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BASIC DESIGN AND CONSTRUCTION OF AN EXPERIMENTAL PLANT FOR THE STUDY OF THERMAL OILS TO BE USED AS HEAT TRANSFER FLUIDS

RT/2024/9/ENEA

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ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES,
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I. Balog, G. Caputo, A. Cemmi, A. Lampasi, M. Ciotti, I. Di Sarcina, E. Mansi, F. Filippi, F. Panza, N. Ratto, A. Simonetti, G. Tiranti

Abstract

The following technical report describe a pilot scale plant able to study liquid heat transfer fluids behaviour undergoes to thermal cycles. A single pipe joule heated heat exchanger was designed and constructed in ENEA C.R. Casaccia in the framework of ARDECO Project to test the thermal stability of different thermal oils to be used in a safety system for a Sodium cooled generation IV nuclear power plant. The oil loop is equipped with a thermocouples system placed along the tube allowing to measure temperature values online and then to experimentally calculate the heat transfer coefficient and its variation. By testing heat transfer fluids in real-like conditions the thermal stability can be experimentally tested; degradation processes and related heat exchange coefficient drop can be studied. The oils degradation rate was periodically checked through offline analysis of oil sampled from the loop. Solid and gaseous degradation products can also be detected and analysed.

Key words: *Heat transfer fluids, thermal cycles, thermal degradation, heat transfer coefficient, oil loop.*

Riassunto

Il seguente rapporto tecnico descrive un impianto sperimentale in grado di testare fluidi di scambio termico sottoposti a cicli di riscaldamento – raffreddamento. L'impianto è stato progettato e realizzato nell'ambito del progetto ARDECO, nato tra l'accordo tra ENEA e CEA, per lo studio della stabilità termica di diversi oli diatermici da usare in un sistema di mitigazione incidentale per impianti nucleari di IV generazione raffreddati a sodio liquido. L'impianto è costituito da uno scambiatore di calore tubolare a singolo tubo riscaldato elettricamente per effetto Joule e dotato di un sistema di termocoppie in grado di misurare la temperatura dell'olio sulla parete e nel centro del tubo, permettendo di determinare sperimentalmente il coefficiente di scambio termico ed eventuali variazioni causate dalla degradazione termica del fluido testato. Nel corso dei test lo stato di degradazione dell'olio termico è stato periodicamente analizzato mediante misure offline di campioni di fluido. L'impianto permette inoltre l'analisi di eventuali prodotti di degradazione termica in fase solida e gassosa.

Contents

1. Introduction

Heat exchangers are widely used in industrial and engineering applications. The design procedure of heat exchangers is quite complicated, as it needs exact analysis of heat transfer rate, efficiency and pressure drop apart from issues such as long-term performance and the economic aspect of the equipment. In the last years, considerable effort has been devoted to research in traditional applications such as chemical processing, general manufacturing, energy devices, including general power systems, heat exchangers, and high-performance gas turbines. A major effort is directed toward the design, modelling, numerical analysis, and correlation of existing data on heat exchangers. A variety of approaches, some simple and straightforward, others novel or complex, are explored to enhance heat transfer.

A heat transfer process or equipment can be studied either experimentally by testing and taking measurements or analytically by analysis or calculations. The experimental approach has the advantage of dealing with the actual physical system and the desired quantity can be determined by measurement, within the limits of experimental error. However, this approach is expensive, time-consuming, and often impractical. The analytical approach (including numerical approach) has the advantage that it is fast and inexpensive, but the obtained results are subject to the accuracy of the assumptions and idealizations made in the analysis. In heat transfer studies, often a good compromise is reached by reducing the choices to just a few by analysis, and then verifying the findings experimentally. This last approach was followed in the present study. Heat transfer equipment, such as heat exchangers, boilers, condensers, radiators, heaters, furnaces, refrigerators, and solar collectors, is designed primarily based on heat transfer analysis. The heat transfer problems encountered in practice can be considered in two groups:

1. Rating problems, that deal with the determination of the heat transfer rate for an existing system at a specified temperature difference;
2. Sizing problems, that deal with the determination of the size of a system in order to transfer heat at a specified rate for a specified temperature difference.

In the framework of the ENEA-CEA ASTRID Research and Development Cooperation (ARDECO) project, a High Performance Oil Loop (HPOL) was designed and constructed to perform thermal cycles in safe conditions and very close to a real scenario. For the considered case study, one of the key points consisted in reaching a wall temperature of around 430°C (which is the liquid sodium working temperature) without using pressurized systems; the oil loop was configured as a single pipeline in which the joule heating was directly applied to the oil pipe, i.e. using the pipe itself as a resistance.

The ASTRID project, under development in France, aims at the construction of a Sodium cooled generation IV nuclear power plant that will be equipped with enforced safety systems, according to the nuclear safety philosophy, redundant in number and diversified in the basic physical concepts. One of the problems concerning safety is that of the cooling medium to be used during the emergency shut down of the reactor. In the ASTRID reactor, the heat produced by the nuclear reaction, during normal operating conditions, is subtracted from the circulation of liquid sodium. In the case of the "core melting" event, an emergency cooling circuit is provided in the reactor. In this context, the ARDECO agreement was launched to provide, among other things, for a joint CEA-ENEA study with the aim of testing three different diathermic oils as possible thermal vectors to be used as refrigerant fluid of the safety system of the ASTRID reactor.

One of the initial phases of the work was the setting of an effective plant model, trying to find the best configuration to carry out the experimentation. For the considered case study, different configurations were evaluated in order to identify the best setup in terms of expected experimental purposes as well as being more practicable from a technical point of view. Therefore, to overcome the problem of boundary conditions for complex geometry and the related heat exchange issues, the realized geometry is a single tube heat exchanger directly heated by the Joule effect. In this way, the use of other heat transfer media and the related problems was avoided.

The key concept was to apply the Joule heating directly to the oil pipe, i.e. using the pipe itself as a resistance. This would lead to a single pipe system, with many simplifications for the construction and positioning of the heating and monitoring setup. Joule monotube heating is also a simpler system to be simulated for calculating and analysing data.

During the design phase, some diathermic oils were identified as particularly suitable for the purpose and were considered as cooling media. However, due to the high temperature expected in the above emergency conditions, the need to test the selected oils was envisaged to prevent any degradation during the heat exchange phase from reducing the ability to remove the heat produced in the reactor beyond possibly produce products of thermal degradation of the oil that could occur.

The preliminary decision was directed towards a dual fluid configuration with molten salts to be used to simulate sodium and making as few modifications as possible compared to the Astrid configuration.

The result was a "crown" shape test section (TS) immersed in a molten salt mixture bath. This preliminary configuration was overcome, because it highlighted some problems related to heat exchange that could have led to difficulties in the construction of the experimental plant. Therefore, to solve the problem of boundary conditions for complex geometry and the related heat exchange problems, ENEA proposed the possibility of examining a different configuration for the heat exchange between molten salts and oil which, through simulations and experiments, would have provided for the construction of a double straight tube, with molten salts circulating in the outer tube and oil in the inner one. However, during the aforementioned evaluations, some doubts emerged about the corrosion resistance of the TS construction material (carbon steel) in the external part of the double tube in contact with the molten salts. In fact, to reach the correct experimental conditions, it emerged that the salt flow must be extremely turbulent and at a high temperature (550 °C), conditions that lead to a phenomenon of high erosion/corrosion on carbon steels. The experiments in ENEA showed that this material was not safe due to serious corrosion processes occurred after a few hours of tests. Therefore, two alternatives emerged: to continue, switching the TS material from carbon steel to stainless steel, not subject to corrosion, or to change the configuration again.

The final proposal was to directly heat the tube by the Joule effect. In this way, the use of molten salt and the related safety problems mentioned above were avoided.

2. Description of the plant configuration

The final experimental plant, as shown in the layout reported in Figure 1, consists of a circulation and cooling system for the diathermic oil and a heating section, the TS, in which an electric current heats the diathermic oil that circulates inside the pipe. The circulation and cooling system consist of a primary circuit fed with diathermic oil and a secondary circuit fed with glycol water. The air cooler (Figure 2) is equipped with a cooling power adjustment system made by installing three fans driven by electric motors equipped with power inverters. The secondary circuit is connected to the primary circuit by means of a plate heat exchanger with a thermal power of 350 kW. The circulation of fluids in the respective circuits is achieved by means of centrifugal pumps. In addition, in the primary circuit there is the installation of a reserve pump for which there is also the possibility of parallel operation to appropriately vary the oil flow. The centrifugal pumps will be equipped with a flow rate regulation system by means of a power inverter.

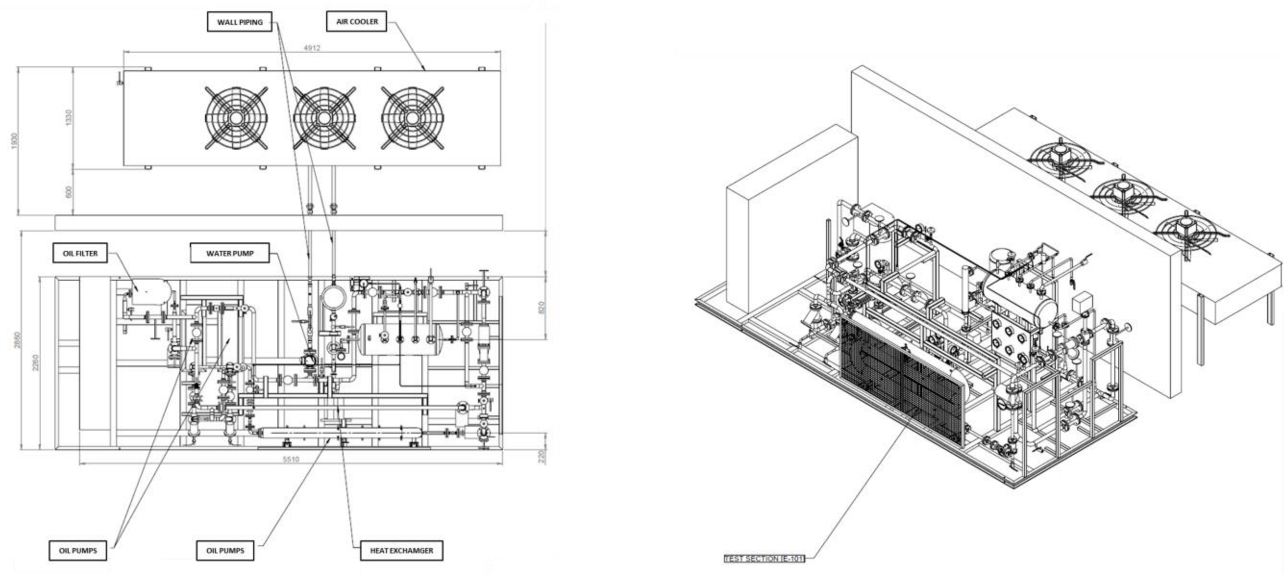


Figure 1. HPOL facility layout; top view (left) and side view (right).

Figure 2. Experimental plant: Air Cooler system.

An oil filtration system is provided in the primary circuit to remove any possible degradation residues. Furthermore, a by-pass, regulated by means of a three-way regulating valve, is installed in the primary circuit to allow further regulation of the oil temperature entering the TS. Both circuits include expansion vessels. In the case of the primary circuit, the expansion vessel has been made by means of inert gas (S1) which is maintained under pressure by a regulation valve. In the expansion tank of the primary circuit, beyond the safety valve, a system for collecting and analysing gas and oil samples is installed with the aim of analysing their status during experimental tests.

The TS is heated by means of a direct current (DC) power supply, able to provide a power up to 350 kW (Figure 3). The power supply unit and the TS are connected by mobile fixtures to allow the variation of the heating length according to the type of oil to be tested (Figure 4). As shown in Figure 5, the electrodes are easily movable to match the correct heating length. They are also instrumented to verify that no significant heating develops in the fitting itself. Its extension along the direction of the pipe can be changed according to the experimental results and the related calculations.

Figure 3. Power supply.

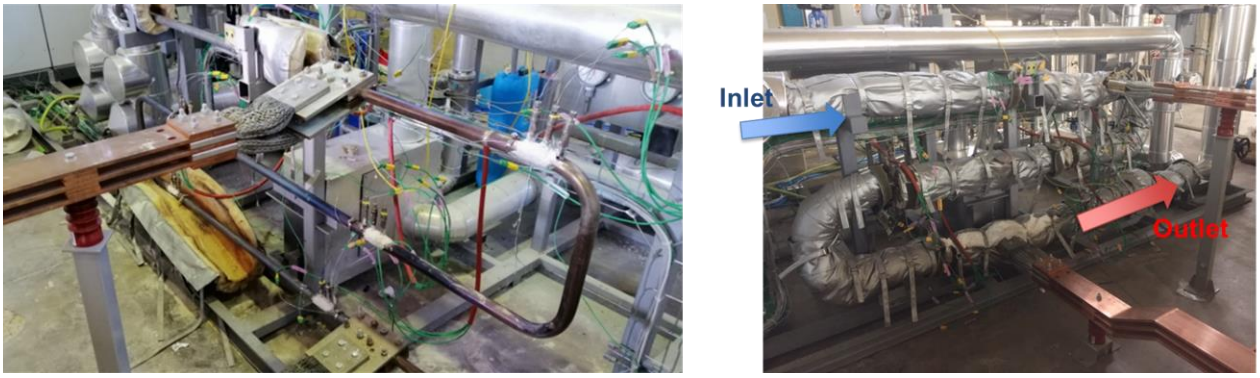


Figure 4. Connection of power supply: electrode on TS (left) and fixtures (right).

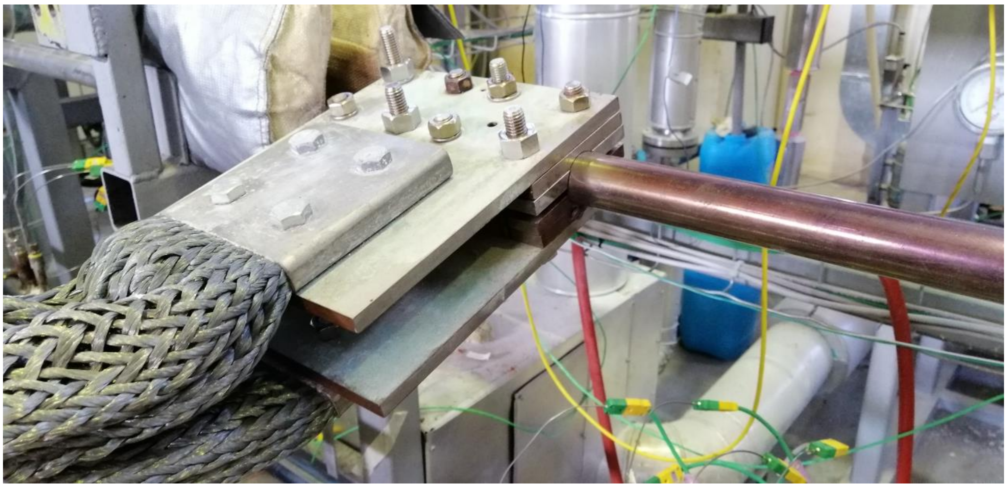


Figure 5. Experimental Plant: detail of electrode connecting power supply to TS.

An overall view of the system is shown in Figure 6 and Figure 7.

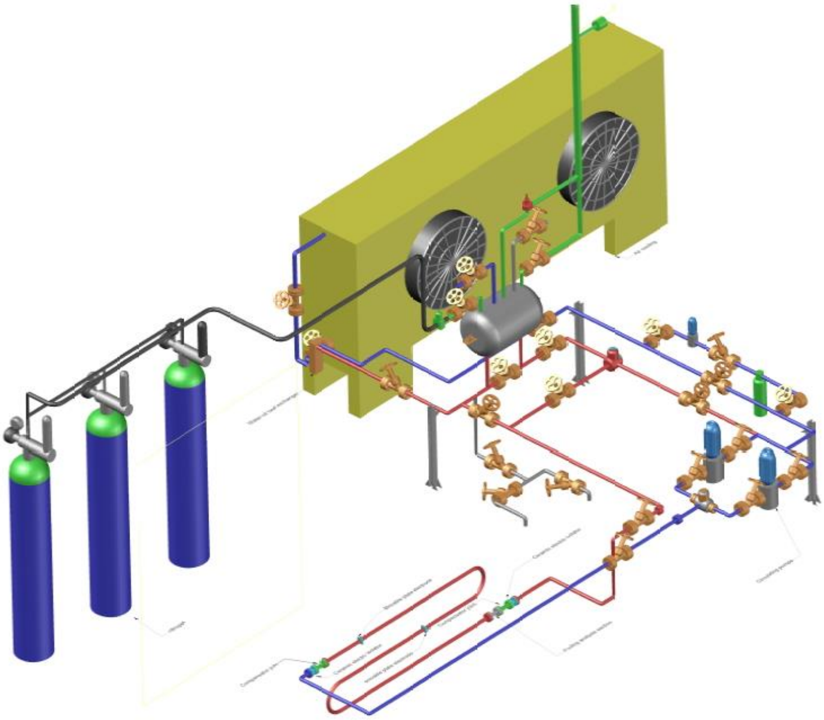
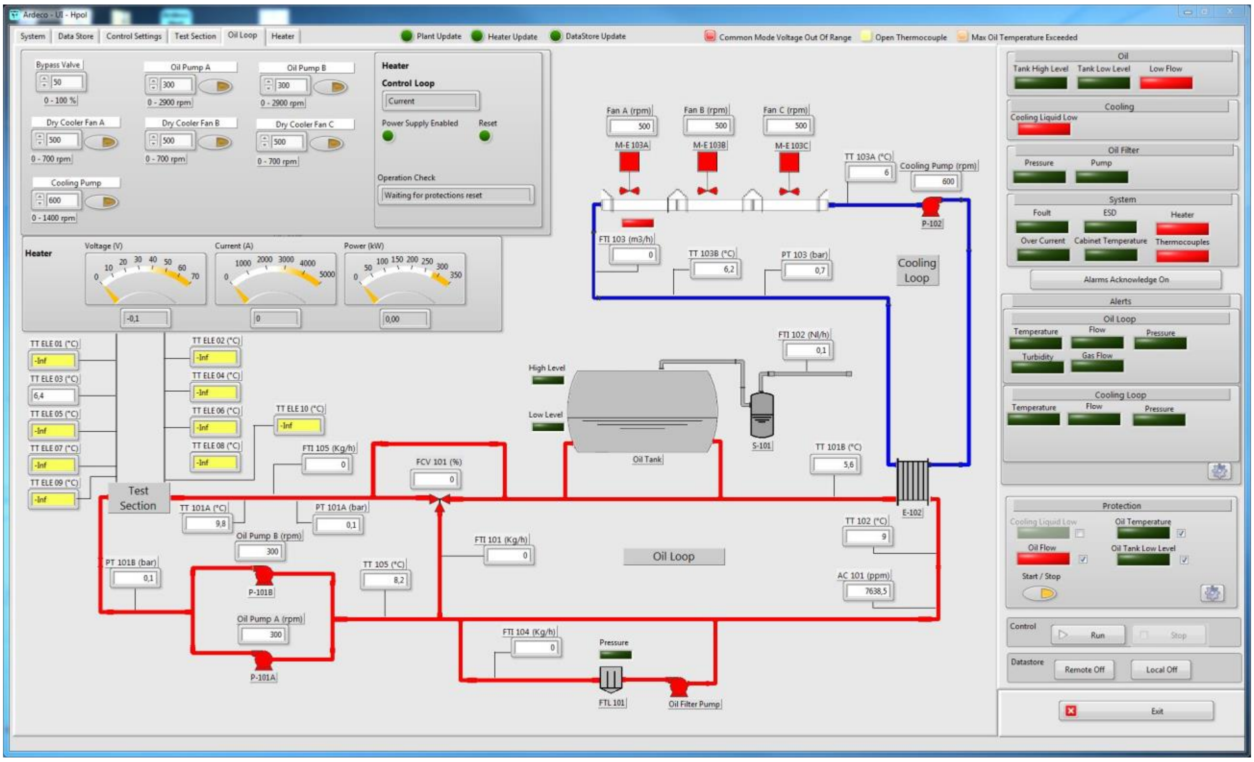


Figure 6. Schematic overall view of the experimental plant.

Figure 7. Experimental plant: overall view.

3. System for Plant control and monitoring

The plant is equipped with a control and monitoring system for process equipment and for measuring and recording data related to the physical parameters of the process fluids (temperatures, flow rates, pressures, turbidity). The data detected by the plant are stored to be made available for subsequent analysis and processing. In addition, the system allows to control the system from a remote computer connected via the web network. The software of the above system was developed in ENEA with National Instrument LabVIEW. Figure 8 shows one of the control system screens with some operating parameters.



Bypass Valve: 50 (0 - 100 %)
Oil Pump A: 300 (0 - 2900 rpm)
Oil Pump B: 300 (0 - 2900 rpm)
Dry Cooler Fan A: 500 (0 - 700 rpm)
Dry Cooler Fan B: 500 (0 - 700 rpm)
Dry Cooler Fan C: 500 (0 - 700 rpm)
Cooling Pump: 600 (0 - 1400 rpm)
Heater Control Loop: Current
Operation Check: Waiting for protections reset
Voltage (V): -0,1
Current (A): 0
Power (kW): 0,00
TT ELE 01 (°C): -Inf
TT ELE 02 (°C): -Inf
TT ELE 03 (°C): 6,4
TT ELE 04 (°C): -Inf
TT ELE 05 (°C): -Inf
TT ELE 06 (°C): -Inf
TT ELE 07 (°C): -Inf
TT ELE 08 (°C): -Inf
TT ELE 09 (°C): -Inf
TT ELE 10 (°C): -Inf
FTI 105 (Kg/h): 0
FCV 101 (%): 0
TT 101A (°C): 9,8
PT 101A (bar): 0,1
Oil Pump B (rpm): 300
PT 101B (bar): 0,1
TT 105 (°C): 8,2
FTI 101 (Kg/h): 0
Oil Pump A (rpm): 300
FTI 104 (Kg/h): 0
Fan A (rpm): 500
Fan B (rpm): 500
Fan C (rpm): 500
TT 103A (°C): 6
Cooling Pump (rpm): 600
FTI 103 (m3/h): 0
TT 103B (°C): 6,2
PT 103 (bar): 0,7
FTI 102 (Nl/h): 0,1
TT 101B (°C): 5,6
TT 102 (°C): 9
AC 101 (ppm): 7638,5

Figure 8. Front panel for plant control and monitoring.

Along the TS (Figure 9) wall and oil temperatures were instantaneously measured during the tests thought a system of thermocouple stations placed along the tube (Figure 10). Each station records (Figure 11):

- The external wall pipe temperature above (thermocouples R01D-R06D) and below (thermocouples R01E-R06E) the tube;
- The tube inner surface temperature (thermocouples R01C-R06C);
- Oil temperature at the centre of the tube (thermocouples R01A-R06A);
- Oil temperature a ¾ of the tube cross sectional area (thermocouples R01B-R06B).

Figure 9. Tube of the TS.

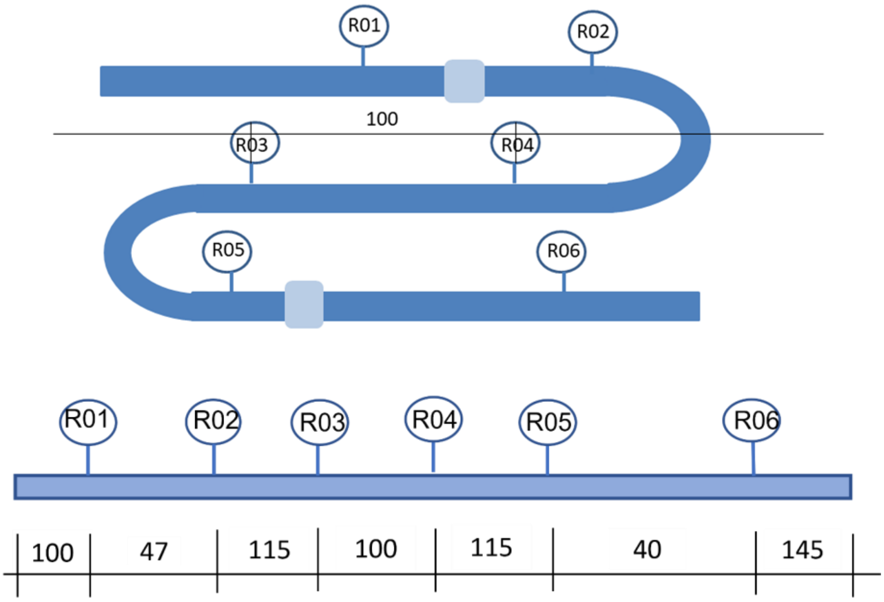


Figure 10. Thermocouples station position.

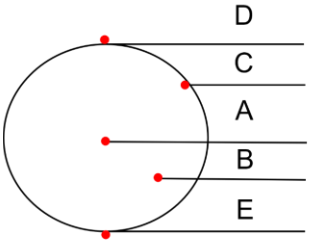


Figure 11. Thermocouples position for each measurement station.

4. Power supply dimensioning and electrical configuration

In the basic design of the power supply, it emerged the problem of finding the resistivity data of the TS steel (P256GH) as a function of the temperature. In fact, the resistivity data were not available and those provided by the various producers of the used type of steel referred to the ambient temperature and were constantly different from each other. This is also possible since the material composition has some ranges of elemental compounds variability, so that products from different producer can really have different resistivity values.

On the other side, once the material and the TS length is determined, the voltage-current supply characteristics are defined and any deviation from the assessed values risks being not covered by the power supply.

So, the seller of the pipes was selected in order to have material coming from the same manufacturer and was asked to arrange a system to measure the electrical resistance vs temperature. Figure 12 shows the experimental setup for the determination of resistivity vs temperature curve (1", 1 m long, P256GH pipe) showed in Figure 13.

Figure 12. Experimental set-up to measure the tube resistivity as a function of temperature.

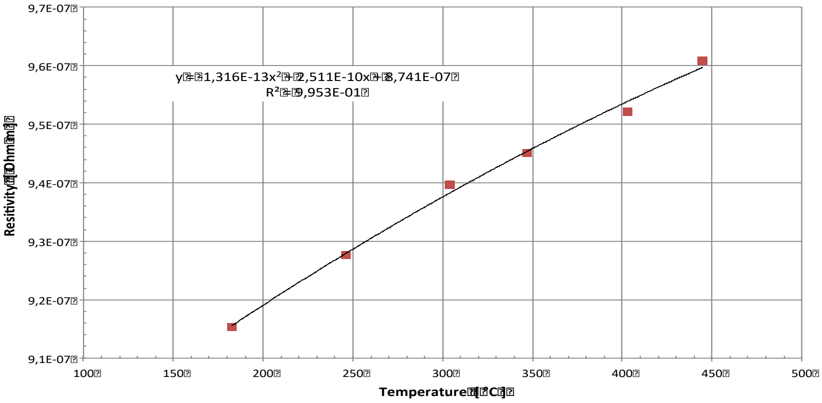


Figure 13 Resistivity vs temperature as calculated from V-I characteristic.

On the basis of this result it was possible to define the characteristics of the power supply with a degree of flexibility that was able to cope with some uncertainties not completely overcome in the design and construction phase of the experimental plant, such as:

- The thermo-physical characteristics of Bluesil not yet fully known and which could lead to large differences in the length of the TS and consequently in the required power supply voltage;
- The inevitable errors in simulations for determining the length TS;
- The possible differences for different batches of material even if they come from the same manufacturer;
- Contact resistances of the electrodes enhanced by the possible oxidation of the material.

The required parameters that were established for the power supply are 70 V, 5000 A, for a total possible heat output of 350 kW, approximately double that required to heat the oil with a single pass.

The power supply could be controlled to deliver to the TS a desired current, voltage or power.

5. Sampling points

In order to follow the oil degradation rate, oil samples were taken at shut down of the circuit, from a purge valve placed upstream the TS (with an outlet oil temperature around 130°, see Figure 14); the obtained samples (t48 hours) were analysed and compared with fresh oil features. A proper analytical protocol was defined starting by results obtained from a previous laboratory work on fresh and thermally aged oil samples; the more significant results were found by thermogravimetric curves, viscosity measurements, infrared and mass spectra.

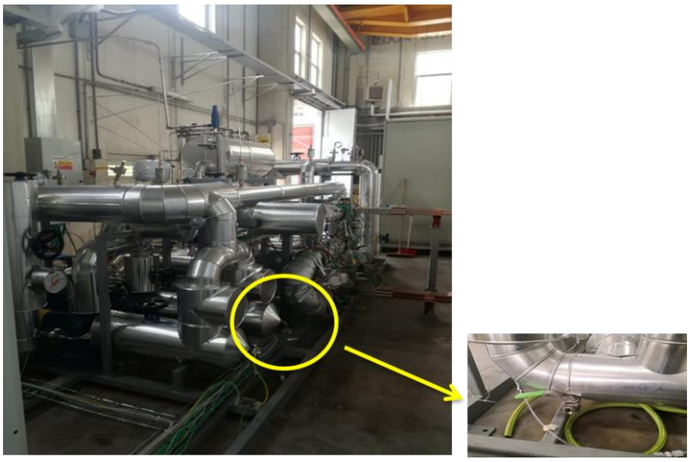


Figure 14. Oil sampling point.

Regarding the gas materials circulating in the loop, nitrogen is continuously fed into the plant and the gas purge valve is kept open during the test. From thermal degradation kinetics study, was found that under thermal stress oils produce permanent gases (mainly hydrogen and methane). In order to detect and quantify gaseous products, samples were collected at the outlet using a gas bag was sampled every around 8 hours (Figure 15) and analysed offline with the micro-GC, in order to preserve the instrument from eventual liquid contaminations.

Figure 15. Gas bag and zoom of gas sampling point.

6. Simulation tool

Preliminary theoretical evaluations were necessary to define the power supply and the tube length able to cope with the required test parameter. At this purpose the heat exchange between the oil and the tube wall in a single pipe geometry was studied; an oil flowing in a pipe, in turbulent flow condition, that cools down the wall tube surface heated by Joule effect has been considered. The required parameters for the loop are summarized in Table 1.

Table 1 Target parameters for the described case study

Parameter	**Value**
Tin oil	130 °C
Tout oil	200 °C
Twall	430 °C
Di	0.02664 m
Fluid velocity	0.9 m/s
Construction material	PGH265HG Carbon Steel

Convection heat transfer takes place whenever a fluid is in contact with a solid surface that is at a different temperature than the fluid. If the fluid is moving on the solid surface because of an external driving force, like a pump or blower, then it is called forced convection.

Newton's Law of Cooling is an equation that is widely used for both forced and natural convection calculations. The equation for Newton's Law of Cooling is reported below (Eq. 1):

$$\dot{Q} = h * A_s * \left(T_s - T_{fluid}\right) \qquad \text{Eq. 1}$$

For the convection heat transfer, it is a common practice to non-dimensionalize the governing equations and combine the variables, which group together into dimensionless numbers (groups). Those correlations are typically expressed in terms of dimensionless numbers. The dimensionless numbers used for forced convection heat transfer coefficients are the Nusselt number (Nu), Prandtl number (Pr), and Reynolds number (Re). Definitions of Nu, Pr, and Re are shown below. The heat transfer coefficient, h, appears in the Nusselt number, so the correlations are typically in the form of an equation for Nu in terms of Re and Pr.

Nusselt number is non-dimensional heat transfer coefficient where Di is the characteristic length that corresponds to the diameter of the tube in pipe case-study. Nusselt number represents the enhancement of heat transfer through a fluid as a result of convection relative to conduction across the same fluid layer (Eq. 2).

$$Nu = \frac{h * k}{Di} \qquad \text{Eq. 2}$$

Reynolds number (Eq. 3) represents the ratio between inertia forces to viscous forces in the fluid at high Re numbers, the inertia forces, which are proportional to the density and the velocity of the fluid, are large relative to the viscous forces; thus, the viscous forces cannot prevent the random and rapid fluctuations of the fluid (turbulent regime). The Reynolds number at which the flow becomes turbulent is called the critical Reynolds number.

$$Re = \frac{\rho * v * Di}{\eta} \qquad \text{Eq. 3}$$

Prandtl number (Eq. 4) is a measure of relative thickness of the velocity and thermal boundary layer (molecular diffusivity of momentum versus molecular diffusivity of heat).

$$\mathrm{Pr} = \frac{\eta * Cp}{k} \qquad \text{Eq. 4}$$

Forced convection heat transfer takes place when a fluid is pumped or blown past a solid surface that is at a different temperature than the fluid. For each forced convection configuration, including different geometry and fluid-dynamic conditions (laminar or turbulent flow), the heat transfer coefficient can be obtained by a proper correlation. For fully developed (hydro-dynamically and thermally) turbulent flow in a smooth circular tube, in this contest it is possible to use the Dittus-Boelter equation (Eq. 5), with n=0.4 for the fluid being heated, and n=0.3 for the fluid being cooled.

$$Nu = 0.023 * Re^{0.8} * Pr^{n} \qquad \text{Eq. 5}$$

The mean velocity, which remains constant for incompressible flow when the cross-sectional area of the tube is constant, is defined in Eq. 6 according to the principle of the mass conservation. Even if fluid density changes with temperature, it is acceptable to work with mean values in the work temperature range.

$$\dot{m} = \rho * V_m * A_c \qquad \text{Eq. 6}$$

Inlet and outlet oil temperatures, wall temperature and fluid velocity are input parameters; once the thermophysical properties of the tested oils are known, it is possible to define the heat flow and the length of the heated part of the test section, satisfying the required parameters. According to conservation of energy for steady flow of a fluid in a tube, the heat flux can be expressed by the following relation (Eq. 7):

$$\dot{Q} = \dot{m} * C_p * (T_{fluid,in} - T_{fluid,out}) \qquad \text{Eq. 7}$$

Assuming that the surface tube temperature is constant, the heat flux can also be expressed as reported in Eq. 8, leading to a relationship between the thermal power and the heat transfer surface required; the heat transfer coefficient (h) is calculated, while the mean temperature logarithmic difference is given by Eq. 9.

$$\dot{Q} = h * A_s * \Delta T_{ML} \qquad \text{Eq. 8}$$

$$\Delta T_{ML} = \frac{\left(T_s - T_{fluid_{in}}\right) - \left(T_s - T_{fluid\_out}\right)}{\ln \left(T_s - T_{fluid_{in}}\right) \Big/ \left(T_s - T_{fluid\_out}\right)}$$

Eq. 9

Once the heat flux required is determined for each oil tested, the needed heat exchange surface, and then the tube heated part length, are evaluated according to Eq. 10 and Eq. 11.

$$A_s = \frac{Q}{h * \Delta T_{ML}}$$

Eq. 10

$$A_s = l_{Heated\ part} * 2\pi * r$$

Eq. 11

where:

$\dot{Q}$ = heat flux [W]

h = heat transfer coefficient [W/m^{2}K]

As = heat transfer surface [m^2]

$\dot{Q}$ = heat flux [W]

$\dot{q}_s$ = surface heat flux [W/m^2]

As = heat transfer surface [m^2]

ρ = fluid density [kg/m^3]

v = fluid velocity [m/s]

Di = diameter of the pipe [m]

η = kinematic viscosity [Pa s]

$\dot{m}$ = mass flow [kg/s]

ρ = Oil density [kg/m^3]

V_m = mean cross sectional area velocity [m/s]

A_c = cross sectional area [m^2]

h = heat transfer coefficient [W/m^{2}K]

k = Thermal conductivity of the fluid [W/mK]

Di = diameter of the pipe [m]

Cp = specific heat [J/kgK]

k = Thermal conductivity of the fluid [W/mK]

η = dynamic viscosity [Pa s]

$\dot{Q}$ = heat flux [j/s]

Cp = specific heat [J/gK]

ΔT_{ML} = Mean logarithmic temperature difference [K]

T_s = Wall temperature [K]

T_{fluid_in} = Oil inlet temperature [K]

T_{fluid_outlet} = Outlet temperature [K]

Appendix 1 – Operating procedure

Before the HPOL start-up, should be verified that the following devices are working properly:

- All measurement (thermocouples, fluxmeter, manometer) devices,
- The power supplier and related connections,
- The oil pumps,
- The safety bottoms,
- The control system.

The cooling fluid and oil loading points are showed in the picture reported below (Fig. 1).

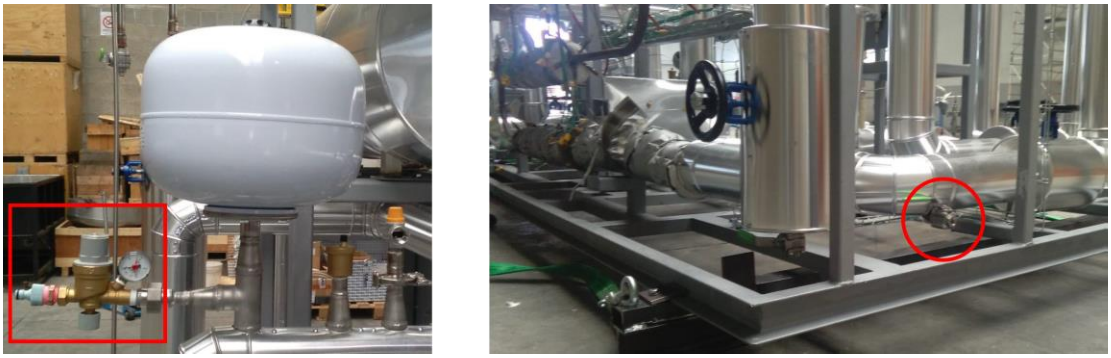


Figure 16. Cooling system (left) and oil (right) loading points.

Trought the HPOL control and monitoring system, the oil loop is remotely controlled by the developed software. The power supplied to the test section is regulated until the desired temperature conditions are reached.

For the cleaning procedure, a Therminol product (Therminol FF) is recommended. In the Therminol FF Material and Safety Data Sheet (MSDS) the operating temperatures are reported. The oil can be discharged by the several draining points placed in different loop positions such as the valves placed at the test section inlet and outlet.

Appendix 2 – MATLAB code

```
Qpunt [j/s] = (mpunt [Kg/h]/3600) * (Cp [Kj/KgK]*1000) dT [K]

Qpunt [j/s] = h [j/m2Ks] * As [m2] *dtML [K]

function [G] = lunghezzaTS(X)

global v D Tin Tout Ts rho rhoin Cp mu k;

As = X(1); %surface Heat exchanger (m2)
qpunt = X(2); %  thermal power (W)
h = X (3); %HEC oil-wall (W/m2K)
L = X (4); %Heated part length (m)

Re = rho * v * D/mu ;
Pr = (Cp *1000) * mu / k ;
Nu = 0.023*(Re^(0.8))*(Pr^(1/3));
A = ((D/2)^2)*3.14; %m2
mpunt = v*rhoin*A; %Kg/s
dTin = Ts-Tin; %°C
dTout = Ts-Tout; %°C
dTML = (dTout-dTin)/(log(dTout/dTin)); %°C

clc
clear all;
close all;

global v D Tin Tout Ts rho rhoin Cp mu k;
 v = 0.9; %m/s
 D = 0.02664; %(m)
 Tin = 130; %°C
 Tout = 200; %°C
 Ts = 430; %°C
 mu = 0.00106; %Pas
 k=0.1074; %W/mK
 Cp= 2.122; %Kj/KgK
 rho=899; %Kg/m3
 rhoin= 913; %Kg/m3

options=optimoptions (@fminimax, 'MinAbsMax',2, 'MaxIter', 100e15, 'TolFun', 1.0000e-16);
lb = [0.2 60000 750 3];
ub = [0.4 75000 900 5];
x0 = [0.315 68000 820 3.77];

fun2=@(X)lunghezzaTh66(X);
```

```
[S,v,m,exitflags]= fminimax(fun2, x0, [ ], [ ], [ ], [ ], lb, ub, [ ], options);

disp(exitflags);

disp(v);
```

Appendix 3: Python code

```
@author: Utente ENEA
"""
import numpy as np
from scipy.interpolate import make_interp_spline, BSpline
from numpy.fft import fftshift, fft, fftfreq
from scipy import interpolate
import csv
import matplotlib.pyplot as plt
import glob

files = glob.glob ('*.csv')
plt.close ('all')
"""
SET INPUTS
"""
# TEST SECTION PROPERTIES
distElectrode = 3.77 # m
diam = 0.02664 #m

# OIL PROPERTIES
Tin = np.linspace(130, 130, 170708)
Tout = np.linspace(200, 200, 170708)
Twall = np.linspace (430, 430, 170708)
corr = np.linspace (180, 180, 170708)
ThViscx=np.linspace(0, 340, 35)
ThViscy= [ ]
```

```
"""
ACQUIRE DATA
"""
h=0
TT01A=[ ]
TT01B=[ ]
TT01C=[ ]
TT01D=[ ]
TT01E=[ ]
TT02A=[ ]
TT02B=[ ]
TT02C=[ ]
TT02D=[ ]
TT02E=[ ]
TT03A=[ ]
TT03B=[ ]
TT03C=[ ]
TT03D=[ ]
TT03E=[ ]
TT04A=[ ]
TT04B=[ ]
TT04C=[ ]
TT04D=[ ]
TT04E=[ ]
TT05A=[ ]
TT05B=[ ]
TT05C=[ ]
TT05D=[ ]
```

```
TT05E=[ ]

TT06A=[ ]

TT06B=[ ]

TT06C=[ ]

TT06D=[ ]

TT06E=[ ]

dTML= [ ]

# FTI102= [ ]

# FTI103= [ ]

# FTI104= [ ]

# FTI105= [ ]

DT=[ ]

DTInOut=[ ]

flux=[ ]

pressure=[ ]

pressureB=[ ]

V=[ ]

I=[ ]

power=[ ]


for i in files:

  print(i)


  DTTemp=[ ]

  fluxT=[ ]

  with open(i) as csv_file:

    csv_reader = csv.reader(csv_file, delimiter='\t')

    line_count = 0
```

```
for row in csv_reader:
    if line_count == 0:

        line_count += 1
    else:
        line_count += 1

        TT01A.append(float(row[1].replace(',','.')))
        TT01B.append(float(row[2].replace(',','.')))
        TT01C.append(float(row[3].replace(',','.')))
        TT01D.append(float(row[4].replace(',','.')))
        TT01E.append(float(row[5].replace(',','.')))
        TT02A.append(float(row[6].replace(',','.')))
        TT02B.append(float(row[7].replace(',','.')))
        TT02C.append(float(row[8].replace(',','.')))
        TT02D.append(float(row[9].replace(',','.')))
        TT02E.append(float(row[10].replace(',','.')))
        TT03A.append(float(row[11].replace(',','.')))
        TT03B.append(float(row[12].replace(',','.')))
        TT03C.append(float(row[13].replace(',','.')))
        TT03D.append(float(row[14].replace(',','.')))
        TT03E.append(float(row[15].replace(',','.')))
        TT04A.append(float(row[16].replace(',','.')))
        TT04B.append(float(row[17].replace(',','.')))
        TT04C.append(float(row[18].replace(',','.')))
        TT04D.append(float(row[19].replace(',','.')))
        TT04E.append(float(row[20].replace(',','.')))
        TT05A.append(float(row[21].replace(',','.')))
```

```
TT05B.append(float(row[22].replace(',','.')))
TT05C.append(float(row[23].replace(',','.')))
TT05D.append(float(row[24].replace(',','.')))
TT05E.append(float(row[25].replace(',','.')))
TT06A.append(float(row[26].replace(',','.')))
TT06B.append(float(row[27].replace(',','.')))
TT06C.append(float(row[28].replace(',','.')))
TT06D.append(float(row[29].replace(',','.')))
TT06E.append(float(row[30].replace(',','.')))
flux.append(float(row[41].replace(',','.')))
pressure.append(float(row[42].replace(',','.')))
pressureB.append(float(row[43].replace(',','.')))
dTML.append(float(row[44].replace(',','.')))
V.append(float(row[84].replace(',','.')))
I.append(float(row[85].replace(',','.')))
power.append(float(row[86].replace(',','.')))

DT.append(TT03D[-1]-TT03A[-1])
DTTemp.append(TT06A[-1]-TT01A[-1])
DTInOut.append(TT06A[-1]-TT01A[-1])
fluxT.append(float(row[41].replace(',','.')))
```

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