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TECHNOLOGICAL AND MECHANICAL STUDIES

THIS REPORT DESCRIBES
THE WORKS CARRIED OUT
IN THE FRAME OF THE
ISPRA TECHNOLOGICAL SERVICE

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1. Introduction

The research program related to technology of ORGEL type reactors is under development. Some programs have been readapted on the basis of preliminary results and new problems arising from further studies of conceptual design.

This paper is mainly a survey to show what lines are followed in carrying out the investigations and the partial results obtained. The most significant results concern the elaboration and construction of the experimental set-up foreseen for each assignment.

2. Channel Connections

The problem of the connections of channel tubes to the primary circuit and the reactor vessel have been tackled analytically.

A distinction was made between cold aluminum or zircalloy to stainless steel, hot SAP to steel and junctions using gaskets. The main effort was concentrated on the two last points.

2.1. Hot SAP to steel connection

The requirements of a SAP steel junction are related to the leaktightness to be achieved under design temperature and the fatigue resistance implied by temperature and pressure variations.

For the experimental investigation a gas loop has been built in which these connections are tested under conditions of thermal and pressure cycling. The thermal cycling is obtained by regulating the power of an internal heating element and the cold gas circulation inside the test section. The pressure cycling is obtained by switching alternatively two tanks at different pressures on the test section. Series of tests are carried out on various connection designs which differ either in the material and the thicknesses involved or in the machining of the steel surfaces in contact with SAP or in the connecting systems.

The results of a particular test considered satisfactory for a sandwich type rolled joint of following dimensions:
Stainless steel tube (304 AISI) Ø 96 - 102 mm
SAP-AIAG 14 % oxide Ø 90 - 96 mm
Stainless steel ring (304 AISI) Ø 84 - 90 mm
are:
Cold tests: Leak detection with helium gas spectrograph showed no leakage
Axial load test: 5.900 kg pull-out strength
Hot tests performed in the gas loop (see photo 1):
45 temperature cycles between 250°C and 400°C
$1,8.10^5$ pressure cycles at 400°C between 19,5 kg/cm^2 and 17 kg/cm^2
1.10^5 pressure cycles at 20°C between 19,5 kg/cm^2 and 17 kg/cm^2

No leakages have been measured during all the tests with a special rig using a calibrated glass capillary for volumetric measurements of the leaks. This result will be checked further with a helium mass spectrograph leak detector.

Tests with a hydraulic mandrel have been done as a tentative to avoid the problems of torque and the necessity of a rigid external support during rolling. This mandrel deforms the tubes by hydraulic pressure, transmitted through a copper membrane. Tests on this type of connecting system are in development.

A new approach to the problem of connections of SAP to steel tubes is a technique involving the detonation of explosive charges inside the tube assembly. The resulting shock waves create an instantaneous high pressure and temperature condition which can lead to metallurgical bonds.

Preliminary tests performed with SAP on aluminum and SAP on SAP using this technique are very satisfactory (photo 2 and 3). The welding of SAP on stainless steel and aluminum on stainless steel present a rather brittle interlayer (900 Vickers hardness) (photo 4). A recent test on a connection of Al tube plated before with a layer of copper (12 μ thick), and stainless steel tube gives an interlayer of 415 Vickers hardness and a pull-out strength of 4000 kgs on a diameter of the inner tube of 60 mm. This result looks promising.

In order to simplify the problem of connections, a research has been launched to form SAP tubes, with a reduction or increase of diameter. Increase of diameter with the ordinary system of mandrel with rolls is limited to values quite smaller than the elongation at rupture of cold SAP.

An important variation in diameter can be obtained by explosive forming. A tube of SAP AIAG 14 % Al_2O_3, Ø 90/96 mm has reached successfully a reduction of 20 % in diameter (photo 5). In order to avoid ripples on the tube it was found out that it was helpful to provide vacuum between the tube and the inner mandrel.

2.2. Junction using gaskets

Systematic tests on gaskets at pressure and temperature corresponding to normal operating conditions with the real medium or helium gas will be performed.

The sealings on which tests will be performed are:
Metaflex gaskets, K-seals, Flat gaskets, Conoseals, Bar-X-seals.

Influence of following parameters will be measured: inner pressure, temperature, bolt forces, creep, surface finishing, bending and radial displacement of flanges, temperature and pressure cycling.

Testing apparatus:
An apparatus for high temperature tests with helium leak detection in which all the above mentioned parameters will be measured is already under test (photo 6). Another apparatus has been constructed in order to compare the leakages of a gas and an organic liquid under the same physical and geometrical conditions (photo 7). Measurements of leakages of organic are performed by means of an ionisation chamber.

3. Thermal Insulation of the Channel

3.1. As far as the liquid insulation is concerned, the program has been centered on omitting the use of a thin liner tube by a special design of the fuel assemblies which would include at their periphery the device for limitation of the flow in the insulating space. Measurements of the flow rate versus the pressure drop in the insulant space have been done for different devices, with water. One of them (metallic O-ring, coated with silice tissue) looks promising. With a pressure drop of the order of 0,5 atm. for each ring, it is possible to obtain a N_{Re} less than 80 in an annular space of 2 mm.

3.2. The solid insulation test program has been defined. The basic design for the tests is a channel with liner tube and pressure tube axially connected and prestrained mechanically or thermally.

The program has been started with the construction of a first model (see fig.8) which has to be considered as a mechanical test apparatus for solid insulated channels.

In this apparatus the liner and pressure tubes are connected by a mechanical jack which allows free expansion of the liner tube or a variable amount of prestrain. This model will be used first for experimental stress analysis in static condition, and afterwards, will be submitted to thermal cycling and to a residual stress analysis. Special attention will be given to the behaviour of the insulating material (porous alumina, in the first tests) in operation. This model will operate in next July.

Two other models (one 30 cm long, the other 2 m long) including rolled joints are now under project. Some samples of the insulating material under development in private firms are now available (see photo 9). The characteristics of porous alumina made by Norton Company which will insulate the first model are the following:

- porosity	55 %
- radial compression resistance	200 kg/cm^2
- tensile resistance (circumferential)	36 kg/cm^2
- elasticity modulus	2000 kg/mm^2
- thermal expansion coefficient	$8.10^{-6}\ {}^{o}C^{-1}$

It has been delivered in 6 mm thick tubes. Tests for obtaining thinner tubes have been undertaken.

CSF firm has delivered alumina tubes of 70 % of porosity, the conductivity of which is about 6.10^{-3} W/^{o}C cm, available in 6 mm and 3 mm thickness. The material is very homogeneous but rather friable and will probably give problems for full scale use.

Zirconia is under development at Desmarquest (Paris): 5 mm thick tubes are available with a porosity of 50 % and thermal conductivity of about 2.10^{-3} W/^{o}C cm. A new process for obtaining 3 mm thick tubes is now under research. The dimensional tolerances of the tubes available are approximately:

- diameters: $\pm \frac{2}{10}$ mm ($\pm \frac{1}{10}$ mm on the same tube)

- thickness: $\pm \frac{5}{100}$ mm ($\pm \frac{3}{100}$ mm on the same tube)

Another process avoiding problems of the feasibility of tubes of small thickness and high tolerance requirements, in addition to the difficult problems of their mounting in the channel, is to perform the insulation layer by means of ceramic spraying.

Thermal conductivity and mechanical characteristic measurements concerning zirconia layers sprayed on SAP tubes have been undertaken. The results are following:

- thermal conductivity: $5{,}2.10^{-3}$ W/^{o}C cm ($\pm$ 15 %) at 300^{o}C. The layer had a porosity of about 10 %, controlled by microscopic examination and density measurements.
- traction resistance: 215 kg/cm^{2}
- modulus of elasticity: 2000 kg/mm^{2} ($\pm$ 10 %)
- thermal expansion coefficient: 8.10^{-6} ^{o}C^{-1} between 0 and 400^{o}C.

Actually, the research concerns especially the improvement of the thermal resistivity of sprayed layers using special techniques for spraying to increase the porosity. Appreciable gains in this field would allow the use of sprayed alumina instead of zirconia, the behaviour of which under radiation is less known up to now than that of alumina.

3.3. A gas insulated channel has been chosen for the first full scale experiment in the technological loop, on the basis of the following considerations:

- it is easier to fabricate since it implies fewer technological problems.
- good insulation properties are foreseen.

On the other hand we studied a particular solution (see fig. 10) in order to limit the thickness of the hot pressure tube. This solution, if the test will be successful, is very interesting from the neutron economy point of view and technological aspect. Reference data for this channel are:

Vertical channel, up to down flow.

Active lengths:	4.8 m
Maximum organic velocity:	10 m/sec
Maximum flow rate:	11 l/sec
Outlet pressure:	8 kg/cm^2
Maximum pressure drop:	12 kg/cm^2
Maximum temperature:	420°C
Inner hot tube (SAP) thickness:	2 mm
Outer cold tube thickness aluminum-magnesium-alloy:	1 mm
alternatively zircalloy 2:	0.8 mm
Insulation thickness (nitrogen)	3 mm

The pressures in the gas insulation space and at the exit of the channel are equalized. This is obtained by putting in communication the insulation space with the lower collector which acts also as a pressurizer for the loop. To avoid organic vapour diffusion and condensation into the insulation space a small flow of clean nitrogen is provided in counterflow with the organic vapours through an annular gap around the hot tube.

A preliminary test has been done in a small organic loop at Progil Laboratories to determine the minimum flow rate to avoid the organic diffusion through the annular gap. First results show that with an annular gap Ø 64/66 mm, 40 mm high, the minimum velocity of the gas counterflow in the pressure and temperature operating conditions corresponds to the theoretical diffusion velocity of organic vapour in non turbulent nitrogen.

The application of this principle of channel in the reactor implies the presence of a tank at the outlet of the channel with a gas cushion connected with the gas of the pressurizer of the primary circuit. Every channel can also be connected to a single collector which may constitute the organic circuit pressurizer.

3.4. The flow-sheet of the technological loop in which the channel will be tested is given in fig. 11.

The operating conditions of the loop are:

- maximum pressure: $40\ kg/cm^2$
- maximum temperature: $420^{\circ}C$
- flow-rate: $40\ m^3/h$
- total head of the circulation pumps at $40\ m^3/h$: $25\ kg/cm^2$
- maximum length of a vertical test section: 6 m

The loop is composed of 2 different circuits which may run independently at different temperatures and be switched on alternatively on the test section in order to perform a thermal cycling and thermal shocks as occur in the outlet end of the channel after a reactor scram.

Experimental program on the test channel is the following one:

- Measurement of thermal insulation. Around the channel a jacket is provided with water circulation at a controlled temperature equal to the moderator temperature in the reactor. The cross section of the water jacket is relatively small in order to increase the accuracy of the measurement of thermal losses.
- Stresses and displacement measurements on the internal and external tubes at some particular points of the channel.
- Behaviour of spacers between the hot and cold tube as a consequence of thermal cycling.
- Leak measurements and diffusion of organic vapour in the insulating gas.
- Mechanical behaviour of end plates and connections, vibrations of fuel rods and filler pieces of fuel assemblies.

4. Thermo-mechanical Stability of Fuel Clusters

A theoretical study of the problem of temperature distribution in the cladding of fuel elements and of the deformation of the fuel rods has been carried out in order to evaluate the relative importance of the various hydraulic, thermal and mechanical parameters. (Influence of the local heat transfer coefficient, along the circumference of the thermal resistance between pellets and cladding, of the free length of a rod between spacers).

It was found that for a relative variation of 20 % i.e. of the local heat transfer coefficient, where the specific power is assumed to be 100 W/cm^2, the temperature difference along the circumference is about 3^{o}C or 13^{o}C depending on whether the distribution has a symmetry of the order of 6 or a maximum and minimum diametrically opposed. In the second case, where deformation of the rod is maximum, the circumferential conduction in the cladding has little importance and almost equal temperature differences are found between cladding made of SAP of 1.3 mm thickness and steel claddings of 0.2 mm thickness. The thermal resistance between pellets and cladding influences not only the average temperature of the fuel pellets but also the circumferential temperature variation of the cladding. When this thermal resistance is inferior to 2^{o}C/W/cm^2, the thermal conductivity in the fuel pellets lowers the temperature variation in the cladding. For higher value of this resistance the local heat transfer coefficient becomes the governing factor.

An additional factor leading to temperature differences along the periphery of the fuel cladding is the non uniform temperature distribution of the organic coolant in the cluster subchannels.

As a consequence of all the above mentioned factors and for a cluster of 7 rods (uranium carbide - Ø 1" SAP cladding) circumferential temperature differences of about 10^o to 15^{o}C are expected on the peripheral fuel rods in nominal conditions.

It is the object of the experimental program to ascertain this estimate, to study the resulting deformation in the cluster, and to define the values of the hydraulic, thermal and mechanical parameters which will insure a fuel element which is thermomechanically stable.

The experimental program includes:

a) The study of fluid velocity distribution in channel cross-sections, of sub-channel mixing and of pressure drops due to spacers.
b) The study of the local heat transfer coefficient
c) The measurement of deformations of rods
d) The analysis of temperature distribution in the cladding

The following test equipments have been constructed:

1) A water loop (photo 12) for the study of point a) and b). The model is at scale 2. The radial position of peripheral rods can be changed.
2) An organic loop (photo 13) for the study of point c). The test section (photo 13-1) contains a dummy fuel cluster of seven rods. One peripheral rod will be heated internally by a thermocoax wire inbedded in a silver core, the SAP cladding being free to deform. The gap is filled with silver powder simulating the contact resistance between fuel and cladding. The boundary conditions for this rod are satisfied by heating the surrounding three rods.
3) A rheoelectrical analogy installation using paper "Teledeltos" for the study of point d). Results given by points a), b), c) are used in defining boundary conditions.

5. Experimental Stress Analysis on Fuel Element Cage by Application of Photostress and Strain Gages Techniques.

Among the various configurations of fuel element clusters we have started to investigate the mechanical behaviour of a beryllium cage fuel support working in compression, the axial loads being transmitted from cluster to cluster through a central hinge point. The test piece was made from anticorrodal also to take advantages in measuring strains of the lower modulus of elasticity.

The load was applied by an Amsler traction-compression machine, this load reaching the maximum value of 600 kg, expected on the last fuel cluster of piled up fuel units in an ORGEL channel.

Both photo stress methods and strain gage measurements have given same results and indicated high bending stresses. Consequently we tested a new concept where the axial load is transferred to the periphery directly. The compressive stresses obtained are allowable.

This design is better suited for longer cages since safety coefficient with regard to buckling can be set with respect to the theoretical value of the buckling load.

6. Friction and Wear

A wear machine (photo No. 14) has been built to investigate resistance to wear of materials foreseen in the ORGEL channel and primary circuit. The machine is designed to simulate point-line-contacts as can occur in the channel due to thermal expansion and vibrations. The specimens are submitted to rotational and hammering movements at various frequencies, amplitudes and loads.

Preliminary program includes tests in terphenyl at 400°C on following pairs of materials:

SAP/SAP

SAP/Aluminum

SAP/Stainless Steel (304 AISI)

SAP/Sprayed ZrO_2

SAP/Sprayed Al_2O_3

SAP/Metal containing graphite

SAP/Soft material

Stainless Steel (304 AISI)/Stainless Steel (304 AISI)

The final object is to improve the resistance to wear if necessary by metal coating the surfaces.

7. Channel Rupture in the Reactor Core

Aim of the study is to determine the consequence of the rupture of a channel on the surrounding channels and on the vessel. Two phenomena resulting from the rupture of the stress tube are the shock wave due to pressure release and the effect of the local increase in pressure due to vapour formation consequent to the heat transfer between the hot organic and the water. On the basis of theoretical study it is justified to say that energy absorbed by elastic deformation result in a negligible stress increase of the surrounding tubes.

The water vapour amount resulting from heat exchange between hot organic and moderator is a function of the organic temperature and the shape assumed by the organic jet streaming out of the fissure. This energy release could be quite rapid and be of primary importance in causing damages and therefore influence the safety criteria. A third phenomenon that has to be considered is the heating of the surrounding tubes, which could endanger particularly a cold pressure tube.

For the solution of the problems of rupture of the pressure tube, different steps of experiments are forseen. The aim of the first step is to find out the shape of the fissure which can be expected when a SAP tube explodes.

These experiments are now performed with a small test loop (photo 15) equipped with strain measuring devices at high temperature (photo 16). One of the SAP tubes tested is shown on photo No. 17, showing the fissure and the kind of fracture of the material.

The second part of the experiments is meant to measure the coefficient of heat transfer between hot organic and water, by injection of a controlled amount of hot organic in water, and visualisation of the mixing as well as measurement of pressure rise.

A third global experiment is foreseen in a vessel whose geometry reproduces a model of a part of the ORGEL core. Pressure and temperature rise and mechanical strains will be measured.

8. Conclusion

The work done on the different research program has been undertaken with the emphasis on the basic aspect of the problems in order that the results satisfy a rather large field of application. At the same time, the conceptual design evolves along different lines since we do not want to fix a single configuration of ORGEL for the moment.

On the other hand the program established so far was intended to fulfil a planning which includes the construction and the tests of ORGEL channels in ESSOR: this fact corresponds to a precise and pressing task.

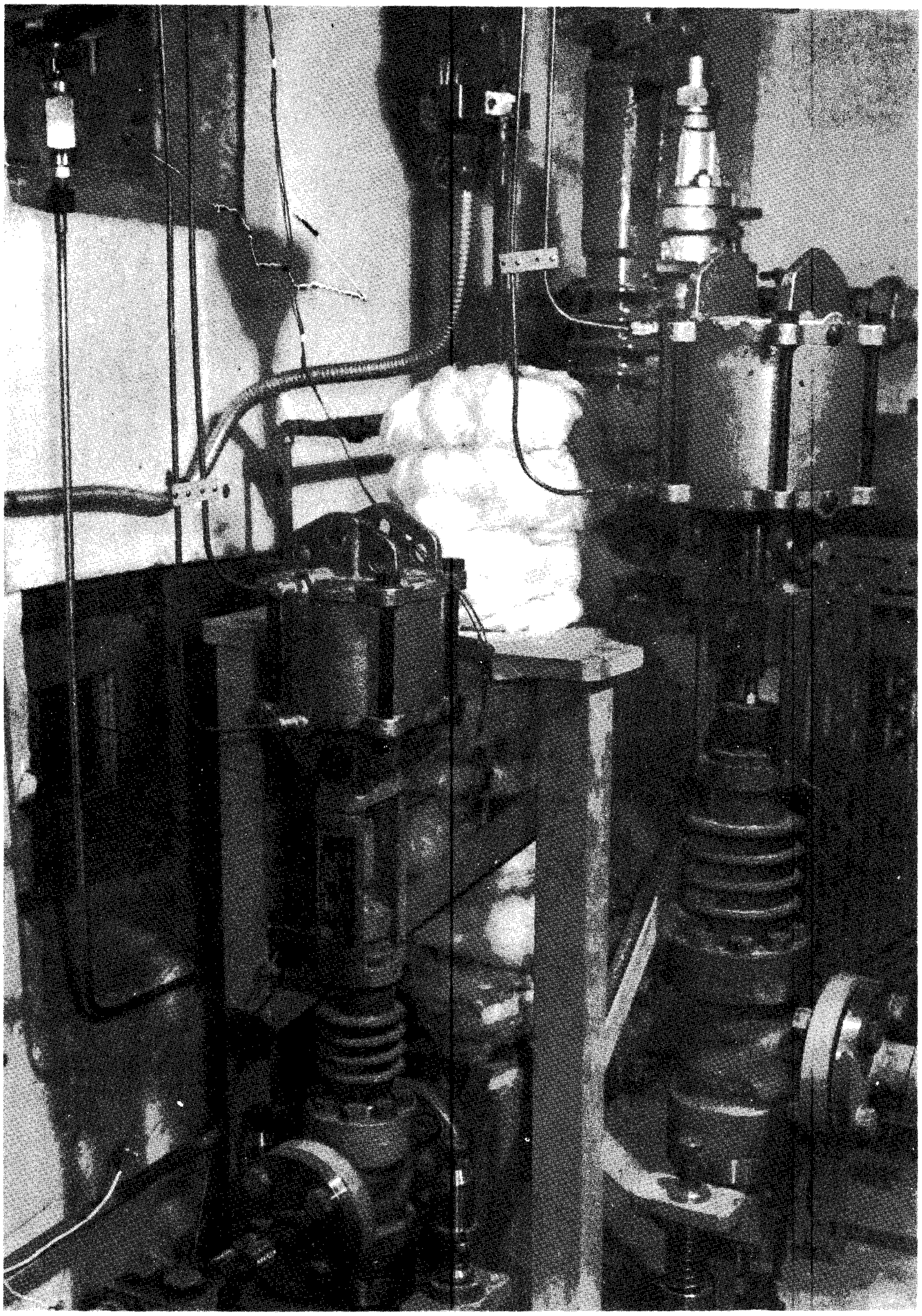


Photo n° 1 Rolled joint test section during experiment with extensometric bridge, leak detection tube, inspection window, heating element connexions, and operating valves.

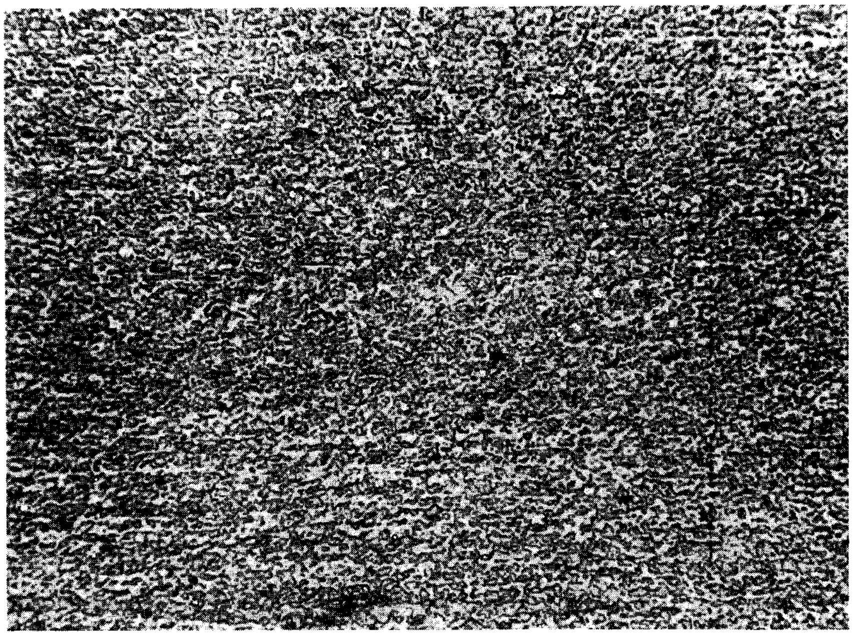


Photo n° 2 Explosive welding
SAP - SAP
enlarged 600 x etched.

Photo n° 3 Explosive welding
SAP - Aluminium
enlarged 400 x etched.

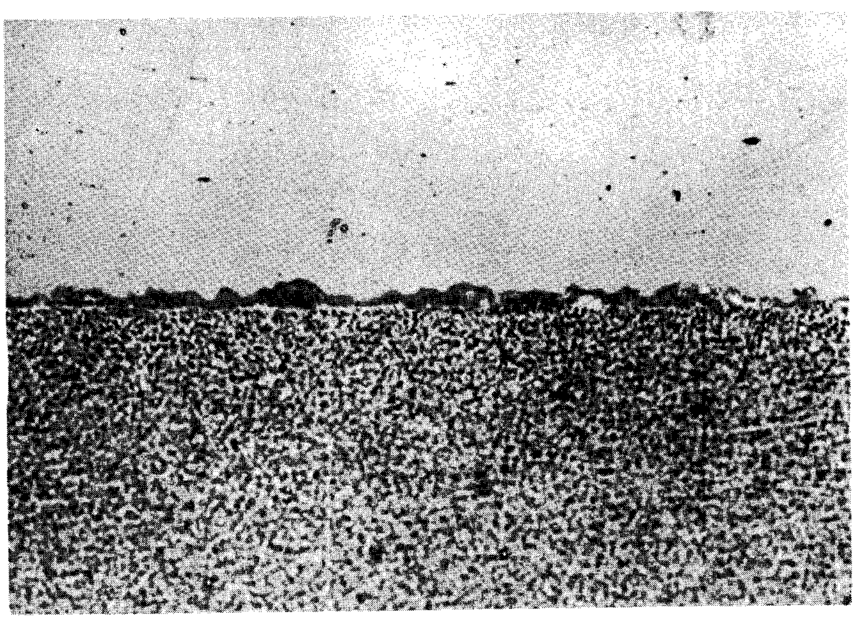


Photo n° 4 Explosive welding
SAP - Stainless stell
enlarged 400 x

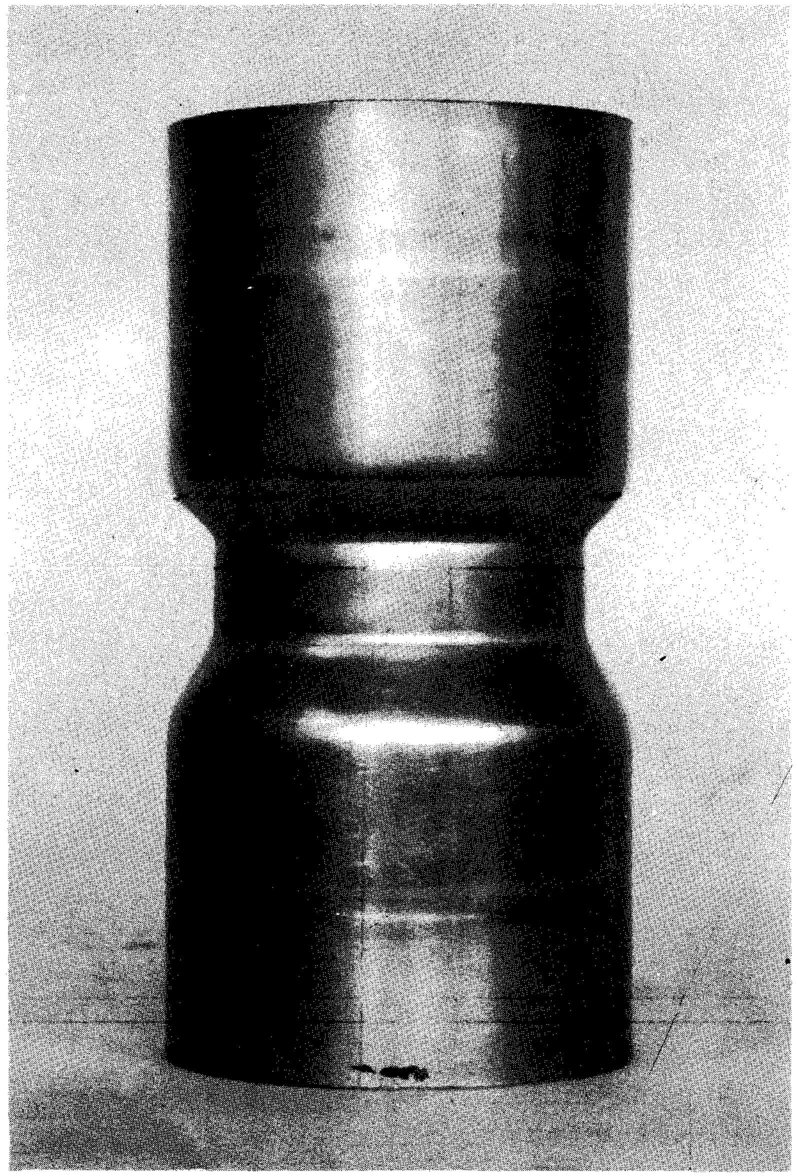


Photo n° 5 Deformed tube

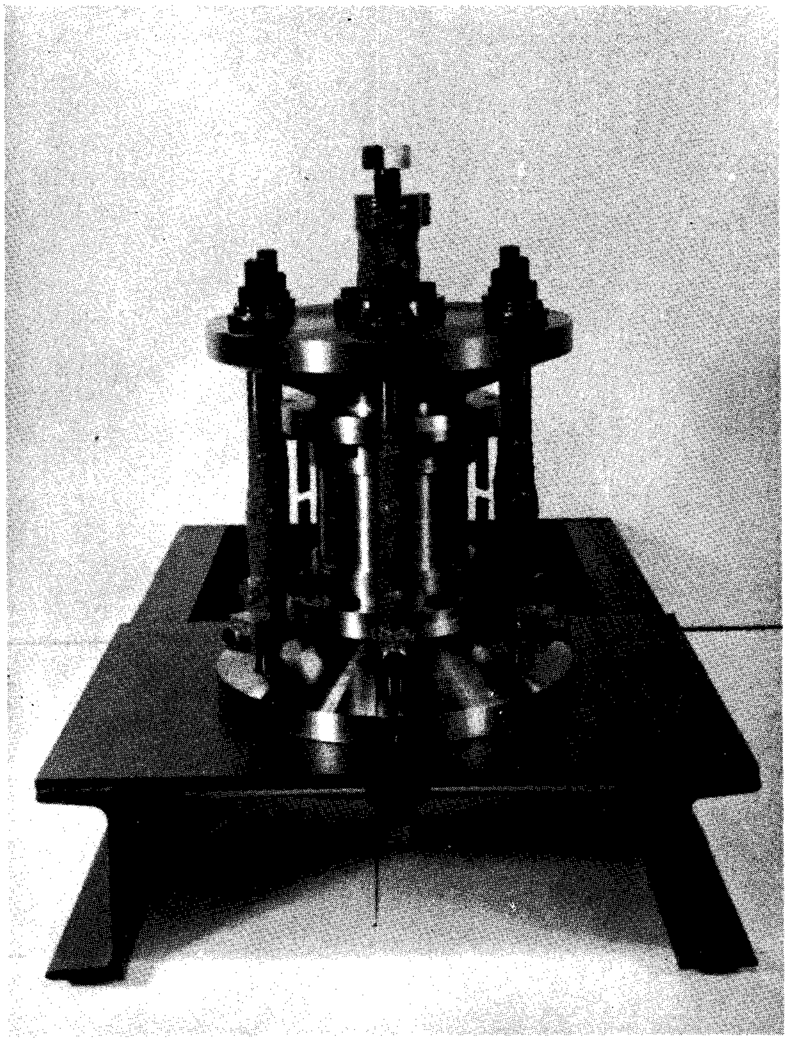


Photo n° 6 - Sealings testing apparatus

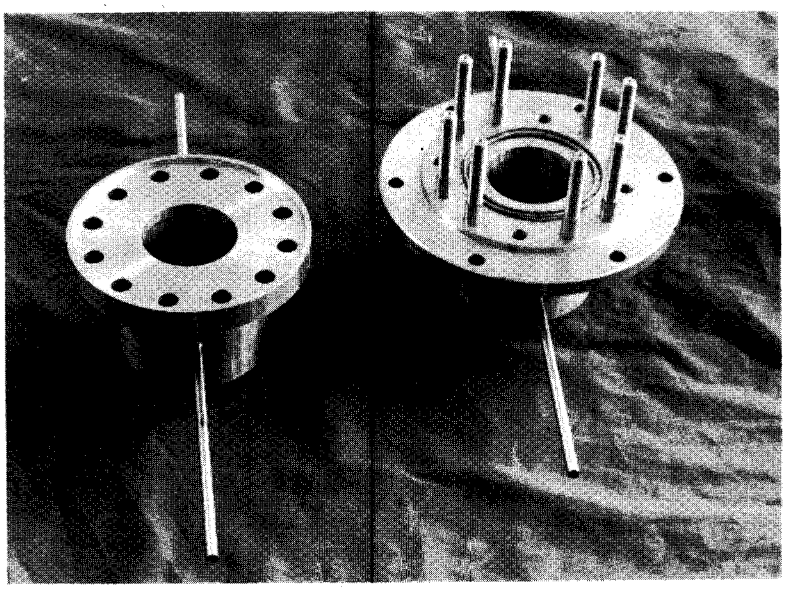
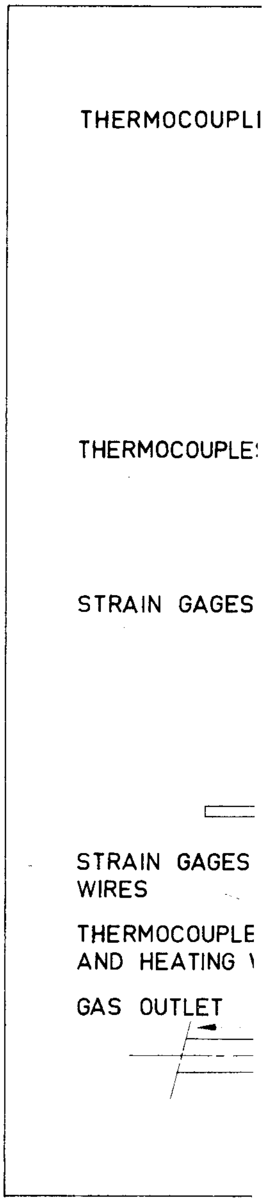


Photo n° 7 Gasket and leak test apparatus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STRAIN GAGES
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GAS OUTLET

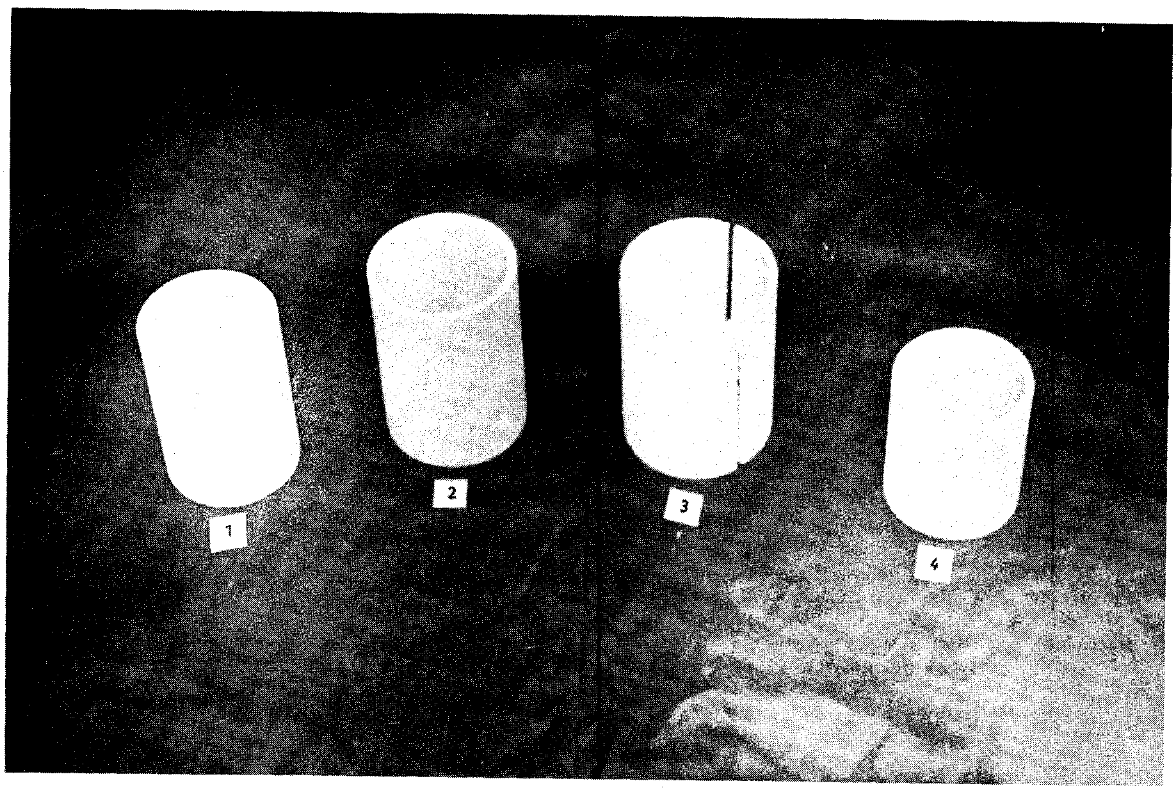
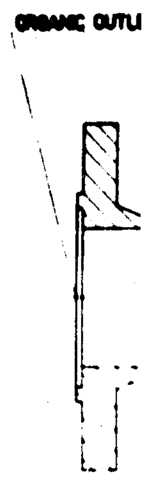
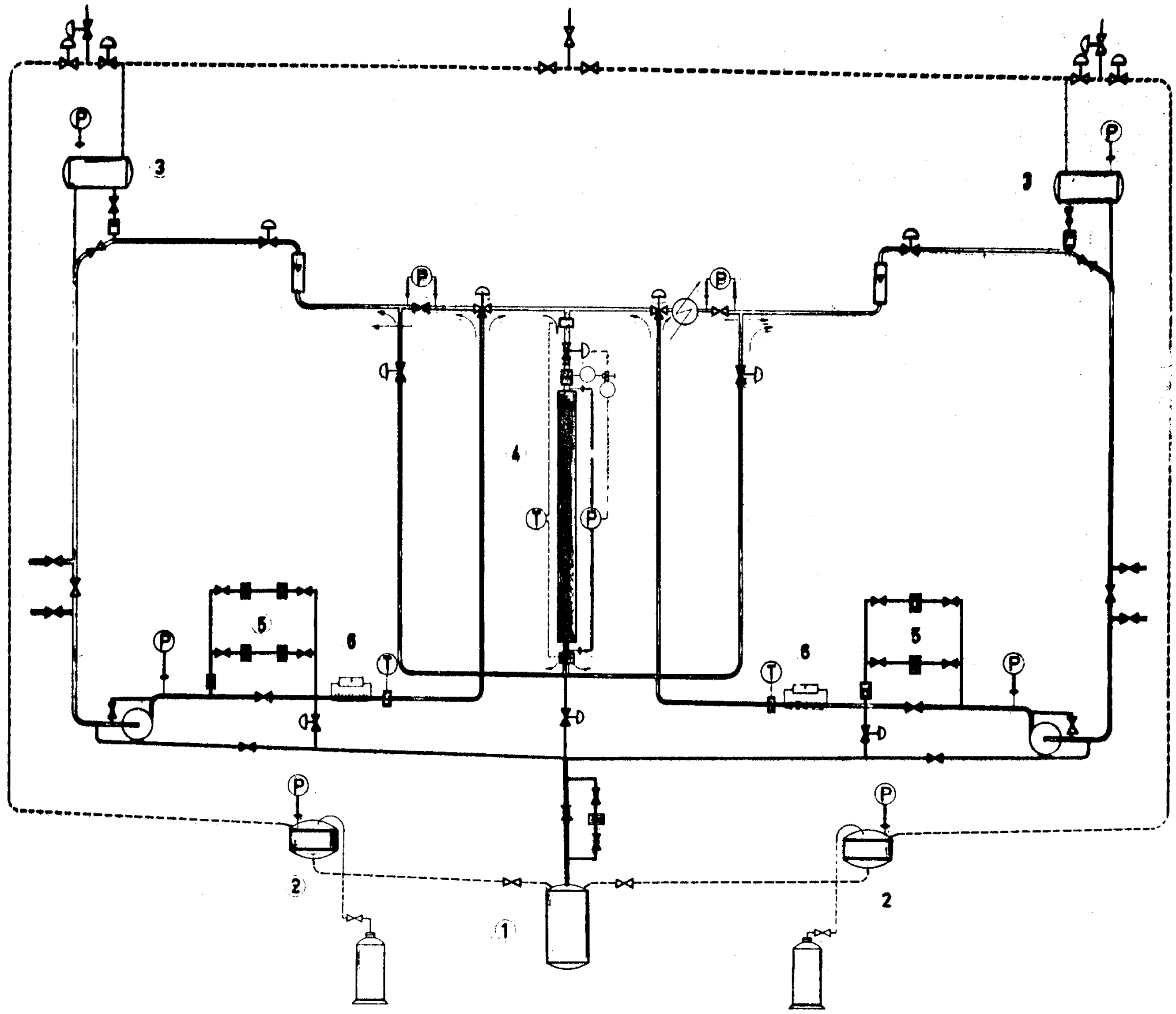


Photo n° 9


ORGANIC OUTLI



① DUMP AND FUSION TANK

② PRESSURIZER

③ DEGAZIFIER

④ TEST-SECTION

⑤ FILTER

⑥ HEATING SYSTEM

——— HIGH TEMPERATURE TEST

—·—·— LOW TEMPERATURE TEST

------ NITROGEN

▪▪▪▪ CAPILLARY TUBES

Figure 11

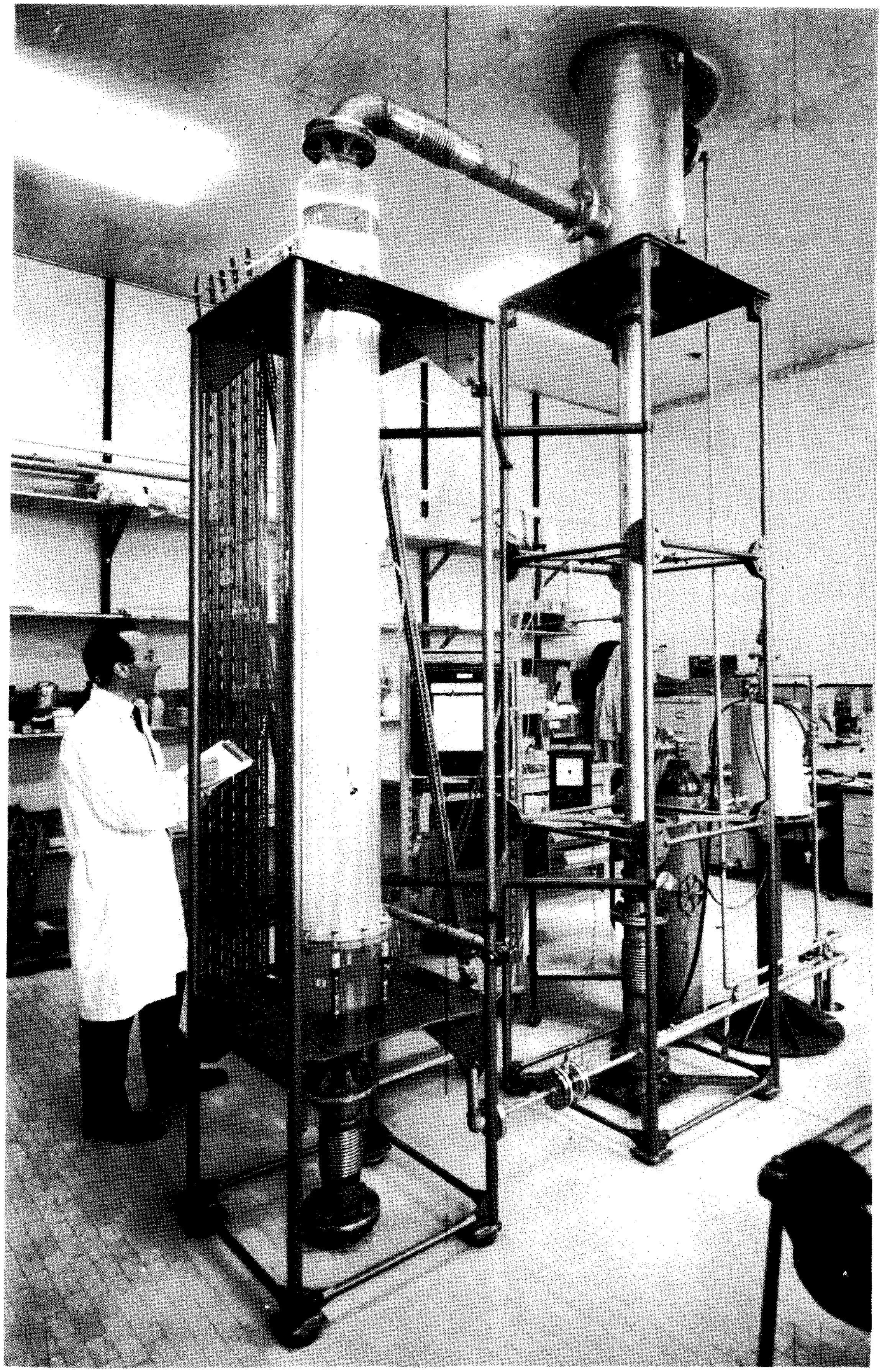
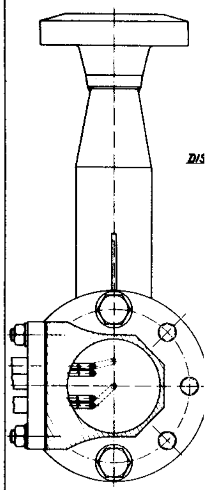


Photo n° 12 Upper part of water test loop with experimental model

Photo n° 13 Organic Test Loop (Photo S.E.P.R.)

COUPE B



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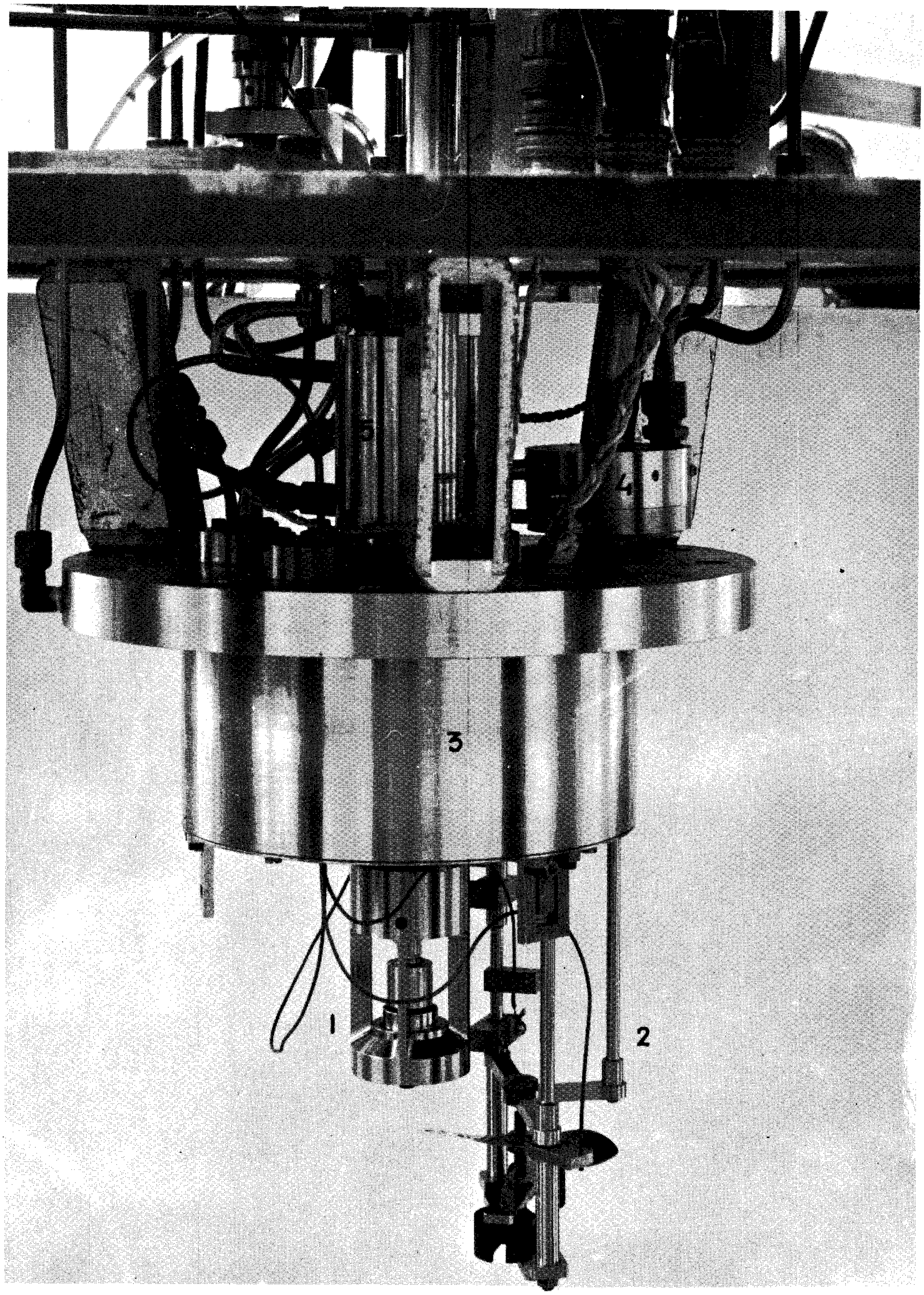
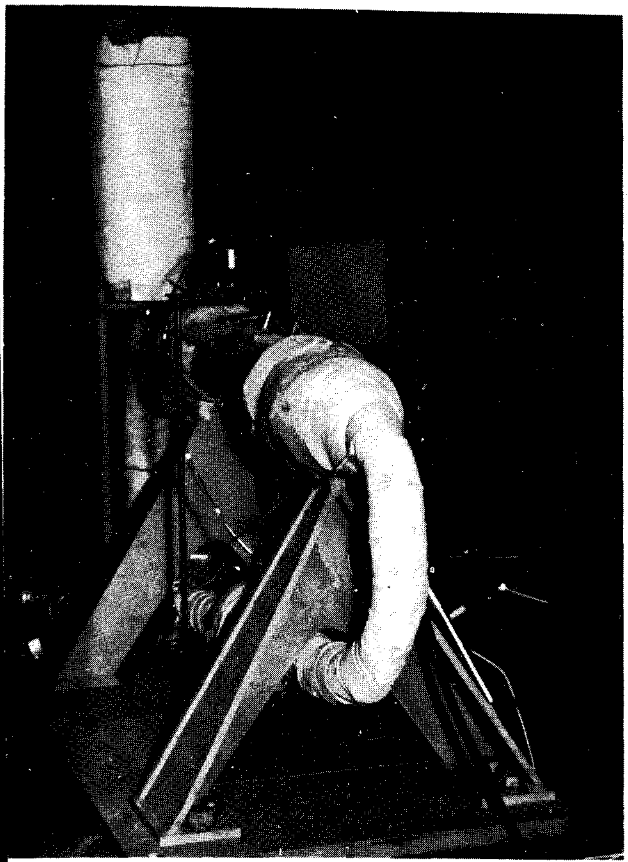


Photo n° 14 Detailed view of the contents of the reaction vessel, showing :

1.- specimen assembly
2.- magnetic stirrer and rotation indicating system
3.- cooler, filled with boiling water (to prevent the access of hot terphenyl vapours to the measuring equipment)
4.- manometer for measuring the alternating oil pressure
5.- column containing the lower vibrating piston and the vertical amplitude measuring system.



to nº 15 Test loop equipped with instrumentation ready for the test.

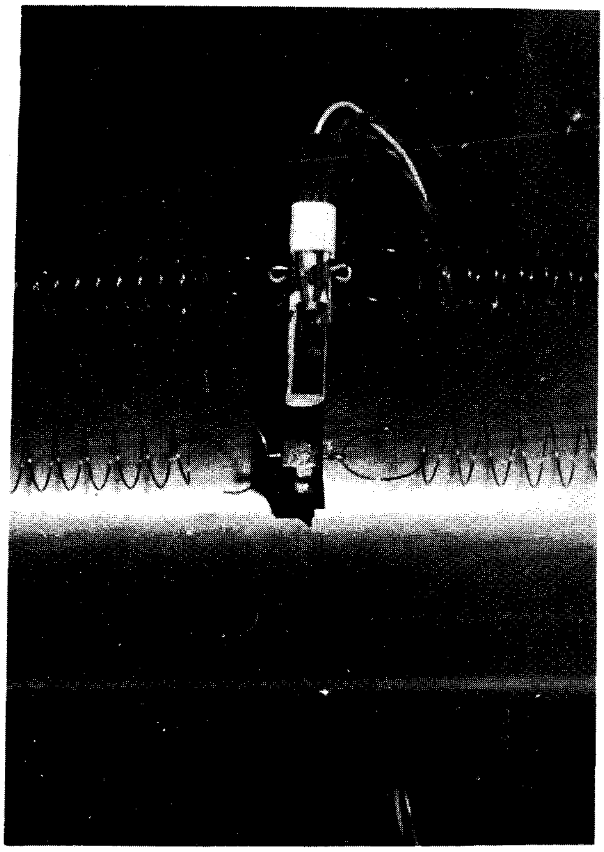


Photo nº 16 Strain transfer system for measuring high values of elongation at high temperatures.

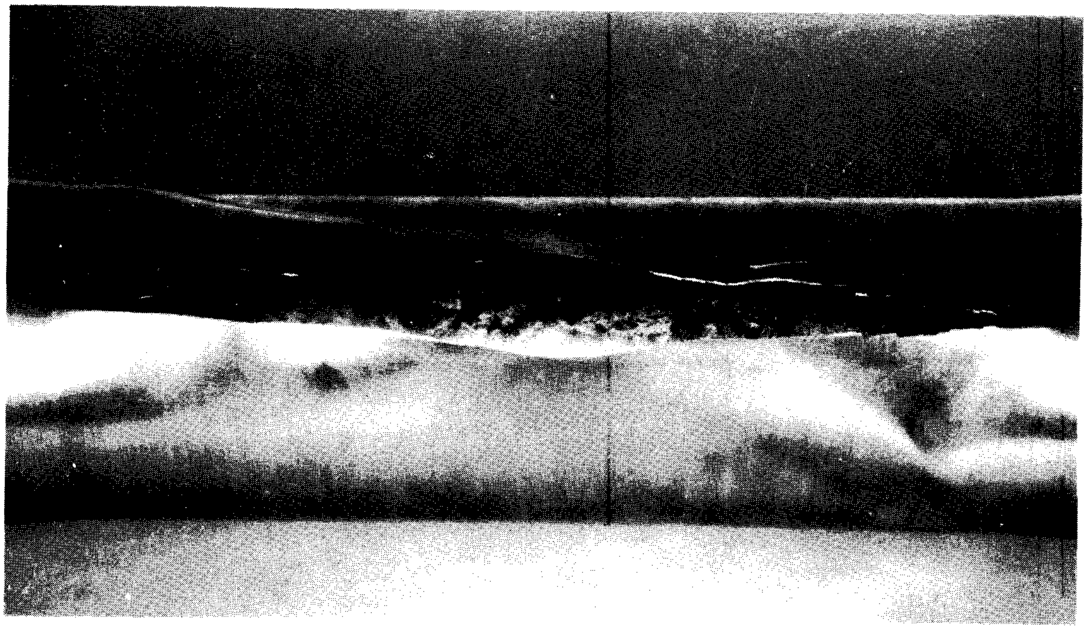


Photo nº 17 Test N. 2
Tube after explosion.