THERMAL AND THERMOGRAPHICAL MODELING OF THE RUST EFFECT IN OIL CONDUITS

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Abstract
The design and the maintenance of the conduits and the pipelines is a challenge for oil industry seen the serious consequences which can occur because of several reasons, example: defects of the cracks types, rust… etc Which can cause escapes of the transported matter or ruptures of these conduits with all that involves like economic loss and pollution of the environment.
In this article, a thermal method of non destructive testing of these conduits, based on numerical modeling in three dimensions is presented.
The goal of this article is to show the thermal and the thermographical behavior of these conduits in the presence of defects of the corrosion type. For that defect of the rust type of different size and positions in the structure are considered and simulated.
For these various simulated configurations, the thermographical images, as well as the space evolution of the temperature on the external face of these structures, are presented and analyzed. The numerical resolution of this problem was carried out using a numerical computation software based on the finite element method.

Keywords: corrosion, rust, conduits, infra-red thermography, finite elements.

1. Introduction
The corrosion defect is one of serious concern to several industries like nuclear, chemical and petrol industries. Such defects can occur severe economic and social damage, that's why it's so important to detect them as soon as possible to avoid those lost [1,2].
The purpose of the study is to show by calculating of surface temperature and by analysing the themographical images the effect of corrosion defect which can exist in these conduits.
To undertake the study we modelled conduit (tube) by a steel cylinder like those used in oil transport and the defect by a circular layer of rust. The dimensions of the cylinder and those of the layer of rust are taken as parameters. To see the effect of each geometrical parameter on the thermal state of the considered structure we studied the thermal state of the structure by taking this parameter as a variable and all the others as constant.

2. Principle of the method
When a material is thermically requested (artificial excitation in the case of Laboratory measurements or in-situ measurements), the heat diffuse in uniform way in material. The presence of a defect within the material (e.g. a crack or a rusted layer) acts like a heat insulator and idle this diffusion. It follows from there the appearance of a hotter region on the surface compared to the close one without anomaly [3].

3. Structure of the model
The study is undertaken on a cylindrical structure, fig.1, of geometrical parameters: external diameter d=254mm, the cylinder thickness e_P =19mm and the length of tube l =1000mm.

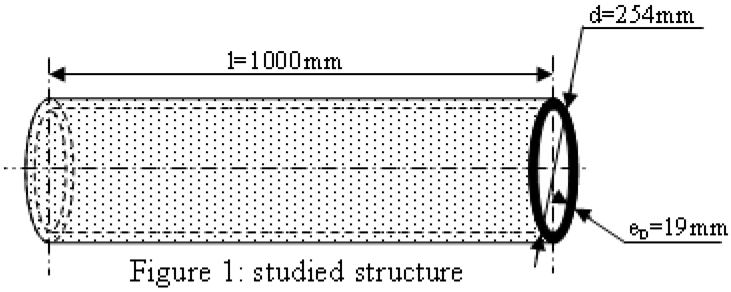

Figure 1: studied structure

4. Mathematical model

To solve the following thermal equation:

$$a\nabla^2 T = \frac{dT}{dt} \qquad (1)$$

The parameter $a = \dfrac{\lambda}{\rho c}$ is called thermal diffusivity.

We call upon the numerical method of the finite elements [4,5]. The analytical resolution is indeed impossible being given the geometry of the problem. The method consists in using an approximation by finite elements of the unknown functions T to discretize the variational form of the equation (1) and to transform it into system of algebraic equations of the form:

$$[A]\ T=F. \qquad (2)$$

With:
A square matrix of dimension [Nh, Nh].
F a vector of Nh components.
T the vector of the temperatures to be calculated
We start by building the variation form of the equation (1). We carry out a spatial discretization which consists in calculating the elementary integrals by using the finite element and a temporal discretization.
There are many specialized software which make it possible to implement the method of resolution of problems by finite elements in a more or less simple and convivial way. They take care in particular of the grid of the studied object, the automatic numbering of the elements and the nodes, the calculation of a solution then of the chart of the results.
In this study, we used commercial software "Comsol" based on the finite element method and which makes it possible to calculate the evolution of temperature at any moment and in any point of material. The material is considered isotropic. The calculation of the thermal answer is made in the case of a portion of oil pipe, subjected to a step of flow on the outer face, continuous and is extended at Q=50W/m2 density. the Inner surface of the pipe were subjected to convectional heat transfer with heat transfer coefficient, h=10 W/m².K. The initial temperature is of T0=25 °C.

5. Results of simulation

5.1 Considered model

In order to detect the rust thermal effect on the thermal state of the steel pipe, many situations are considered. The study concerns the effect of the diameter of a circular rust stain, the effect of the depth of the rust in the steel layer and finally the effect of the pipe thickness on the surface temperature on the given structure for a given defect.
Generally, from a thermal point of view the rust element is compared to water, since both have very close thermal characteristics [6]. When the rust attacks a cylindrical structure, the steel section decreases with the increase of corrosion layer [7], which involves a no homogeneous reduction of steel section accompanied by its embrittlement and a modification of the interface physical properties (increase then reduction in adherence) [8].

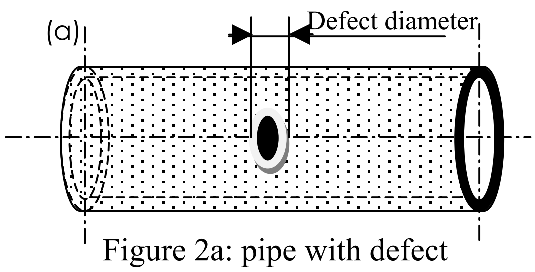

Figure 2a: pipe with defect

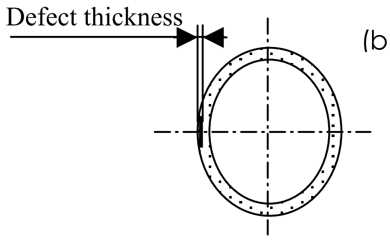

Figure 2b: cross section of steel

Fig.2: considered model

The physical and geometrical characteristics of the pipe and the rust are recapitulated in the table below (table 1)

Pipe	
External diameter	254mm
Cylinder thickness	19mm
lenthg	1000m
thermal conductivity	44.5 w/m.K
Rust	
Thermal conductivity	0.6 w/m.K

Table 1: physical and geometrical characteristics of pipe and rust.

5.2 Effect of the rust layer diameter

In order to illustrate the effect of the diameter of the rusted layer on control, three layers of rust in the shape of circular stain of a constant thickness (6mm) and with variable diameters: 60mm, 80mm and 100mm, are considered Fig.3. The calculate thermographical images (figures 4, 5, 6 and 7) and the surface temperature curves fig.8 obtained show that the more the diameter of rust increases, the more the surface temperature of the entry face increases and consequently the detectability of the defect becomes easier but the excess of temperature brought back by the presence of the defect remains weak and between the healthy state of control and the state in the presence of the defect is about 0,10°C for d = 60mm, 0,214°C for d= 80mm And 0,26°C For d= 100mm this shows that the use of such results on the experimental level requires infra-red thermographic cameras very precise of which the sensitivity is about 0,01

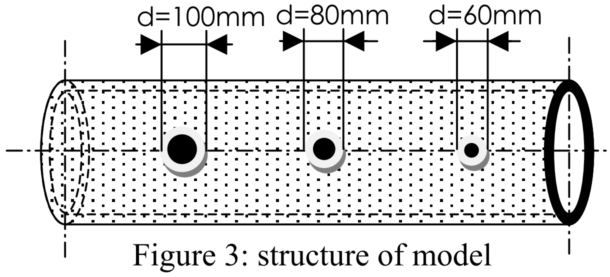

Figure 3: structure of model

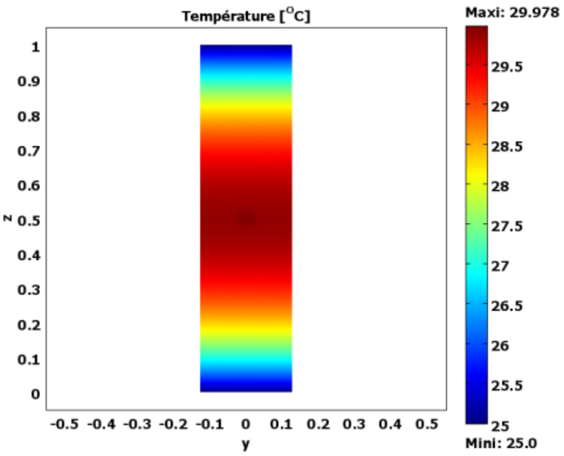

Figure 4: Thermographical image of the entry face(d=60 mm)

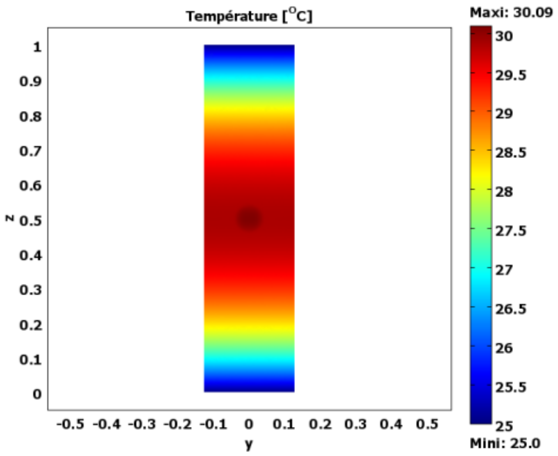

Figure 5: Thermographical image of the entry face(d=80 mm)

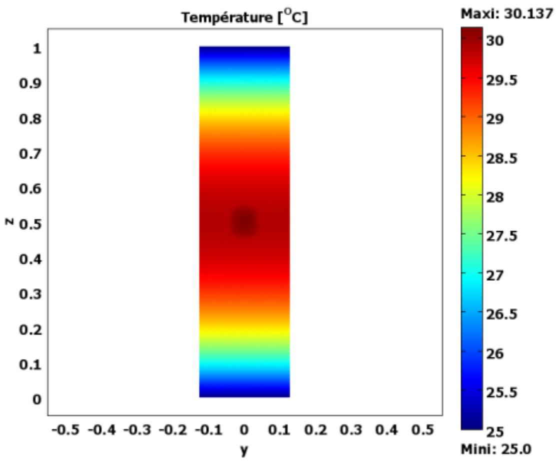

Figure 6: Thermographical image of the entry face(d=100 mm)

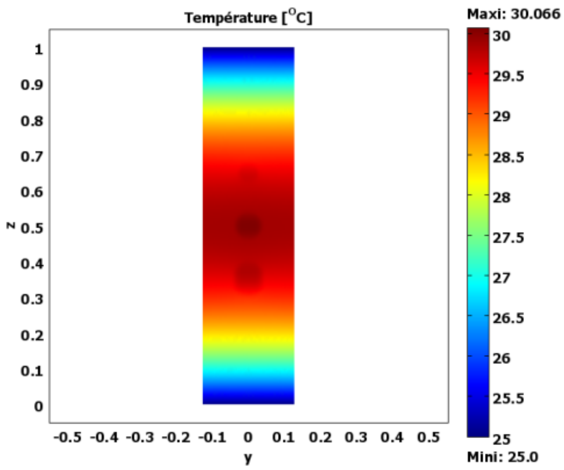

Figure 7: Thermographical image of the entry face for the three cases together

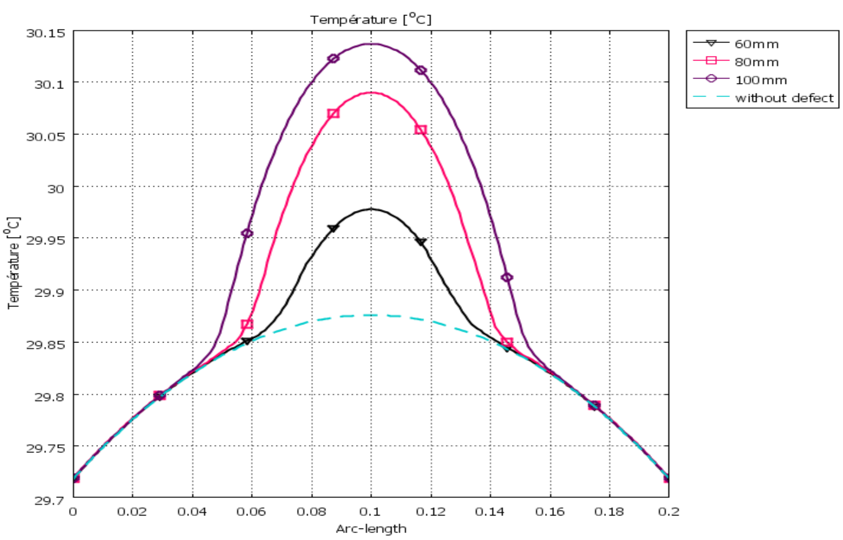

Figure 8: spatial evolution of the temperature on the entry face

5.3 The effect of rust layer thickness

The pipe used before is considered and this time the defect thickness takes the following values: 4mm, 6mm and 9mm. The diameter of the rust stain is constant and equal to 80mm.The thermographical images of the three cases (figures 10, 11, 12 and 13) and the surface temperature curves fig.14 obtained show that the more the rust layer thickness increases, the more the surface temperature of the entry face also increases and consequently the detectability of these defects becomes easier.

In the same way, one can show that the changes of temperature due to the presence of the defect remain weak compared to the healthy state of control. Indeed the difference in temperature of the healthy structure and that containing the defect is of 0.15°C For e_d = 4mm, of 0.24°C for e_d = 6mm and of 0.30°C for e_d = 9 mm. On the experimental level, precise measurements are essential for such detections.

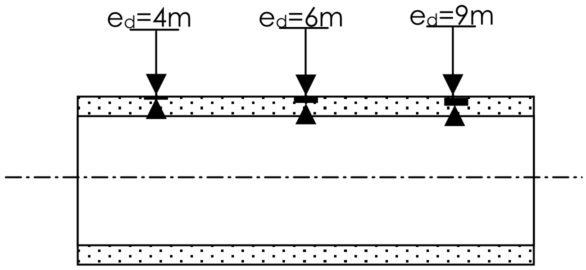

Figure 9: structure of model

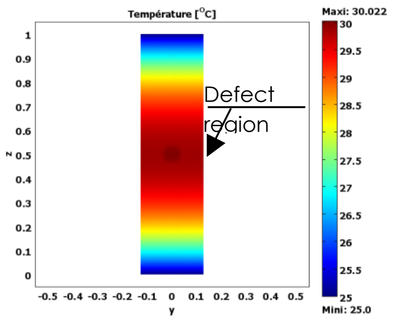

Figure 10: Thermographical image of the entry face(e_d=40 mm)

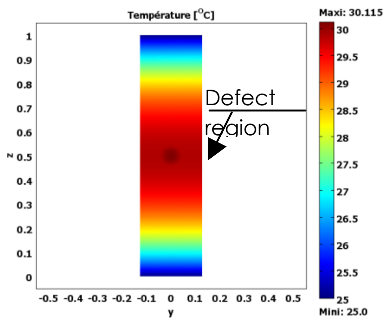

Figure 11: Thermographical image of the entry face(e_d=60 mm)

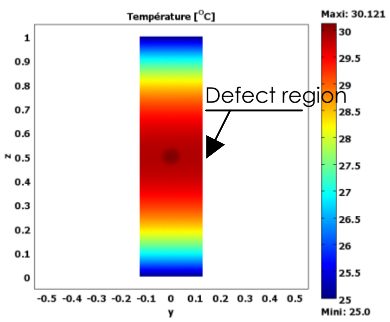

Figure 12: Thermographical image of the entry face(e_d=90 mm)

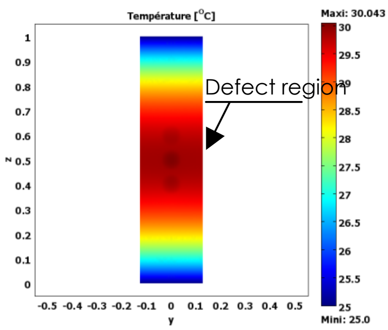

Figure 13: Thermographical image of the entry face for the tree cases together

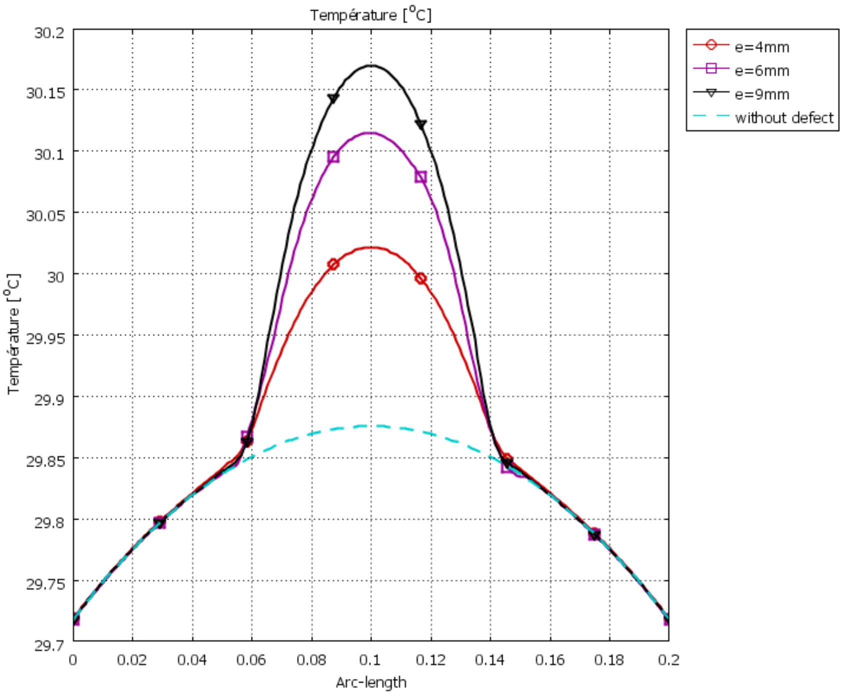

Fig.14: change of the temperature on the entry face

5.4 Effect of the variable thickness of pipe

In this last case of study, the variable parameter is the thickness of the pipe, Fig.15. The taken values of thickness for simulations are ep= 19mm, 14mm and 12mm, and one study the detectability of the circular rust layer having a arbutary constant thickness 4mm and an arbitary constant diameter of 8cm.
From these curves it comes out that when the thickness of the pipe is low, the delectability of the presence of rust in the controlled structure is relatively easy according to the thermographical images (figures: 16, 17 and 18) and also on the level of the spatial evolutions of the surface temperatures of the pipe, Fig.19. The detection of the defect of rust will be more difficult for a larger thickness of control.

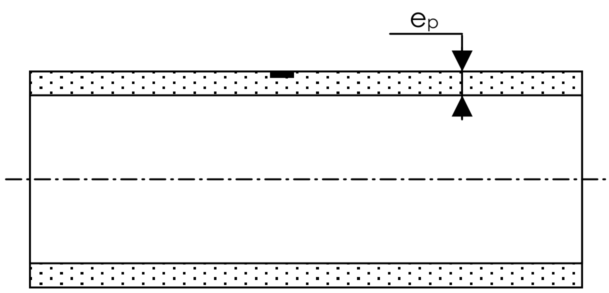

Figure 15: structure of model

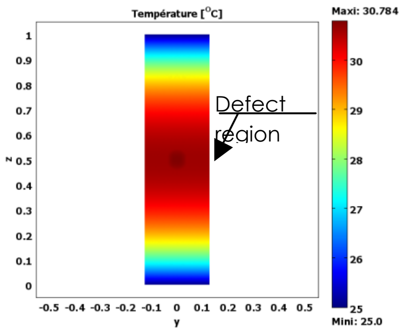

Figure 16 : Thermographical image of the entry face (e_p=120 mm)

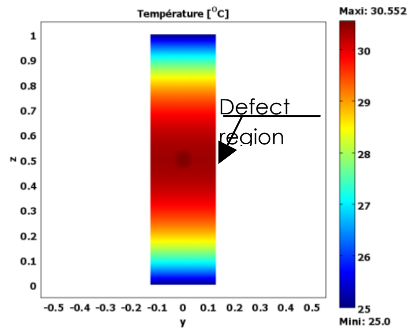

Figure 17: Thermographical image of the entry face (e_p=140 mm)

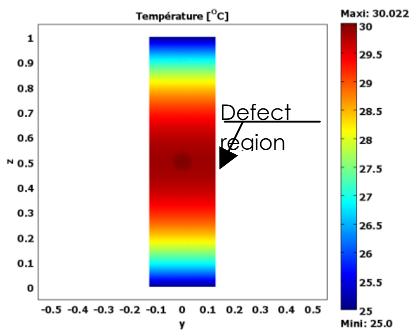

Figure 18: Thermographical image of the entry face (e_p=190 mm)

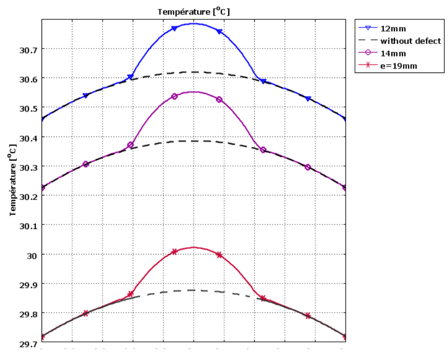

Figure 19: change of the temperature on the entry face

6. Conclusion

In this paper, we presented the effect of several parameters of the circular rust layer on its delectability in steel conduits, namely the effect of its diameter and its thickness. The effect of the pipe thickness was also considered. In general, one can draw the following conclusions:

• The detectability of corrosion is easier for a larger rust diameter.
• The detectability is easier for a larger thickness.
• More the thickness of pipe is low more the easier of detectability of defect is.

7. References

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