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# RESEARCH REGARDING THE CONSTRUCTION AND RELIABILITY OF THE HIGH-TEMPERATURE PERFORMANCE TESTING SYSTEM FOR CRIMPED COPPER PIPE AND FITTING ASSEMBLIES USED IN NATURAL GAS SUPPLY INSTALLATIONS

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***Abstract:*** *The use of copper as the preffered material for more and more supply systems, including those for natural gas, is a generalised worldwide trend. In the given context, this article presents the technology used on crimped conections between copper pipes and fittings for natural gas supply installations and the high temperature preformance testing procedures for the resulting assemblies using a system designed, built and tested by the authors.*
***Keywords:*** *oven, temperature, fitting, pipe, copper*.

## 1. INTRODUCTION

During the last few decades, the supply and demand for household and industrial natural gas has undergone a permanent growth. Natural gas represents a relatively cheap source of energy, which, by means of a simple and highly efficient conversion process, yields very little residue when used.
Stimulated mainly by industrial applications, natural gas installation engineering has developed solutions for all usage requirements and scenarios applicable to a natural gas supply network or installation. Given the existing context there is a generalised worldwide trend of using copper as the material for building natural gas and liquid petroleum gas supply systems, plumbing, fire suppression installations, etc. The advantages of using copper pipes and fittings as opposed to steel are the following, [2]: high resistance to corrosion and low use of material (as copper pipe walls are thinner than steel pipe walls), good performance in high or low temperatures and simpler assembly technology. Due to these advantages use of copper pipes and fittings for natural gas supply installations has been authorized in the E.U. based on a stringent system of authorization procedures. This endeavour has led to the establishing of the following European standards [1]:

- The EN 1254 standard, which regulates the use of five types of fittings for copper pipe assemblies, their types and dimensions corresponding to specific methods of assembly;
- The EN 1982 standard, which regulates the technical requirements for copper and copper ally ingots and cast parts used for the manufacture of pipes and fittings;
- The EN 1057standard, regulating the types, dimensions and technical requirements of non-welded pipes used for water and natural gas supply on plumbing and heating installations.

## 2. TECHNICAL REQUIREMENTS

### 2.1. Fitting and pipe assembly technologies used in natural gas supply installations

The following technologies for assembly of copper pipes and fittings have been developed worldwide,[4]:
- soft soldering (added materials are tin and lead; made using soldering alloys that melt at temperatures lower than 450 °C; soldering alloy has a breaking resistance of 5 – 7 daN/mm$^2$);
- hard soldering or brazing (added materials copper-zinc or silver-copper-zinc alloys; made using alloys with a melting temperature between 450 °C and 1000 °C);
- flaring, providing radial pressure by use of removable threaded elements;
- crimping (cold pressing), accomplished by plastic radial distortion of the fitting element thus creating an assembly by crimping the fitting on the pipe.

Resilience and technical security requirements for natural gas installations have led to authorisation of the hard soldering and crimping assembly methods.
Hard soldering assembly and the relevant fittings ate regulated by the EN1254-1 standard. The hard-soldering technology has the following disadvantages, [5]:

- localized material degradation due to temperature and soldering flux compounds;
- degradation of corrosion protection applied to copper pipes due to high temperature exposure and flux compounds;
- alteration of material microstructure;
- risk of seal failure in case of fire, which may cause the solder material to melt.

To remove these shortcomings, a system of permanent fitting crimping assembly has been developed, using a sealing ring gasket and an electro-hydraulic press (Figure 1).

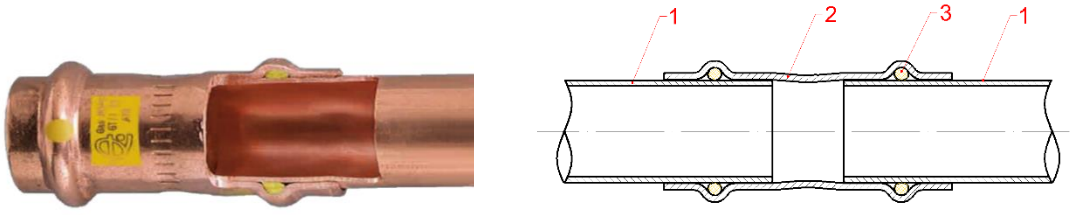



**Figure 1:** Crimping assembly
1 – copper pipe; 2 – crimped connector fitting; 3 – sealing ring.

Connectors are made of either copper (Cu 99,9%) or bronze (cu 0,4-0,8% Ni; 3-3,5% Pb; 6,5-7,5% Zn; 3,8-4,5%Sn; with the remaining percentage Cu). The sealing ring gaskets are made of etilen-propilen-dien synthetic rubber or acril-nitril-butadien rubber.
The main advantages of the permanent crimping assembly system over the traditional hard soldering technology are as follows, [4,8]:

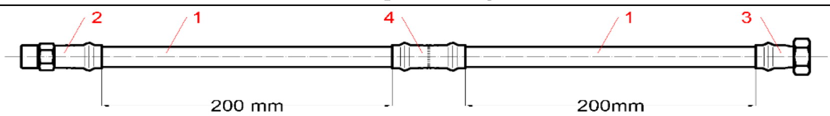
- the time necessary for the assembly operation is approximately 30% of that required for soldering (assembly takes roughly. 4 s);
- pipe priming and post-soldering clean-up operations are eliminated;
- use of soldering materials is eliminated (flux, soldering alloys, etc.)
- reduced risk of copper pipe corrosion due to the effects of flux reaction by-products and effects of heat
- fire prevention measures specific to soldering operations are no longer necessary;
- mechanical stress in the pipe system is removed as cold pressing can be carried out after the installation elements are fitted in place and corrections are made for errors caused by wall geometry, slight pipe segment cutting errors, etc.;
- copper pipe installations for natural gas systems are guaranteed for a period of at least 50 years.

Because of the severity of technical security requirements for natural gas installations the creation of technical standards regarding design, assembly technology and use of copper pipe and fittings installations is based on a set of technical certification for the manufacturing technology and experimental testing of assembly performance on all types mechanical, thermic, fatigue and sealing trials specific to natural gas applications.

### 2.2. Procedure for experimental testing of high temperature performance for crimped copper pipe and fitting assemblies used in natural gas supply installations

Within the experimental quality testing procedures for copper pipe and fitting assemblies, normal usage conditions for natural gas supply installations are observed in order to establish the trial envelope, these are: maximum operating pressure (1 bar … 5 bar), Class 2 fittings (flammable gases), operating temperature (-20 °C … + 70 °C). Experimental copper pipe and fitting crimped assembly quality trials procedures are devised to evaluate compliance with all technical prerequisite that guarantee the completely safe usage of gas supply installations under normal operating conditions as well as in abnormal hazardous situations caused by earthquakes, fires, etc. The trials cover evaluation of resistance and sealing performance during: alternative symmetrical deformation (vibrations), static deformation, torsion, rise of inner pressure (pneumatic and hydrostatic), normal operating temperature, high temperature. The experimental testing procedure of high temperature performance for copper crimped pipe and fitting assemblies used in natural gas supply installations is based on establishing the resistance and sealing performance of the assembly using a pipe sample test rig and the parameters listed in Table 1, but also an original system, designed and built by the authors.

**Table 1:** Pipe assembly test rig and parameters used to assess high temperature performance of the copper pipe and fitting assembly, [4].

<table>
<tr><td colspan="4">Sample test rig</td></tr>
<tr><td colspan="4">

1 – copper pipe; 2 – compression connector fitting;<br>3 – measuring connection; 4 – copper pipe connector</td></tr>
<tr><td colspan="4">Trial parameters</td></tr>
<tr><td>Temperature</td><td>Maximum working pressure</td><td>Flow loss</td><td>Time</td></tr>
<tr><td>[°C]</td><td>[bar]</td><td>[dm$^3$/h]</td><td>[min]</td></tr>
<tr><td>650 ± 10</td><td>5 ± 0,5</td><td>max. 30</td><td>30</td></tr>
</table>

Crimped copper pipe to fitting type assemblies used in natural gas supply installations meet the high temperature operation requirements if they exhibit no flow losses or these losses do not exceed 30 dm$^3$/h.

### 2.3. Construction and operation of the high-temperature performance testing system for crimped copper pipe and fitting assemblies used in natural gas supply installations

The components of the original system, designed and built by the authors to test the high temperature performance of crimped copper pipe and fitting assemblies used in gas supply installations shown below in Figure 2[4].

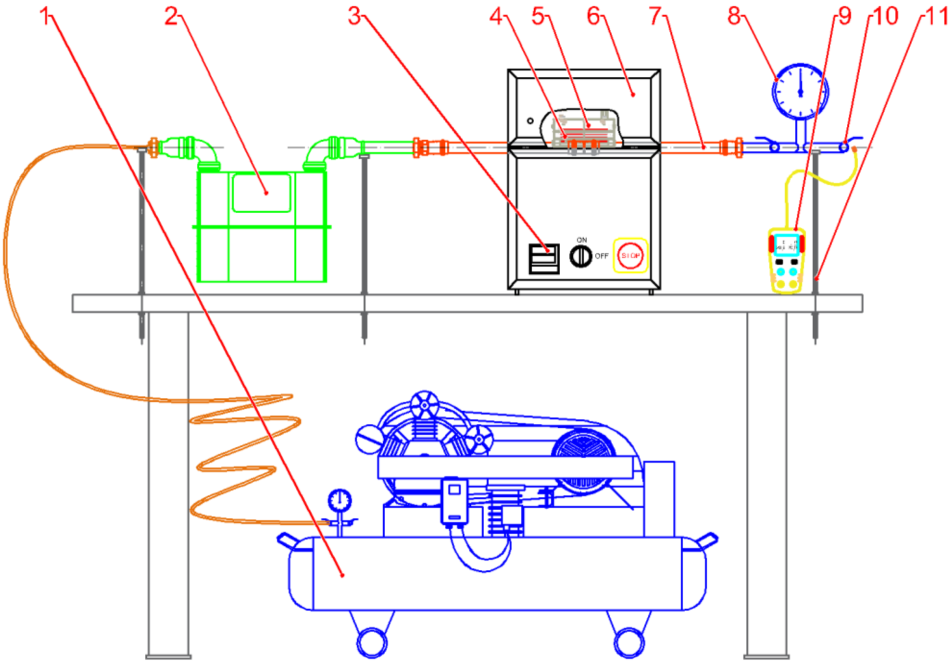



**Figure 2:** High-temperature performance testing system for crimped copper pipe and fitting assemblies used in natural gas supply installations:
1 - compressor; 2 - gas meter; 3 - controller; 4 - thermal coupling probe; 5 - heat source; 6 - electric oven; 7 - test sample rig; 8 - pressure gauge; 9 - nitrogen gas detector with cartridge; 10 - purge valve; 11 - threaded rod supports with mounting bands.

The compressor (1) is used to supply and maintain a constant nitrogen pressure 5 ± 0,5 bar to fill the test sample rig (7). The shape and size of the test sample rig are shown in Table 1. A gas flow meter (2) is fitted between the compressor and the test rig using threaded connectors. To measure the test pressure (see Table 1) a pressure gauge with a maximum range between 10-25 bar (8) is fitted on the other end of the test rig using threaded connections. To allow for purging of air from the test assembly a nitrogen gas cartridge detector (9) and a purging valve (10) are fitted after the pressure gauge on the end of the test assembly. Mounting support bands with threaded rods are used to hold the gas meter, test sample rig and pressure gauge in position on the system test bench. The test sample rig is filled with nitrogen and placed in the heat source chamber (5) of the electric oven (6) where it will be hated to 650 ± 10 °C. A thermal coupling temperature probe (4) is placed within the heat source chamber to measure its temperature and the real-time temperature reading is shown on a temperature controller (3) display panel. Test pressure and temperature are maintained at constant levels for 30 minutes. During this time the gas meter is used to measure the amount of gas losses that may occur due to partial/total failure of assembly integrity or pressure sealing.

Crimped copper pipe and fitting type assemblies used in natural gas supply installations are compliant to high temperature operation requirements if nu flow loss occurs or occurring leaks are under 30 $dm^3/h$ [4].

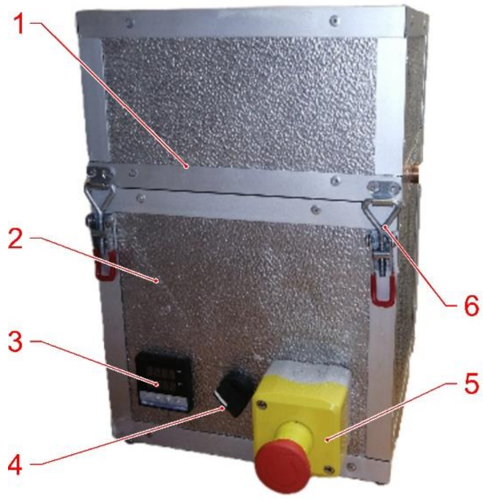



**Figure 3:** Electric oven
1 - lid; 2 - base; 3 - controller;
4 - mechanical operation switch;
5 - emergency control button;
6 - quick lock clamp.

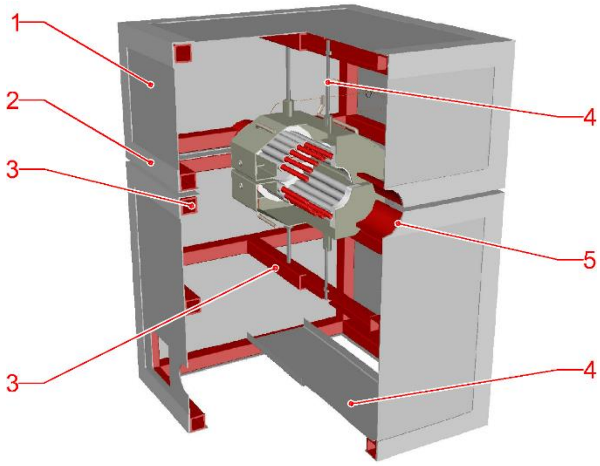



**Figure 4:** Case
1 - profiled aluminium panel; 2 - L-type profile;
3 - rectangular pipe frame;
4 - equipment supports;
5 - test sample rig support mount.

The main element of the high-temperature performance testing system for crimped copper pipe and fitting assemblies used in natural gas supply installations, shown in Figure 2, is the electric oven (2). By using the Joule-Lenz effect the oven transforms electrical energy into heat, reaching temperatures up to 1000 °C. The oven components of the electric oven shown in Figure 2, as designed and built by the authors of this article, are: the metal case (Figure 4), heat source and thermal insulation (see Figure 5) and the electrical system (see Figure 6). Using size measurements of these and other auxiliary components a CAD model of the electric oven, it consists of a lid(1) 250 x 250 x 135 mm in size and a base (2) measuring 250 x 250 x 235 mm, held together with the help of a hinge and quick-lock clamp system (6).

The oven case, shown in Figure 4, is made of profiled aluminium sheet panels (1) (Al99,5 1050), 1,5 mm thick, mounted using L-sections (2) made of angled profile aluminium (20 x 20 x 1 mm), on a rectangular pipe frame (3), manufactured from S235 steel (EN 10219, 15 x 15 x 1,5 mm). Inside the oven case, the built-in supports (4) are used for mounting equipment and the test sample rig is held in position by the dedicated rig support mount (5).

The heat source for the oven, shown in Figure 5, is comprised of two thermal subassemblies (1), each containing 9 electrical resistors. The resistors are made of kanthal alloy (Cr20, Al5, Fe75), have an operating temperature rating of 1300 °C and are individually housed in quartz tubes.

The quartz tubes are mounted in an arc on a ceramic holder (2) inside a metal casing (3). The metal casings are fitted symmetrically with the active component side laid horizontally, secured to the oven frame by threaded rods and covered by insulation. The heat source is connected by heat resistant wiring (4), it can provide a maximum constant temperature of 800 °C and up to 1200 °C for short periods. A thermal coupling (5) is used to measure the temperature inside the heat source chamber.

The thermal conductivity coefficient of the oven heat source is calculated as:

$$\lambda = 60 + 0,080 \cdot \theta_m, [^0C] \quad (1)$$

where $\theta_m$ is the static average temperature

The electric oven insulation (6) is manufactured from boards of ceramic fibre pressed using a bonding agent with a density of 400 $Kg/m^3$, this product is a replacement for asbestos based insulation in all applications where the insulation support surface is plane and rigid. The interior chamber created between the two thermal subassemblies (1) allows for testing of crimped copper pipe and fitting assemblies up to 35 mm in diameter.

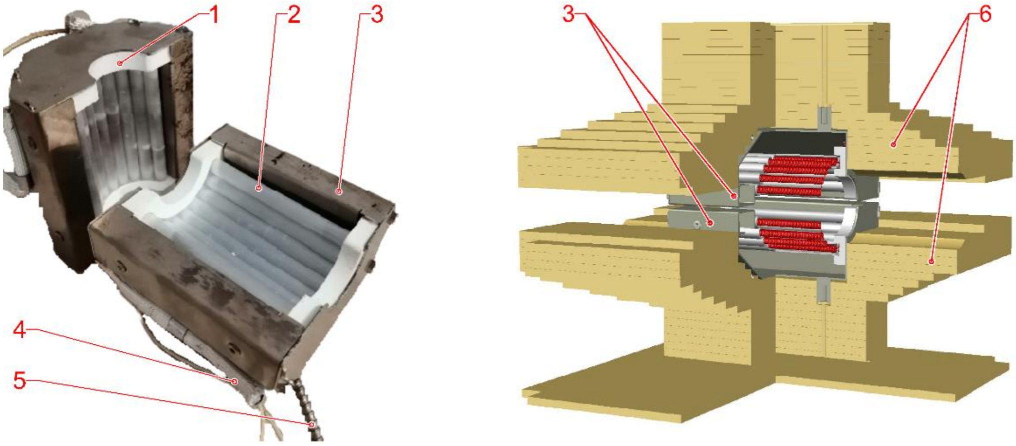



**Figure 5:** Heat source:
1 - thermal subassemblies; 2 - ceramic holders; 3 - metal casing;
4 - heat resistant wiring; 5 - thermal coupling; 6 - insulation.

The electrical system schematic for the oven is shown in Figure 6 and is composed of a solid state relay (1), type SSR-40 DA, (input 3 – 32 VDC.; output 24 – 380 VAC.), temperature regulator(2), REX-C100 type, (SSR input; supply 100-240 V; 50Hz/60Hz), thermal coupling (3), fitted to the lower thermal subassembly , mechanical operating switch (4) and an emergency off switch. Using the Joule-Lenz effect, the oven transforms electrical energy into heat, reaching temperatures up to 1000 °C.

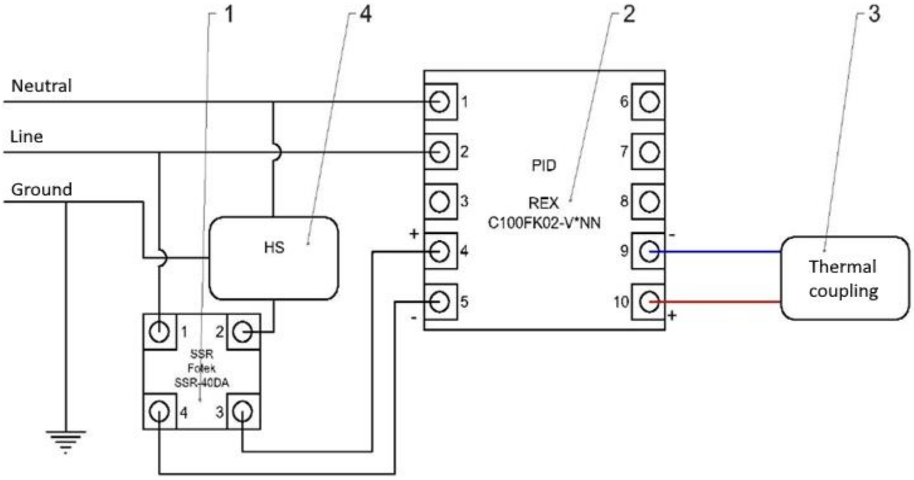



**Figure 6:** Oven electrical system schematics
1 - solid state relay; 2 - temperature regulator; 3 - thermal coupling;
4 - mechanical switch; 5 - emergency switch.

**2.4. Experimental reliability of the high-temperature performance testing system for crimped copper pipe and fitting assemblies used in natural gas supply installations**

In order to evaluate its behaviour during operation, the high-temperature performance testing system for crimped copper pipe and fitting assemblies used in natural gas supply installations has a testing schedule comprised of three experimental reliability trials: a first trial to validate the proper operation of the electric oven (see Figure 3), and two other trials to verify the system performance and proper operation respectively (see Figure 2), in all situations an envelope limit testing method was employed.
The first experimental test of reliability applies to the electric oven itself, without using a test sample rig. The test result evaluation criteria for validating the proper operation of the electric oven regards its operational safety when the heat source chamber (see Figure 5) reaches the testing temperature limit of 650 + 10 °C and maintains it constantly for 30 min (see Table 1).

The testing procedure commences by checking the electric oven components as shown in Figure 3 followed by connecting the oven to a source of electricity and powering it on using the mechanical operating switch. Using the digital display on the oven temperature controller the testing temperature is set to 650 + 10 °C (see Table 1).
When the set value (SV) for the temperature, displayed by the controller in green, is reached or surpassed, the temperature controller will display in red the real-time temperature reading (PV), this marks the gradual rise of the heat source camber temperature (Figure 7). Due to the small volume of the heat source chamber formed between the two thermal subassemblies (see Figure 5) the temperature will reach 660 °C within less than 6 minutes depending on the size of the tested sample rig.
When reaching the set 660 °C temperature, the controller induces a sinewave system voltage variation to keep the heat source chamber temperature constant changing the quartz tube temperature by ± (4 ... 20) °C. The quartz tube temperature variation depends on the size of the test sample rig and the trial parameters. After the real-time heat source chamber temperature has stabilized the 30 min test time countdown begins (see Table 1). On expiration of test period the electric oven is powered off using the mechanical operation switch and the power supply is disconnected.
Proper operation of the electric oven is ascertained when a constant temperature of 650 + 10 °C (see Table 1) was maintained in the heat chamber for 30 minutes, with temperature variations at the quartz tube level within 613 ÷ 674 °C (Fig. 8 a, b), for 8 up to 23 seconds.

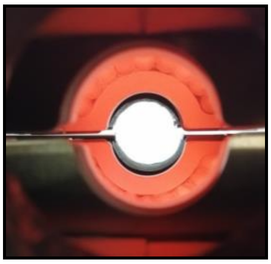
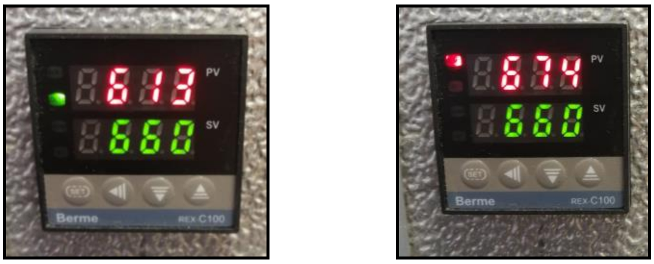


**Figure 7:** The electric oven heat source chamber.




a. b.

**Figure 8:** Quartz tube surface temperature variations: a – thermal deficit; b – thermal excess.

The second experimental test of reliability applies to the system in its entirety, as shown in Figure 2, using a crimped test sample rig with a shape and size in accordance to Table 1. The performance test result evaluation criteria for the high-temperature testing system for crimped copper pipe and fitting assemblies used in natural gas supply installations is its operational safety given that the heat source chamber (see Figure 5) of the electric oven (see Figure 3) houses a test sample rig pressurized with air to 5+0,5 bar at a constant 750°C temperature for 30 minutes.
The testing procedure starts by constructing the test sample rig of the size and dimensions specified in Table 1 by crimping its components, it continues with checking the components of the system as it is illustrated in Figure 2. Using threaded fitting connectors, the test sample rig is attached to the compressor and gas flowmeter assembly [4]. The threaded connector fittings to the gas flowmeter are sealed using rubber gaskets, other connections are sealed using hemp fibre and sealing paste. The threaded connections at the ends of the test sample rig are sealed with Loctite type plumbing thread and heat resistant paste, rated at a minimum 800°C operating temperature. A 10-bar rated pressure gauge is attached with a threaded connector to the output end of the test sample rig and is used to measure the testing pressure followed by a purge valve used to release air from the installation. Using the compressor, the assembly is pressurized to 6 bar and tested for leaks using a leak detection spray [7,8]. Having insured there are no leaks in the compressor-flowmeter-sample-gauge-valve assembly pressure is released. The test sample rig is mounted in the electric oven, the oven lid is closed, and the lid bas secured with the quick lock clamps. Using nitrogen at a pressure lesser or equal to 0,8 bar and the valve at the output end of the test sample rig the air is purged from the assembly. The end of the air purging process is signalled both visually and audibly by the nitrogen cartridge gas detector. The trial assembly is completely sealed and then pressurized by gradually raising the pressure inside to 5 + 0,5 bar, as specified in Table 1. Pressure values displayed by the test sample rig mounted and compressor mounted pressure gauges are noted as well as the gas flowmeter index and time of testing. The high-temperature performance testing system for crimped copper pipe and fitting assemblies used in natural gas supply installations is left in stand-by for ten minutes [7,8]. The electric oven is connected to a power supply and powered on with the mechanical operation switch. Using the digital display of the temperature controller, the temperature is set to 750 °C, the temperature value is set depending on the trial parameters (see Table 1), the proprieties of the copper material used for the pipes and fittings in the test rig and those of the materials used for sealing.
After the real-time temperature reading in the heat source chamber has stabilized (see Figure 7) the timing of the 30-minute test period begins in conjunction with the careful monitoring of the test sample rig pressure. At a

temperature of 750°C (Figure 9, a) the registered test sample rig pressure is 5,85 bar (Figure 9, b), and after 30 minutes the inner pressure in the test assembly will reach 7,41 bar (Figure 9, b).


A b c

**Figure 9:** Final test
a – Testing temperature (750 °C); b – inner pressure at time = 0 and temp= 750 °C;
c – inner pressure at time = 30 min and temp=750 °C.

After the 30 minute test period expires the electric oven is powered off using the mechanical operating switch and disconnected from the electrical power supply. The oven lid is raised and the tested rig left to rest and cool down for at least 10 minutes, then gradually depressurized. The lack of thermal links between the heat chamber and the oven casing, the high degree of insulation and small size of the heat source allow for the quick drop in temperature and the ability to handle the test sample rig within a maximum of 15 minutes.
The evaluation test results of the high-temperature performance testing system for crimped copper pipe and fitting assemblies used in natural gas supply installations guarantees the operational safety of the system while complying to all the technical requirements set in Table 1, a minimum temperature limit of (650 + 10 °C), a pressure of (5 + 0,5 bar) and a trial period of (30 min).
The third experimental reliability test is applied to the entire system, as it is presented in Figure 2, the test uses six test sample rigs in succession with shapes and sizes in accordance to table 1 [4]. The evaluation criteria for the test results on the proper operation trial of the high-temperature performance testing system for crimped copper pipe and fitting assemblies used in natural gas supply installations is that of achieved operational safety given a program of all six successive test sample rig tests with a constant 650°C temperature in the heat source chamber (see Figure 5) of the electric oven (see Figure 3) with each test sample pressurized to 5 + 0,5 bar, for 30 minutes.
For each test sample rig the testing procedure has been carried out following the steps listed in the description of the second reliability test. During each test a maximum inner pressure value greater than 7,2 bar has been recorded. After 3,9 hours of continuous operation of the high-temperature performance testing system for crimped copper pipe and fitting assemblies used in natural gas supply installations, of which 3,5 hours had the electric oven functioning at temperatures greater than 650°C the system was dismantled and its components were inspected.
The test results of the proper operation evaluation trial for the high-temperature performance testing system for crimped copper pipe and fitting assemblies used in natural gas supply installations guarantee the safe operation of the system if full compliance to the technical requirements listed in Table 1 is maintained, 650 ± 10 °C temperature, 5 ± 0,5 bar pressure and 30 minutes test times. The only inconsistency found vas the partial carbonization of the first layer of thermal insulation on the electric oven heat source. The layer, made of thermo-resistant fibre cardboard is removable, easily replaced and is considered a consumable item. When used within the parameters listed in Table 1 the removable insulating layer is replaced after the high temperature testing of eight crimped copper pipe and fitting type test sample assemblies. For trials at temperature ranges between 650 and 800°C the first layer of insulation of the electric oven is replaced after every trial.

## 3. CONCLUSIONS

Experimental testing procedures for the quality of crimped copper pipe and fitting assemblies are designed to evaluate the compliance to all technical conditions that guarantee the complete safety in operation for natural gas supply installations, both under normal operating conditions and under hazardous conditions caused by earthquake, fires, etc.
The procedure for experimental testing of the high temperature performance of crimped copper pipe and fittings assemblies belongs in this operational context as it is based on ascertaining the resistance and sealing performance of these assemblies by using test sample rigs and the testing parameters listed in Table 1.

For the application of the procedure for experimental testing of high temperature performance of the crimper copper pipe and fitting assemblies used in natural gas installations the authors have developed and built the original system shown in Figure 2.
Operational safety of the high-temperature performance testing system for crimped copper pipe and fitting assemblies used in natural gas supply installations (see Figure 2) has been certified by results obtained by the authors of this article following the completion of three reliability testing experiments, using the operational envelope limit testing method, one test to validate the proper operation of the electric oven (see Figure 3) and the other two to verify the system performance and adequate operation respectively.

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