

Considerations regarding the increase of temperature during the tests in explosive mixtures for an enclosure with type of protection “d”

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Abstract. Equipment with type of protection “d” provides explosion protection by its enclosure that withstands the pressure of an internal explosion and prevents the transmission of explosion to the explosive atmosphere that surrounds the enclosure. In this case the explosion protection is maintained even in case of an internal explosion. The maximum surface temperature of a flameproof equipment considers the temperature of external surfaces (for the inclusion of equipment in a temperature class). There is also an increase of temperature during the internal explosion. The purpose of this paper is to monitor the temperature increase in case of an internal explosion considering an equipped flameproof enclosure (using an internal equivalent model instead of internal apparatus). The tests are performed with different gases, including hydrogen, considering the gas concentrations used to perform the tests in explosive mixtures for flameproof equipment.

1 Generalities

The type of protection “d” (flameproof enclosure) is applied (in generally) to equipment generating electrical arcs and sparks. It consists in closing the parts that can ignite the explosive atmospheres inside of an enclosure that is designed to withstand an internal explosion and to prevent the transmission of the internal explosion effects to the surrounding explosive atmosphere [1].

Testing the characteristics providing protection to explosion is very important in this case. In addition to the general tests (ex. determination of rated temperature, determination of maximum surface temperature, impact tests, IP tests, thermal endurance tests etc.) needed to be performed for the confirmation of some explosion protection characteristics according the standard containing the general requirements for equipment designed for use in potentially

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explosive atmospheres [2], specific tests in explosive mixtures (according to the type of protection flameproof enclosures) have to be applied.

When determining the service temperature and maximum surface temperature according to the standard provisions [1, 2] the temperature on the hottest points on the enclosure surface shall be determined.

The applicable specific tests in explosive mixtures, in case of equipment with type of protection flameproof enclosures, level of protection “db”, are [1]:

- Determination of explosion pressure – consisting in igniting a specific explosive mixture inside the enclosure and measuring the pressure developed during the internal explosion [1];
- Overpressure test – consisting in igniting a pre-compressed explosive in order to create an explosion pressure of 1,5 times the reference pressure by using the explosive mixtures specified for the determination of the explosion (reference) pressure [1];
- Test for non-transmission of an internal ignition – consisting in placing the same explosive mixture inside the enclosure and within the testing chamber. The explosive mixture inside the testing chamber is ignited and the explosion shall not be transmitted to the explosive atmosphere that surrounds the enclosure [1].

The explosion protection of equipment shall be preserved during an internal explosion. Also, as a result of an internal explosion (by igniting the internal flammable mixture), the temperature on the external surface of the equipment is expected to increase, considering the energy released by burning the flammable mixture [3, 4].

When performing the tests to determine the explosion (reference) pressure, the explosive mixtures to be used in case of group II equipment (in volumetric ratio with air and at atmospheric pressure), are as follows (Table 1) [1].

Table 1 Testing mixtures used for determination of reference pressure [1]

Crt. No.	Equipment group/subgroup	Testing mixture with air
1.	IIA	(4,6 ± 0,3) % propane
2.	IIB	(8 ± 0,5) % ethylene
3.	IIC	(14 ± 1) % acetylene
		(31 ± 1) % hydrogen.

When performing the overpressure test, with the dynamic method, the enclosure is subjected to a test in explosive mixtures (with the same explosive mixture used to perform the tests for determination of reference pressure) with a pre-compressed explosive mixture, so as to produce an explosion pressure of 1,5 times the reference pressure (with a minimum of 3,5 bar) [1]. Only one test is performed, except for electrical equipment of Group IIC when three tests are made with each gas [1].

To perform the tests for non-transmission of an internal ignition, specific test mixtures are used, according to the equipment group/subgroup classification. In some specific situations the testing mixture can be pre-compressed [1].

In case of flameproof equipment included in group IIA and IIB, the test mixtures, according to the test method, are presented in Table 2; and in case of equipment included in group IIC are presented in Table 3 [1].

Table 2 Non-transmission of an internal ignition for equipment in Group IIA and IIB [1]

Crt. No.	Equipment subgroup	Number of tests	Test mixture (when $0,9 i_C \leq i_E \leq i_C$)	Testing method (when i_E is not according $0,9 i_C \leq i_E \leq i_C$)		
				Test mixture (with air)		Precompression of the normal test mixtures
				i_E/i_C	Mixture	
1.	IIA	5	$(55 \pm 0,5) \%$ hydrogen	$\geq 0,75$	$(50 \pm 0,5) \% H_2$	$P_k = \frac{i_C}{i_E} \times 0,9$ P_k -precompression factor
				$\geq 0,6$	$(45 \pm 0,5) \% H_2$	
2.	IIB	5	$(37 \pm 0,5) \%$ hydrogen	$\geq 0,75$	$(28 \pm 0,5) \% H_2$ at 140 kPa	
				$\geq 0,6$	$(28 \pm 0,5) \% H_2$ at 140 kPa	

Table 3 Non-transmission of an internal ignition for equipment in Group IIC [1]

Testing method		Number of tests	Testing mixture (with air)	Pressure of explosive mixture
First method - increased test gap – all gaps of joints (other than threaded joints) increased to $1,35 i_C \leq i_E \leq 1,5 i_C$		5	$(27,5 \pm 1,5) \%$ hydrogen with air, and	Atmospheric pressure
		5	$(7,5 \pm 1) \%$ acetylene with air	
Second method	(when $0,9 i_C \leq i_E \leq i_C$)	5	$(27,5 \pm 1,5) \%$ hydrogen with air, and	1,5 x atmospheric pressure
	(when i_E is not within $0,9 i_C \leq i_E \leq i_C$)	5	$(7,5 \pm 1) \%$ acetylene with air	Precompression of the normal test mixtures $P_k = \frac{i_C}{i_E} \times 1,35$
Third method – flammable mixture enriched with oxygen		5	$(40 \pm 1) \%$ hydrogen, $(20 \pm 1) \%$ oxygen and the rest nitrogen; and	Atmospheric pressure
		5	$(10 \pm 1) \%$ acetylene, $(24 \pm 1) \%$ oxygen and the rest nitrogen	

Hot surfaces shall be considered when assessing equipment designed for use in potentially explosive atmospheres [4, 5, 6, 7]. The maximum surface temperature of an equipment shall be determined on any part or surface, considering the most adverse conditions [2, 5, 7]. For electrical equipment the most adverse conditions consider supplying the equipment at an input voltage of 90% or 110 % of the rated voltage (the value that will give the maximum surface temperature) [2, 5, 8, 9]. For Group II, equipment is marked according the maximum surface temperature with the specific determined temperature or one of the six known temperature classes T6, T5, T4, T3, T2, T1 [2, 7, 8, 9].

Considering that the flameproof enclosure “d” equipment is designed to withstand an internal explosion, it is important to notice the influence of an internal explosion over the maximum surface temperature.

2 Test methods and conditions

To check the influence of internal ignition on the surface temperature increase for a flameproof equipment a parallelepipedal enclosure was used, as presented in Fig. 1. The

equipment enclosure was provided with a glass window and the internal apparatus of the testing sample was replaced by an equivalent wooden model.



Fig. 1 Test sample used to perform the temperature increase tests

The enclosure used as a test sample was made of aluminium alloy. The enclosure consists of a parallelepipedal box and a cover having a sight window glass. The window glass cover is attached to the box by screwing. The dimensions (in mm) of the box (with the cover mounted) are 385 x 385 x 277 (L x l x H). Unused entries in the enclosure were closed by specific means.

Gas inlet and outlet were provided on the two opposite walls of the enclosure. Two ignition spark plugs were placed at the gas inlet and outlet flanges and one ignition spark plug was placed on a side wall. The ignition spark plugs were connected to high voltage coils in the test rig.

Nine K type thermocouples were used to monitor the temperature increase on the testing sample when performing the tests in explosive mixtures. The thermocouples were placed in the following positions:

- sight glass of the cover windowed glass;
- cemented joint of the cover windowed glass;
- metallic frame of the cover;
- the four side walls of the enclosure box;
- lower side of the enclosure box;
- the last one was used to monitor the ambient temperature;

For the monitoring of temperature increase when performing tests in explosive mixture for this flameproof enclosure, a monitoring system was used. The monitoring system comprised a multiplexer unit (Agilent 34901A) attached to an Agilent 34970A unit and connected to a laptop and controlled with an adequate software for monitoring the temperature values (Benchlink Data Logger). The arrangement used for performing the tests is represented in Figure 2.

The test rig used to control and monitor the performance of tests in explosive mixtures is presented in Figure 3. This is used to control the preparation of the explosive test mixture, to visualise and record the parameters during the tests (concentration, pressure, humidity and temperature of the explosion mixture, ignition point, explosion pressure diagram, the point where the maximum pressure was recorded etc.) and, also, to generate the test report results.

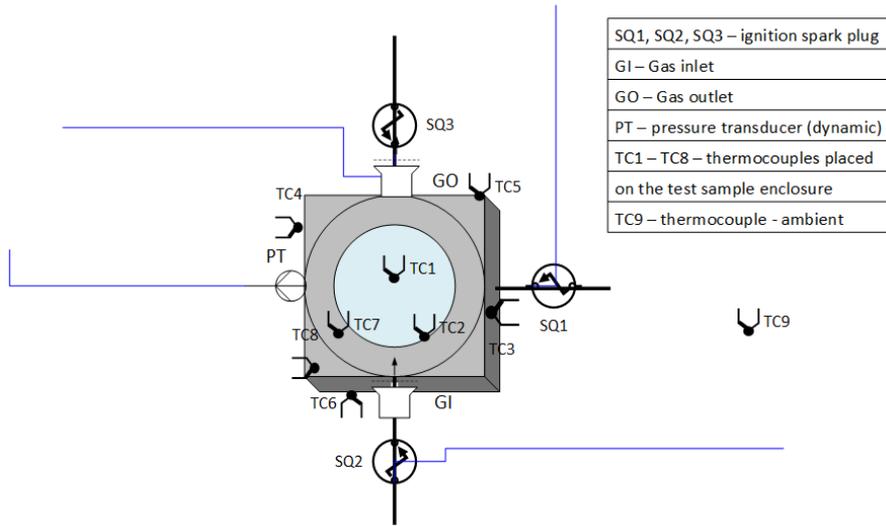


Fig. 2 Test sample arrangement

The test rig used to perform the tests in explosive mixtures comprises an explosion chamber, pipelines and connectors, an oxygen analyser (paramagnetic) to measure the concentration of the explosive mixture (indirectly, by measuring the concentration of oxygen in the explosive mixture), a transducer to measure the pressure of the explosive mixture (piezoresistive) connected to a piezoresistive amplifier, transducers to measure the pressure developed during the ignition of the explosive atmosphere (piezoelectric transducers) that are connected to charge amplifiers (Kistler transducers and charge amplifiers), two fast oscilloscopes for monitoring and recording explosion pressures (HP), a transmitter for humidity and temperature (Kobold), a multimeter with multiplexer and relay board (Agilent), an MESG apparatus (maximum experimental safety gap), a gas mixing control unit, high-voltage coils to supply the ignition spark plugs, coaxial cables, an air compressor etc. [4]. The command-and-control part of the test rig is showed in Figure 3.



Fig. 3 Command and control of the test rig to perform tests in explosive mixtures

Multiple specific test mixtures were used for testing to verify the temperature increase. Two specific mixtures of acetylene-air (one with 7,5% C₂H₂ v/v and the other with 14% C₂H₂ v/v), four specific mixtures of hydrogen-air (27,5% H₂ v/v, 31% H₂ v/v, 37% H₂ v/v and 55% H₂ v/v) and two specific mixtures of ethylene-air (6,5% C₂H₄ v/v and 8% C₂H₄ v/v) were used to perform the tests to check the test sample's surface temperature increase during the tests. Burning of combustible mixtures (acetylene-air, hydrogen-air, ethylene-air) will release a certain amount of energy [3, 4, 10]. The energy resulted during combustion can heat up the walls of the enclosure, thus increasing the temperature of the external surface of the enclosure.

The characteristics of the flammable substances used are:

- hydrogen: heat of combustion (130,8 MJ/kg), relative density to air (0,07 kg/m³), flammability limits (4 ÷ 77 % H₂ v/v), auto-ignition temperature (560°C) [11, 12].
- Acetylene: heat of combustion (49,9 MJ/kg), relative density to air (0,9 kg/m³), flammability limits (2,3 ÷ 100 % C₂H₂ v/v), auto-ignition temperature (305°C) [11, 12].
- Ethylene: heat of combustion (47,2 MJ/kg), relative density to air (0,97 kg/m³), flammability limits (2,3 ÷ 36 % C₂H₄ v/v), auto-ignition temperature (440°C) [11, 12].

With the help of the test rig, the prepared test mixture was introduced inside the enclosure used as a test sample at atmospheric pressure. The ignition of the explosive mixture was made by using spark plugs supplied by high voltage coils.

Five tests with each testing mixture were performed. The test sample was purged after each test (to cool down the test sample and evacuate burnt gases and humidity).

3 Results and discussions

Monitoring the temperature increase when performing the tests in explosive mixture was made by using the thermocouples, placed on the test sample as indicated in figure 2. The thermocouples TC1 to TC6 were placed as follows: TC1 – on the sight glass window; TC2 – on the cemented joint between the glass and the metallic frame of the cover; TC3, TC4, TC5, TC6 – on the external side walls of the testing sample; TC7 – on the metallic frame of the cover; TC8 – on the external bottom side of the enclosure; TC9 - ambient temperature.

The temperatures recorded during the tests in explosive mixtures are presented in Figures 4 to 10. The correspondence of the thermocouples to the figures is given by the Agilent 34970A channels used to monitor the temperature: TC1 – 101, TC2 – 102, TC3 - 104, TC4 - 105, TC5 - 106, TC6 – 107, TC7 – 103, TC8 – 108 (the ambient temperature diagram was not included in the diagrams).

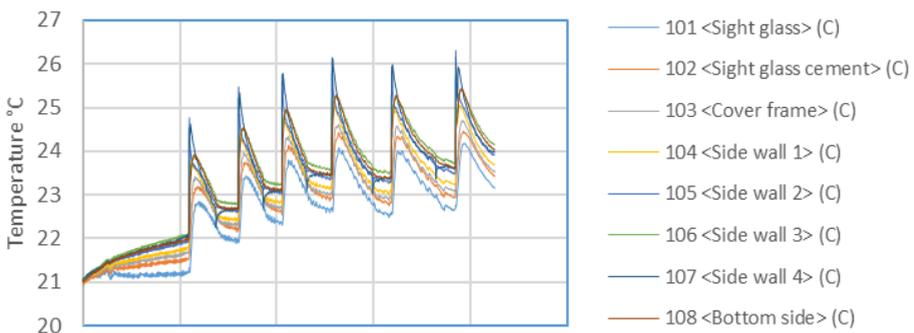


Fig. 4 Temperature increase when testing with 7,5% acetylene - air test mixture

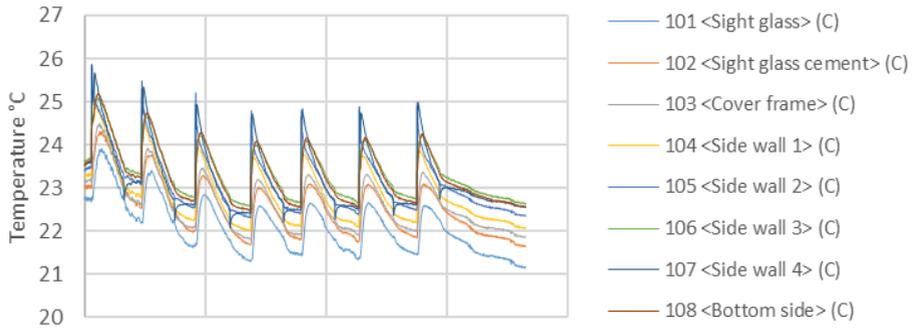


Fig. 5 Temperature increase when testing with 14 % acetylene - air test mixture

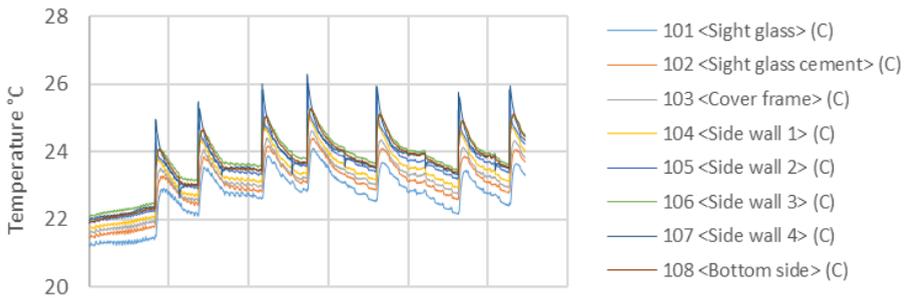


Fig. 6 Temperature increase when testing with 6,5 % ethylene - air test mixture

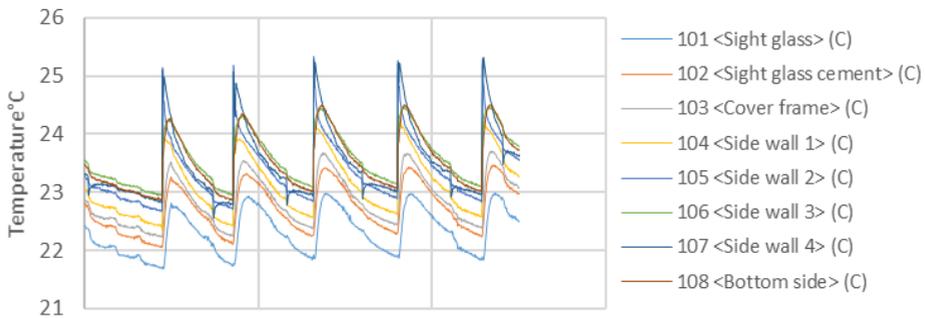


Fig. 7 Temperature increase when testing with 8 % ethylene - air test mixture

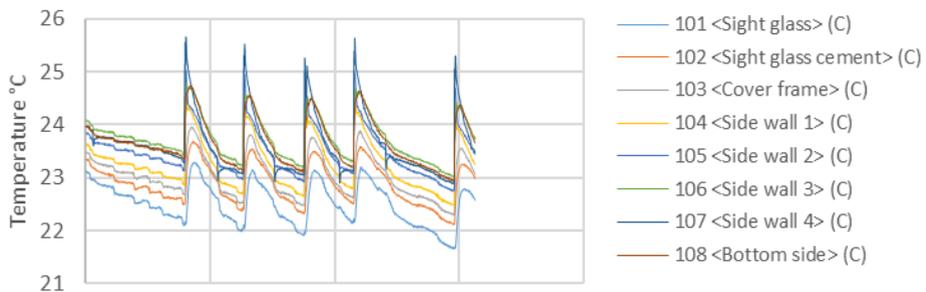


Fig. 8 Temperature increase when testing with 27,5 % hydrogen - air test mixture

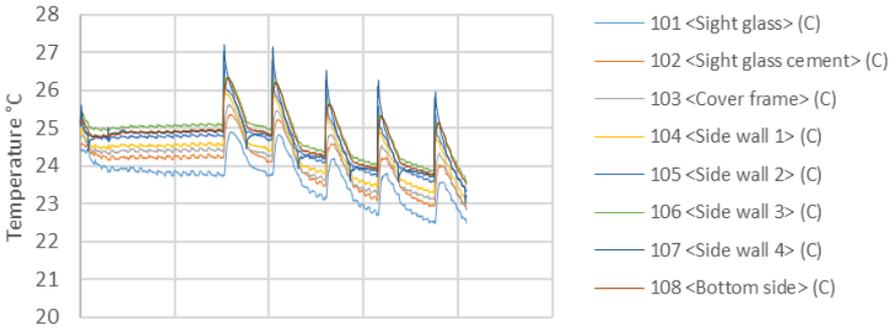


Fig. 9 Temperature increase when testing with 31 % hydrogen - air test mixture

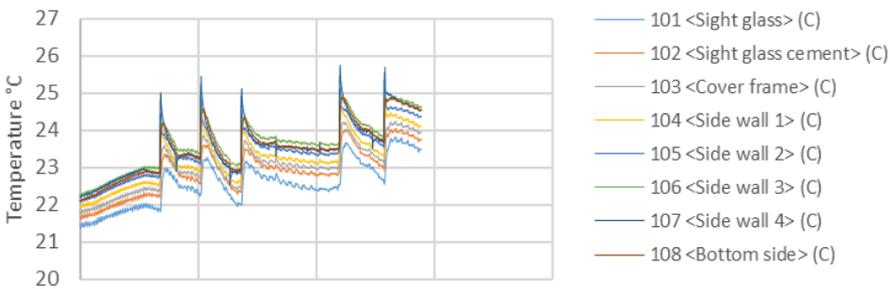


Fig. 10 Temperature increase when testing with 37 % hydrogen - air test mixture

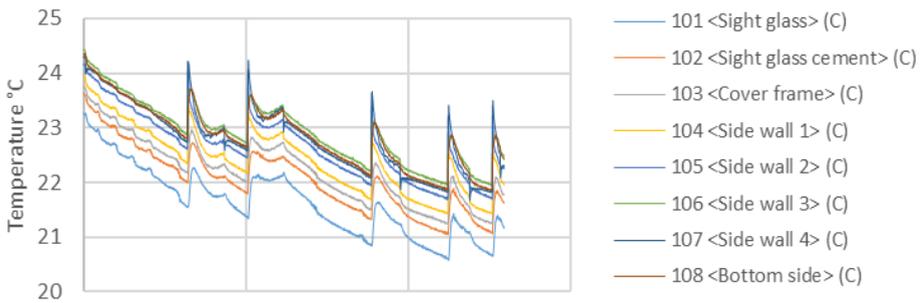


Fig. 11 Temperature increase when testing with 55 % hydrogen - air test mixture

After analysing the temperature diagrams (Figures 4 to 11), the maximum temperature increase on the test sample surface was 3,1 K (for the tests made with acetylene - air test mixtures – 7,5% acetylene). For the other explosive mixtures, the maxim temperature increase was recorded as follows:

- for acetylene-air (14% acetylene) – 2,7 K;
- for ethylene-air (6,5% ethylene) – 2,9 K;
- for ethylene-air (8% ethylene) – 2,6 K;
- for hydrogen-air (27,5% hydrogen) – 2,7 K;
- for hydrogen-air (31% hydrogen) – 2,7 K;
- for hydrogen-air (37% hydrogen) – 2,6 K;
- for hydrogen-air (55% hydrogen) – 1,8 K

All of the highest values were measured with the help of thermocouple placed on the bottom side of the equipment. One explanation can be that the material on the bottom side

has a lower thickness (11 mm) compared to the thickness of the material on the side walls of the test sample (12,5 mm). The sight glass and the cover frame are thicker than the walls of the enclosure (combined with different heat transfer coefficients for glass [10]). Also, the temperature increase can be influenced by the internal components of the enclosure (replaced in this case by wooden models) – a part of the heat released during the burning of the test mixture [3, 4, 10] can be absorbed by the internal components placed inside the enclosure combined with the heat absorbed by the walls of the enclosure.

The obtained results are different compared to the results obtained when testing an empty cylindrical enclosure [4]. The temperature increase in this case is lower when comparing the tests with a mixture of air-hydrogen (27,5% hydrogen) that was used to test the cylindrical enclosure [4].

The increase of temperature, is also considered important in this case, especially in case of equipment included in the type of protection flameproof enclosure “d” for which the maximum surface temperature determination (when performing the thermal tests) showed a maximum surface temperature close to the limit imposed by the temperature class (85°C – 5K – for temperature class T6, 100°C – 5K – for temperature class T5, 135°C – 5K – for temperature class T4, 200°C – 10K – for temperature class T3, 300°C – 10K – for temperature class T2, 450°C – 10K – for temperature class T1).

4 Conclusions

In the first part were mentioned the test conditions and explosive mixtures used to for testing the flameproof enclosure “d” equipment in explosive mixtures. Also, the specification for the maximum surface temperature determination were underlined.

The test sample arrangement and the test rig used to perform the tests in explosive mixtures was described, together with the testing methodology. In the next part the results obtained after performing the tests in explosive mixtures were presented.

Analysing the obtained results during the tests in explosive mixtures, an increase of temperature was observed with a maximum of 3,1 K (in case of air- acetylene 7,5%) and a minimum of 1,8 K (in case of air-hydrogen 55%).

The temperature increase, when performing the tests in explosive mixtures, is considered to be important, especially when the flameproof enclosure “d” equipment presents a maximum surface temperature close to the limit imposed by the temperature class (and can be considered at maximum surface temperature determination).

This work can be continued by performing the determination related to the increase of temperature in case of other equipment enclosures (with other geometrical forms, other enclosure materials, equipped with real apparatus etc.).

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