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Thermal Transient Analysis in a Nozzle with an Inner Thermal Baffle

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Summary

The paper presents an example of application of the Delfine code in a non linear thermal transient study.

The code is part of finite elements CASTEM System developed in CEA Saclay.

The study refers about the analysis of the thermal history of a structure that is subjected to thermal exchange with a fluid flowing in forced convection in open loop.

In the first part it's given the approach used in the computer program to solve the problem and then the experimental theoretical study of a plant component.

The study presents the analysis of the temperature history of a nozzle provided by an inner thermal baffle subjected to cold thermal shocks from the initial temperature (≃ 540°C) with an about 15°C/sec thermal gradient. The used instrumentation includes thermocouples to measure the temperature versus time at various points along the axial length of the nozzle. All instrumentation was put on the outside surface of the structure.

To uniform the temperature at the initial action point of the thermal baffle a little flow of sodium passes in the anular interspace between the nozzle and the thermal baffle.

The by-pass sodium flow is not costant and also the inlet Na temperature is variable in time.

The calculation of the sodium flow rate between the nozzle and the thermal baffle is made by an ad-hoc finite differences code.

The calculation of the fluid temperature is made in transitory regime appreciating the cooling temperature rate of Na in contact with the structural components that it skins and its calorific capacity.

The theoretical-experimental comparison of the trend of temperature in time at different heights shows that there is a very good identity for the different points of the structure.

1. Introduction

Figure 1 shows the IPM-2 section test ; it is formed by two big tanks SE20 and SE21 ($V \simeq 21\ m^3$), a control valve VP210 and a helicoïdal connection pipe EL26 ($\ell = 28$ m, $\phi_e =$ 324 mm and $s = 4$ mm). During the preshock phase a gradient of temperatures is obtained along the pipe length by means of electrical heaters. The temperature varies from 550°C at the SE20 tank to about 400°C at the SE21 tank. When the valve is opened about 2000 liters of sodium flow in 10 s time inside the SE20 tank, realizing a cold thermal shock.

A conical nozzle connects the helicoïdal pipe to the SE20 tank. This nozzle is equiped with an inner thermal baffle to reduce the stress level on this critical structure. The detailed drawing of the nozzle and of the thermal baffle is shown in figure 2 in which thermocouple locations are pointed out.

2. Experimental study

To define the thermal history of the structure the following measurements were made :

- along the pipe
- along the nozzle
- in the sodium
- down stream the thermal baffle.

All the thermocouples, whose diameters are 1.6 mm are in Chromel-Alumel and insolated with Magnesia.

A series of 10 cold thermal shocks were performed. The experimental diagrams registered in the 9th thermal shock are shown (fig. 3) these curves are the temperature history in various points of the structure.

It is to remark how the similarity of the various homogenous curves proved the repetitivity of the tests and the reliability of the recordings.

3. Numerical methods

The procedure to calculate the thermal field in the nozzle and in the thermal baffle is to solve the heat conduction problem in the structure coupled to the advection-diffusion problem in the sodium between the nozzle and the thermal baffle.

Thus the boundary condition is the temperature and the flow rate at the inlet of the gap.

3.1 Flow-rate in the gap

To calculate the flow-rate in the gap a simple finite differences code was developed. Figure 4 shows the sketch and the data referring to the problem.

The equations to solve are :

- $PV^\gamma = cte$ in the two tanks
- $H_1(t) = H_1(0) + S_0/S_1\ (H_0(0) - H_0(v))$ incompressibility of the sodium

$$\begin{aligned}
&P_A(t) - P_0(t) = \rho g\, H_0(t) - \rho H_0(t)\, dV_0/dt \\
&P_B(t) - P_A(t) = \rho g\, H - (K + K_0)\, \rho \frac{u^2}{2} - \rho L \frac{du}{dt} - W(t) \\
&P_1(t) - P_B(t) = - \rho g\, (H + H_1(t)) - \rho (H_1(t) + H)\, dV_1/dt
\end{aligned} \qquad (1)$$

These equations express the pressure drop between the two tanks with

$$K = .316\, \frac{L}{D}\, (Rey)^{.8}$$

Where P is the pressure, V the volume, u the velocity in the pipe, H the height, W(t) the pressure drop in the valve, K_0 the global pressure drop coefficient for the whole singularities, and t the time.

The set of equations (1)are discretized with an explicit finite differences scheme.

To calculate the flow rate in the gap from the velocity u in the pipe, in a first approximation it is assumed that the velocity profile is not disturbed by the rim of the thermal baffle.

The flow rate is calculated by integration of the profil

$$Fr_{gap}(t) = \int_{R-e}^{R} V_{max}(t)\ (1 - \frac{2}{R})^{1/n}\ 2\pi\ 2\ dr$$

Where R is the radius of the nozzle, e the thickness of the gap, V_{max} the maximum velocity, and n a coefficient depending on the Reynolds number (Rey).

$n = 2$ for $Rey \leq 2100$

$n = 6$ $2100 < Rey \leq 4.10^3$

$n = 7$ $4.10^3 < Rey \leq 1,3.10^5$

$n = 8$ $1,3.10^5 < Rey \leq 8.10^5$

$n = 9$ $8.10^5 < Rey \leq 2,5.10^6$

$n = 10$ $Rey > 2,5.10^6$

Figure 5 shows the calculated sodium flow rate in the gap.

As it is shown in the following table this analysis seems to be sufficently refined.

	Variation of level (mm)		Initial pressure (Pa)		Final pressure (Pa)	
	SE20	SE21	SE20	SE21	SE20	SE21
Calculated	3800	840 nm	5.10^3	$2,2.10^5$	$6,5.10^3$	$.4.10^5$
Experiments	3920	867 nm	5.10^3	$2,2.10^5$	*	$.4.10^5$

* No figure was available for the pressure at the end of the transient for the SE20 tank, because it was slighty re-pressurized.

The prediction of the sodium flow rate over rated the experimental result of 4 %.

3.2 Heat conduction problem

To solve this problem it was used the finite element thermal code DELFINE part of the french system CASTEM [1] developed at CEA-Saclay.

In the thermal baffle and in the nozzle the following equation is solved in an axisymetrical geometry :

$$\begin{cases} \rho c(T) \dfrac{\partial T}{\partial t} = \text{div}\ (\underset{\sim}{K}(T)\ \overrightarrow{\text{grad}}\ T) \\ \text{Boundary conditions} \end{cases}$$

Where $\rho c(T)$, $K(T)$ are the thermal capacity and the conductivity.

The boundary condition which represent the flow in the gap is found by solving a one-dimensional energy equation :

$$\rho c \frac{\partial \theta}{\partial t} + \rho c V \frac{\partial \theta}{\partial s} = h\ (T - \theta) + k \frac{\partial^2 \theta}{\partial s^2}$$

where θ is the fluid temperature, T the temperature of the surface in contact with the fluid, V the velocity of the fluid.

k is the convection heat transfert coefficient given by the Harnett and Irwin's correlation.

$$Nu = 5 + 0.15\, P_e^{.8} \qquad P_e \text{ Peclet Number.}$$

4. Conclusion

Figure 6 shows for thermocouple T_{C_3} and T_{C_7} (see figure 2) the comparison of the experimental recordings and the calculated temperature curves.

The predicted temperatures exhibited a slightly stronger cooling effect due to an over estimated flow-rate.

The discrepancy between the calculated temperature and the measurements is within 2 %.

Reference

/1/ A. HOFFMANN, Castem (CEA-SEMT)
A system of finite element computer programs for non-linear analysis of technical structures.
Porto Alegre (Brasil) April 1978, Paper 40.

/2/ F. CORSI, C. APPONI, P. IANNUZZO, A. COMBESCURE, J. JOLY.
Theoretical experimental study of the structural behaviour of a sodium plant connecting nozzli.
SMIRT 6 Division E AUGUST 1981, PARIS.

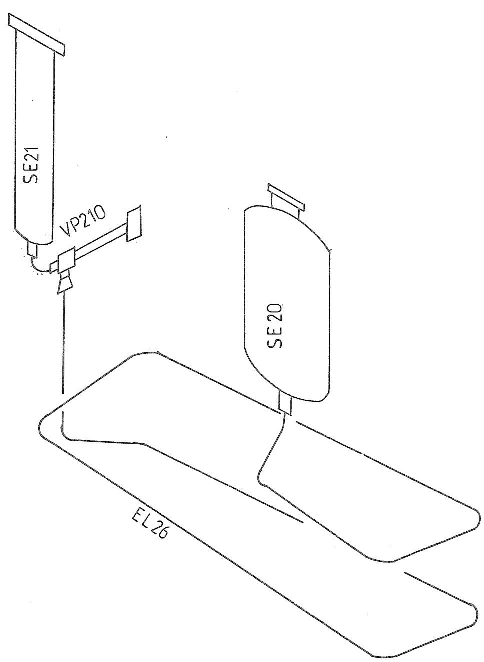


FIG. 1

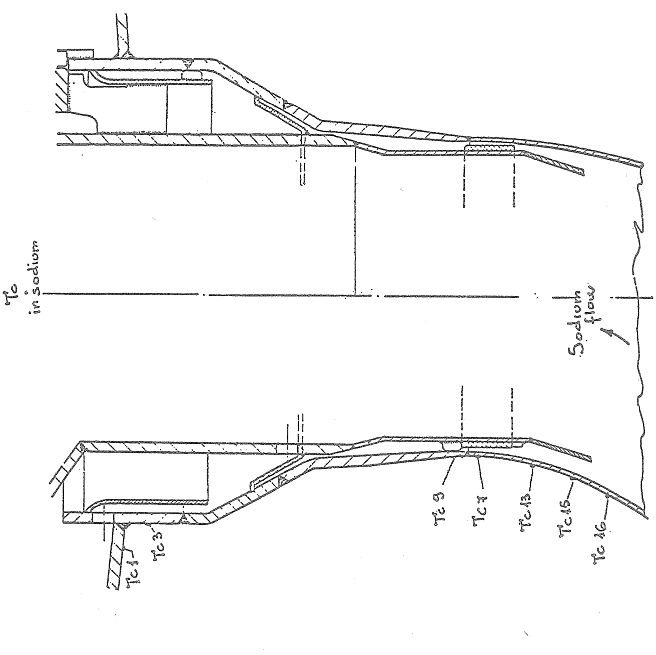


Fig. 2
Nozzle - thermal baffle Detail drawing.

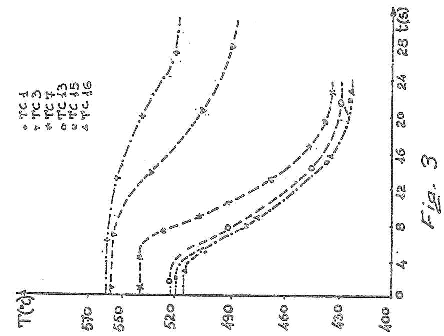
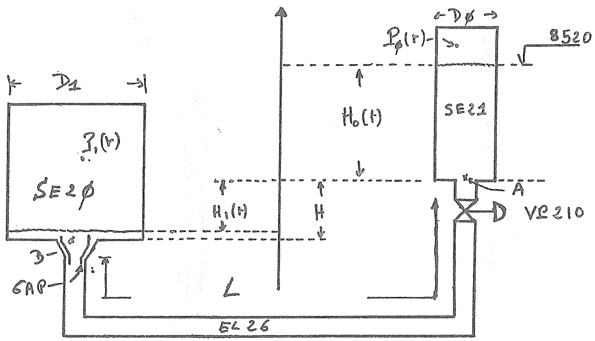
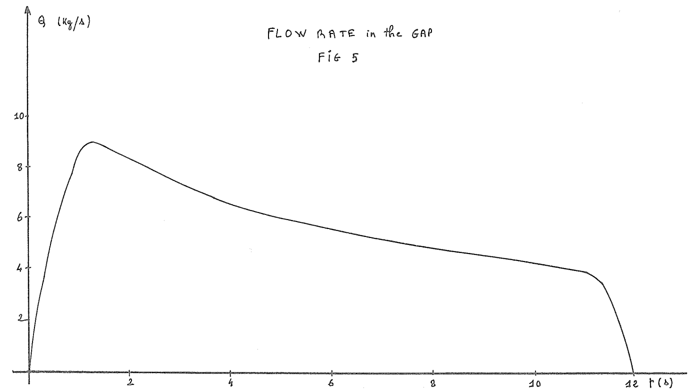


Fig. 3
Experimental temperature curves in the transient



Ho (o) = 4.002 m sodium level in SE21
H1 (o) = - 1.118 m sodium level in SE20
H = 1.252 m difference of level between A and B
Vo = 3 m^3 volume of tank SE21
V1 = 12.1 m^3 volume of tank SE20
Do = .8 m diameter of tank SE21
D1 = 1.850 m diameter of tank SE20
L = 27 m length of the pipe EL26
D = .316 diameter of the pipe EL26



FLOW RATE in the GAP
FIG 5

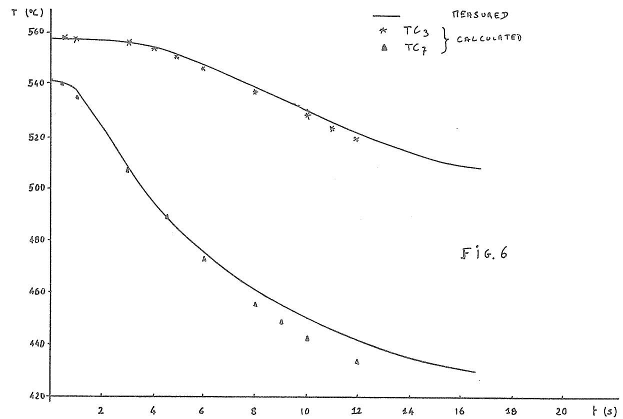


FIG. 6