treated in the scrubber to obtain the proper draft in the stack

Note 1 to entry: The hot gases are the untreated gases going to the scrubber.

Note 2 to entry: The maximum temperature of the hot gases entering the heat exchanger is 200 °C with a normal operating temperature from 160 °C to 120 °C.

## 4 Steel substrates

### 4.1 Delivery

The steel for enamelling shall conform to the requirements of EN 10209 and shall be delivered with a certificate in accordance with EN 10204:2004, 3.1.

### 4.2 Analysis

The chemical composition shall be determined by a ladle analysis and shall conform to the requirements of EN 10209:2013, Table 2. At the request of the enameller, other elements as mentioned in EN 10209:2013, Table 2, shall be agreed with the steel manufacturer. For grades DCO3ED and DCO4ED, the carbon content of the product shall be determined and shall conform to EN 10209:2013, Table 2.

### 4.3 Hydrogen permeability

The hydrogen permeability shall have a minimum hydrogen permeation value (TH1) of 120, calculated in accordance with EN 10209:2013, A.1.8, Formula (A.1), or shall give the result of a minimum of 8 min in accordance with EN 10209:2013, A.1.8, Formula (A.2).

In the absence of a certificate from the steel supplier confirming the above minimum hydrogen permeability, and with prior agreement between the customer and the supplier, the fish-scale resistance shall then be determined as described in 4.4.

The hydrogen permeability method is not acceptable for the steel grades DCO6EK and DCO6ED (see EN 10209:2013, Table 2). For these grades, the fish scaling test described in 4.4 shall be used.

### 4.4 Fish scaling test

The fish scaling test shall be carried out in accordance with EN 10209:2013, A.2, method A.2. The test sheet (150 mm × coil width) shall be pre-treated without a nickel dip. The front and back shall be coated with enamel prepared in accordance with the supplier's milling formula and applied to produce a fired thickness of 100 µm to 130 µm. After drying, the coated test sheet shall be fired for 5 min at 820 °C. The test sheet shall then be subjected to thermal treatment at 60 °C to 80 °C for 24 h and subsequently inspected for fish scales. No fish scales are allowed.

## 4.5 Pickling speed

If required by the enameller, the pickling speed shall be determined in accordance with EN 10209:2013, Annex B, and an acceptable level shall be agreed with the steel manufacturer.

## 5 Enamel frit

### 5.1 Delivery

Enamel frit shall be ordered by the enameller with a certificate conforming to the requirements of EN 10204:2004, 3.1, including the results for the items given under [5.5](#) and [5.7](#).

The tests in [5.4](#) and [5.6](#) shall be carried out whenever there is a change in the frit or a change in the milling formula.

When taking delivery of “ready to use” enamel, enamel slip or enamel powder, the enameller may ask for additional requirements for the application properties in the material certificate.

Any other requirements and the test recipes shall be determined by consultation between the enameller (and/or customer) and the frit manufacturer.

### 5.2 Coefficient of expansion

If required by the enameller, the coefficient of expansion shall be determined in accordance with the house test of the manufacturer of the enamel frit (base material for “ready to use” enamel, enamel slip or powder enamel) or in accordance with ISO 7991.

### 5.3 Fusion flow

If required by the enameller, the fusion flow shall be determined in accordance with the house test of the manufacturer of the enamel frit (base material for “ready to use” enamel, enamel slip or powder enamel) or in accordance with ISO 4534.

### 5.4 Boiling-water (vapour phase) resistance

If required by the enameller, the boiling-water (vapour phase) resistance shall be determined in accordance with ISO 28706-2:2017, Clause 14.

When determined in this way, the maximum loss in mass of the enamel coating shall be as given in [Table 1](#).

**Table 1 — Maximum loss in mass**

| Heater type | Mass loss, max.           |
|-------------|---------------------------|
| Air-gas     | 20 g/m <sup>2</sup> /48 h |
| Gas-gas     | 6 g/m <sup>2</sup> /48 h  |

### 5.5 Acid resistance

The boiling sulfuric acid resistance shall be determined in accordance with ISO 28706-2:2017, Clause 11.

### 5.6 Thermal-shock resistance

If required by the enameller, the thermal-shock resistance shall be determined in accordance with [Annex A](#) at a test temperature of 350 °C on at least three test specimens prepared in accordance with ISO 28764.

After testing five times at the test temperature, the test specimens shall show no damage.

## 5.7 Adherence

The adherence shall be determined in accordance with EN 10209:2013, Annex C, using test specimens with a known pickling speed (see 4.5) prepared in accordance with ISO 28764.

The method of pre-treatment, application and firing of the enamel shall be described.

## 6 Characteristics of the enamel coating

### 6.1 Adherence

Test specimens for the determination of adherence shall be prepared in accordance with ISO 28764 and shall be pre-treated and enamelled under the same conditions as for the production of the heat exchanger panels.

When determined in accordance with EN 10209:2013, Annex C, the adherence of the enamel shall be at least level 2.

Tests shall be carried out on every pre-treated batch of panels.

### 6.2 Thickness

The thickness shall be determined in accordance with ISO 2178. Adjustment of the measurement equipment shall be carried out on the profile concerned. Select a pair of panels, one corrugated and one undulated, and carry out measurements from point A to point I (see Figure 1) on the front and reverse faces of each panel. The measurement points shall be situated at least 50 mm from the edge. The measurement points on the corrugated panel shall be as indicated by numbers 1 and 2, and on the undulated panel as indicated by 3. This will result in 54 measurements from each pair of panels tested, 36 from the corrugated panel and 18 from the undulated panel.

The mean of the 54 measurements shall be  $150 \mu\text{m} \pm 30 \mu\text{m}$ , unless a different mean is agreed between customer and supplier at the time of ordering.

Along the area bordering the edges of the panels, the total thickness may measure up to  $600 \mu\text{m}$  (i.e. two faces of  $300 \mu\text{m}$ ) plus the thickness of the substrate. If a different mean has been agreed between customer and supplier, the total enamel thickness along the area bordering the edge of the panel may vary, but should preferably be kept to a minimum to avoid chipping and spalling, etc.

With the exception of edges and suspension holes, the application thickness beside the measurement point (such as on both sides of the notches of the corrugation) shall nowhere fall below  $80 \mu\text{m}$ .

Measurements other than those at the points indicated shall be carried out on cross sections using microscopy.

The test shall be carried out on a 2 h cycle.

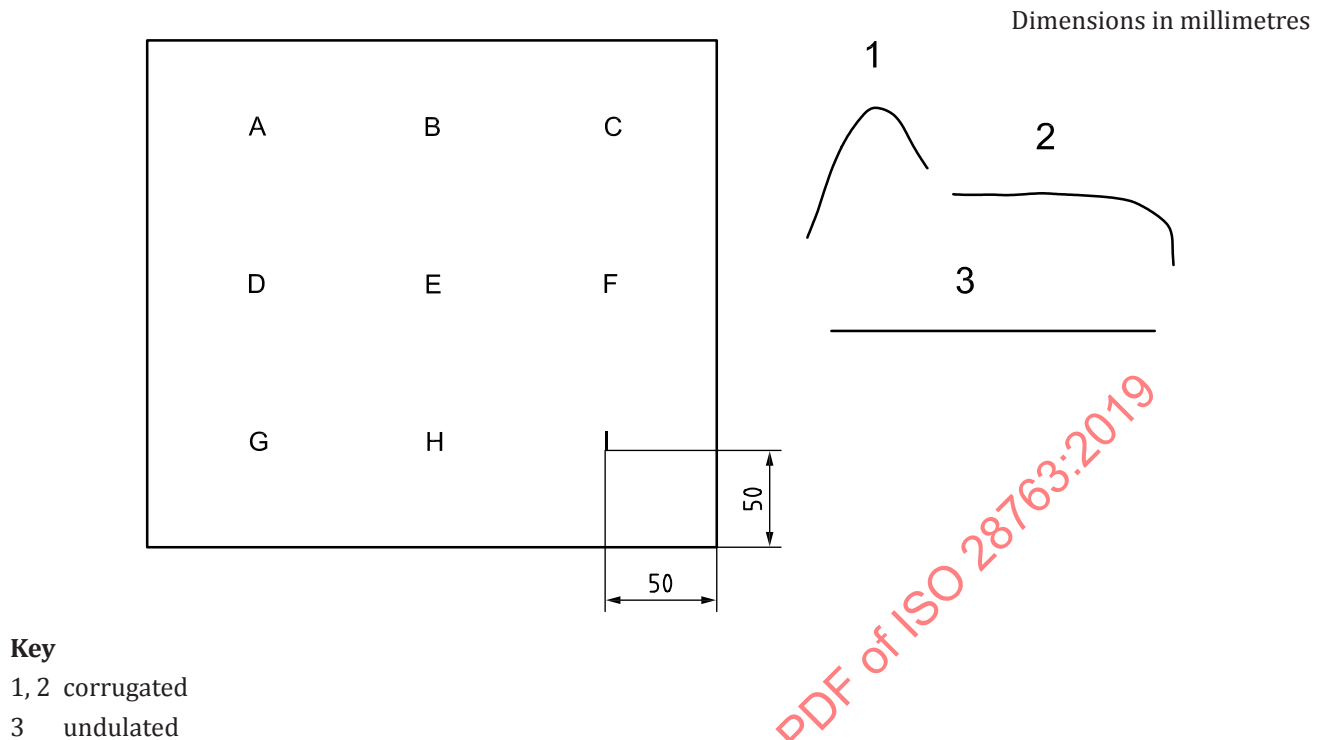


**Figure 1 — Thickness measurement points**

### 6.3 Thermal-shock resistance

Test specimens for the determination of thermal-shock resistance shall be prepared in accordance with ISO 28764 and shall be pre-treated and enamelled under the same conditions as for the production of the heat exchanger. They shall have an enamel layer thickness of  $150 \mu\text{m} \pm 20 \mu\text{m}$ .

The thermal-shock resistance shall be determined in accordance with [Annex A](#) at a test temperature of  $350^\circ\text{C}$  on at least three test specimens.

After testing five times at the test temperature, the test specimens shall show no damage.

The test shall be carried out on every 5 000 kg of enamel frit.

### 6.4 Fundamental defects

A 100 % visual examination of the enamelled surface shall be carried out for fundamental defects. The enamelled surface shall be free of fundamental defects such as blisters, burn-off, chipping, copperheads, cracking, crazing, fish scaling, spalling and tearing. The enamelled surface shall be visually examined from a minimum distance of 1,5 m and a maximum distance of 2,5 m either in natural light or in D65 artificial daylight in accordance with ISO 105-J03.

**NOTE** Fire tool marks can be accepted.

### 6.5 Open defects

Open defects down to the basis metal shall be detected in accordance with ISO 8289:2000, method B.

In a random check of 10 pairs of panels out of a production of 10 000 pairs of panels, the average number of open defects shall be as given in [Table 2](#). This rate of sampling is sufficiently representative of the production whenever the results are within the specified limit. If the results are outside the specified limit, sampling shall be extended to between 2 and 5 per 1 000.

**Table 2 — Maximum numbers of open defects**

| Heater type | Open defects, max. |
|-------------|--------------------|
| Air-gas     | 50/m <sup>2</sup>  |
| Gas-gas     | 15/m <sup>2</sup>  |

Alternatively, if the production process demands it, the number of defects on pairs of heat exchanger panels may be determined by checking 1 % of production on a 2 h cycle.

## 6.6 Edge covering of gas-gas heaters

If required by the customer, the edge covering of the panels of gas-gas heaters shall be determined in accordance with ISO 28723. The mean shall be agreed between the customer and the supplier at the time of ordering.

## 6.7 Boiling sulfuric acid resistance

Test specimens for the determination of boiling sulfuric acid resistance shall be prepared in accordance with ISO 28764 and shall be pre-treated and enamelled under the same conditions as for the production of the heat exchanger. They shall have an enamel layer thickness of 150 µm ± 20 µm.

When determined in accordance with ISO 28706-2:2017, Clause 11, the maximum loss in mass of the enamel coating shall be as given in [Table 3](#).

The test shall be carried out on every 5 000 kg of enamel frit.

**Table 3 — Maximum loss in mass**

| Heater type | Mass loss, max.             |
|-------------|-----------------------------|
| Air-gas     | 10,0 g/m <sup>2</sup> /18 h |
| Gas-gas     | 2,0 g/m <sup>2</sup> /18 h  |

## 6.8 Rework

In the event of enamelled elements being rejected, a maximum of 5 % of rework shall be accepted.

# 7 Characteristics after packing

## 7.1 Packing pressure

The packing pressure applied to the corrugated and undulated plates shall be ± 1 000 kg/m<sup>2</sup>, preferably in the upper limit of the range 4 000 kg/m<sup>2</sup> to 8 000 kg/m<sup>2</sup>. The surface area, in m<sup>2</sup>, of each filled basket is determined from the length and width of the middle pair of plates in the load.

## 7.2 Visual examination

For gas-gas heaters, a visual examination shall be carried out for defects such as chipping, cracking or spalling. Special attention shall be given to the contact points between the corrugated and undulated plates (the second, the middle and the last but one pair of panels in the basket). The maximum number of defects/m<sup>2</sup> at the contact points shall be agreed between the customer and the supplier.

The visual examination shall be performed after pressurizing the basket, complete with elements, but without the pack being welded.

The visual examination shall be carried out on 2 % of the elements and a minimum of one basket per rotor shall be tested.

### 7.3 Edge covering of gas-gas heaters

If required by the customer, the edge covering of gas-gas heater panels shall be determined in accordance with ISO 28723 or by visual examination of the edges in the flow direction.

The edge-covering test shall be performed after pressurizing the basket, complete with elements, but without the pack being welded.

## 8 Documentation

If required by the customer, the enameller shall provide the test results for the measurements listed in [Table 4](#), together with full details of the process parameters.

**Table 4 — Summary of required tests**

| Test                                       | Subclause                                  | Gas-gas heaters | Air-gas heaters |
|--------------------------------------------|--------------------------------------------|-----------------|-----------------|
| <b>Steel (Clause 4)</b>                    |                                            |                 |                 |
| Certificate: EN 10204:2004, 3.1            | <a href="#">4.1</a>                        | Required        | Required        |
| Analyses                                   | <a href="#">4.2</a>                        | Required        | Required        |
| Hydrogen permeability or fish scaling test | <a href="#">4.3</a><br><a href="#">4.4</a> | Required        | Required        |
| Pickling speed                             | <a href="#">4.5</a>                        | If required     | If required     |
| <b>Frit (Clause 5)</b>                     |                                            |                 |                 |
| Certificate: EN 10204:2004, 3.1            | <a href="#">5.1</a>                        | Required        | Required        |
| Coefficient of expansion                   | <a href="#">5.2</a>                        | If required     | If required     |
| Fusion flow                                | <a href="#">5.3</a>                        | If required     | If required     |
| Water vapour resistance                    | <a href="#">5.4</a>                        | If required     | If required     |
| Acid resistance                            | <a href="#">5.5</a>                        | Required        | Required        |
| Thermal shock                              | <a href="#">5.6</a>                        | If required     | If required     |
| Adherence                                  | <a href="#">5.7</a>                        | Required        | Required        |
| <b>Enamel coating (Clause 6)</b>           |                                            |                 |                 |
| Adherence                                  | <a href="#">6.1</a>                        | Required        | Required        |
| Thickness                                  | <a href="#">6.2</a>                        | Required        | Required        |
| Thermal shock                              | <a href="#">6.3</a>                        | Required        | Required        |
| Fundamental defects                        | <a href="#">6.4</a>                        | Required        | Required        |
| Open defects                               | <a href="#">6.5</a>                        | Required        | Required        |
| Edge covering                              | <a href="#">6.6</a>                        | If required     | Not applicable  |
| Acid resistance                            | <a href="#">6.7</a>                        | Required        | Required        |
| Rework                                     | <a href="#">6.8</a>                        | Required        | Required        |
| <b>After packing (Clause 7)</b>            |                                            |                 |                 |
| Packing pressure                           | <a href="#">7.1</a>                        | Required        | Required        |
| Visual examination                         | <a href="#">7.2</a>                        | Required        | Not applicable  |
| Edge covering                              | <a href="#">7.3</a>                        | If required     | Not applicable  |
| <b>Documentation (Clause 8)</b>            |                                            | If required     | If required     |