Characterization of scale in the steel water pipes by infrared thermography

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***Abstract*— We present in this work a numerical model based on the finite element method to detect the calcium carbonate scale presence which is dangerously frequent in steel water pipe. We have used the infrared technique thermography for studing the detection of the scale thickness in steel water pipes. We have proposed a model for estimation the scale thickness in the inner surfaces by calculation the maximum temperature value of the infected pipe heated surface.**

***Keywords*— Infrared thermography; finite element method; Thermal response; Pipe; Scale Thickness**

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I. INTRODUCTION

Deposition of Calcium Carbonate Scale in the water pipes becomes a serious problem for several industrial installations because it can lead to bad considerable technical and economic consequences: clogging pipes, reducing the water pipes diameter, increase in energy consumption [1]. It can also increase the risk of bacterial blooms that can have bad effects on the environment

The metallurgical technique provides a very accurate measure of scale thickness. However, the overall procedure is very time consuming and expensive as it is directly related to downtime. A large number of industries have expressed a need for nondestructive techniques for measuring or detecting scale on the inner surfaces pipes [2].

In the context of detecting the scale thickness in water pipes by infrared thermography, we will use in this work the 3D finite element method as numerical method to simulate the scale presence on the steel pipe inner surface.

To undertake the study we will build a pipe model like a hollow steel cylinder and the scale by annular cylindrical layer. Dimensions of the cylinder and those of scale are taken as parameters. We will study the effect of each geometrical parameter on the thermal response of the considered structure. For the flow of water, we will consider an incompressible laminar flow.

II. CONSIDRED MODEL

We consider a model where the pipe is represented by a cylinder hollow steel external diameter d=240mm, the cylinder thickness ep =20 mm, the length of pipe (cylinder) l =1m, and lime scale will be represented by a ring thickness y (Fig. 1). Inside the pipe, there will be a water flow with a velocity equal to 1.5 m/s. the pipe surface is heated evenly by the flux density Q=100W/m2. The initial temperature structure is T_0 = 293 k. The material is considered isotropic.

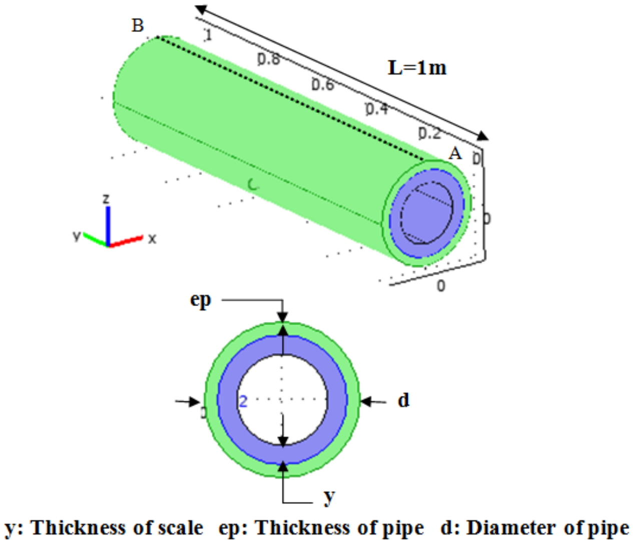

Fig 1. Schema of the considered structure

The materials thermal properties used in the simulation are shown in the following table [3]:

TABLE 1: PHYSICAL PROPRIETIES OF USED MATERIALS

Materiel	**Thermal conductivity λ (W/m.K)**	**Mass Density ρ (Kg/m^3)**	**Specific heat c (J/Kg.K)**
Steel	44.5	7850	475
Scale ($CaCO_3$)	2.7	2600	900
Water	0.6	1000	4200

III. SIMULATION RESULTS

To study the scale presence effect on steel pipe response. We apply a constant heat flux density on the entire outer surface of the infected pipe by scale. Using software based on finite element method, we determine its surface temperature distribution.

Several situations have been considered. We studied the tartar thickness effect, the thickness and pipe diameter on the thermal response of the investigated pipe

A. The scale thickness effect

To illustrate the effect thickness of scale layer on the flawed pipe response. We consider three scale layers of cylindrical annular shape having a thicknesses y=1cm, y=3cm and y=5cm.In Figure 2, we have represented the temperature variation along the pipe AB axis.

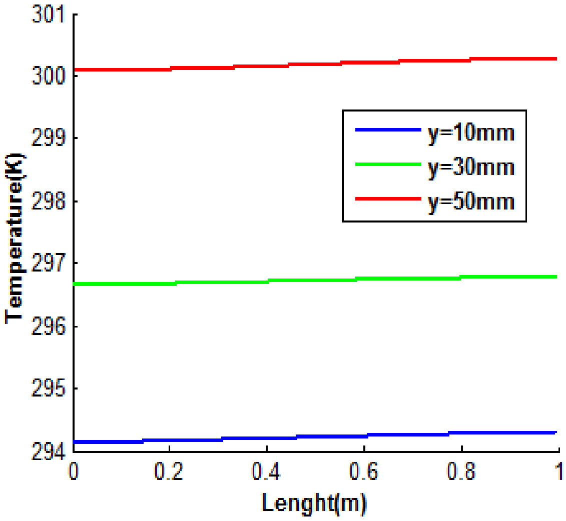

Figure.2: the temperature variation along the AB axis for three scale thicknesses

We note that when the scale thickness increases, the thermal response of flawed pipe increases. Because, the scale layer acts as a thermal insulator.

B. The pipe thickness effect

In industry there are scale deposits on various pipe sizes. To study the pipe thickness effect, we set the thickness of the scale layer and we have considered three different thickness pipe ep =10mm, ep =20mm and ep= 30mm. In Figure 3, we have represented the temperature variation along the pipe AB axis.

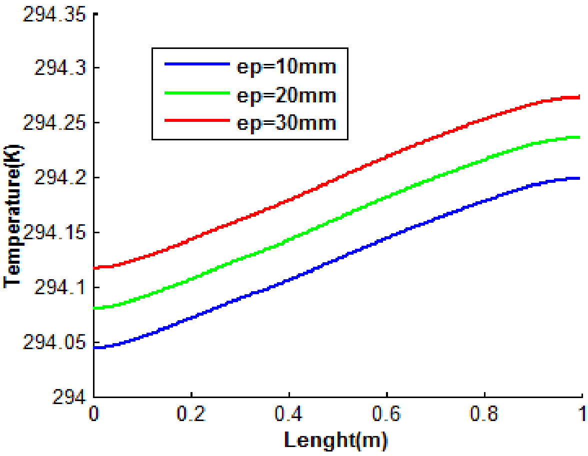

Fig3: the temperature variation along the AB axis for three pipe thicknesses

We can note that the temperature variation of the heated surface is slightly sensitive to the pipe thickness.

C. Pipe diameter effect

In latter case, we consider a pipe which is infected with a layer of a fixed thickness of scale
d= 240 mm, d = 140 mm d = 80 mm in Figure 4, we have represented the thermal response variation along the pipe A B axis.

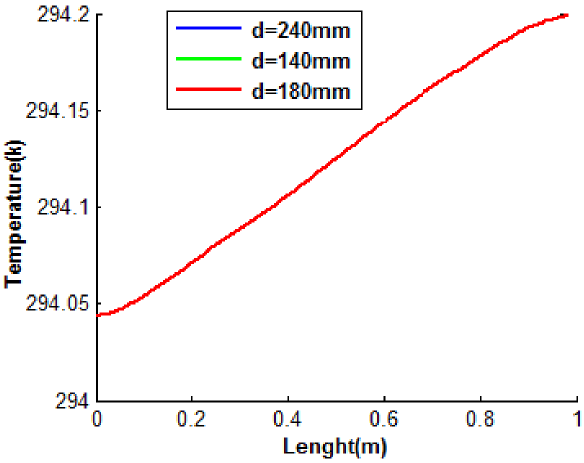

Fig: Thermal response variation along the pipe A B axis for the three diameters of pipe

We note that for each diameter value, the curves are superimposed. Therefore the change in pipe diameter has no significant influence on the temperature variation of the heated surface.

IV. MODEL FOR ESTIMATING THE SCALE THICKNESS

After a preliminary study on the geometrical parameters effects (scale thickness, thickness and pipe diameter).We will seek a model for estimation scale thickness from the maximum temperature value of the heated pipe surface. We performed simulations for a heat flux density equal to 100 W/m^{2}and a pipe diameter equal to 10cm.we introduce The relative temperature as follow:

$$T_{rel} = \frac{T_m - T_0}{T_0} \qquad (1)$$

Where:

- T_m is the maximum temperature of the heated surface
- T_0 is the initial temperature before heating.

We illustrated in the figure below the thickness scale (1) variation versus the relative temperature for three different values of thickness pipes of ep = 10 mm, ep = 14mm and ep=18mm.

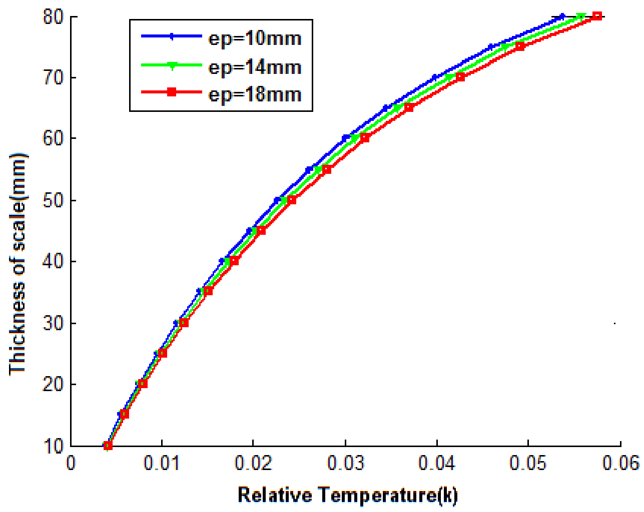

Fig.5: the scale thickness variation versus the relative temperature

It is observed that the variation in thickness is a logarithmic function of temperature relative $\mathbf{T}_{\mathbf{rel}}$ ’it depends slightly on the pipe thickness.

To estimate the scale thickness reducing the water flow in industrial networks. We propose a model which has the following expression:

$$y = A(ep).T_{rel}{}^3 + B(ep).T_{rel}{}^2 + C(ep).T_{rel} + D(ep) \qquad (2)$$

Where:

- y : the estimated value of the thickness scale
- T_{rel}: the relative temperature given by relationship (1)
- ep : The thickness of the steel pipe

The coefficients **A(ep)**, **B(ep)** ,**C(ep)** and **D(ep)** are given by:

$$A(ep) = -17.05232.ep^4 + 955.87.ep^3 - 19653.997991.ep^2 + 16879.36\,ep - 236579.316$$

$$B(ep) = 1.22785721565.ep^4 - 68.8.ep^3 + 1413.945.ep^2 - 11856.1711\,ep - 1136$$

$$C(ep) = -0.021157.ep^4 + 11.836.ep^3 - 242.514665.ep^2 + 1885.5\,ep + 2.7224$$

$$D(ep) = 0.00009175.ep^4 - 0.005.ep^3 + 0.1.ep^2 - 0.9247\,ep + 1.572$$

To verify the model as we do not currently have a way to measure, we simulated pipes infected scale (reference) by a calculation code based on 3D finite element a steel pipes containing a circular cylindrical layer of scale. Figures 6-a, 6-b, 6-c, and 6-d represent the obtained points by the simulation and the curves obtained by the model suggested in the relationship (2). We plotted the scale thickness variation as a function of relative temperature T_{rel} for different pipe thicknesses

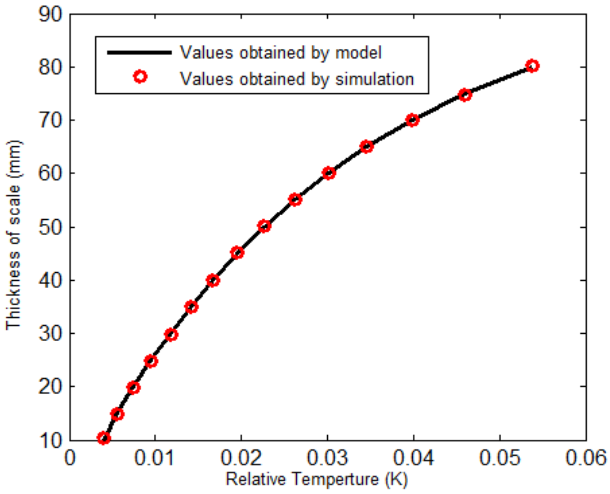

Fig.6-a: Comparison of the proposed model results with reference. Pipe thickness ep=10 mm

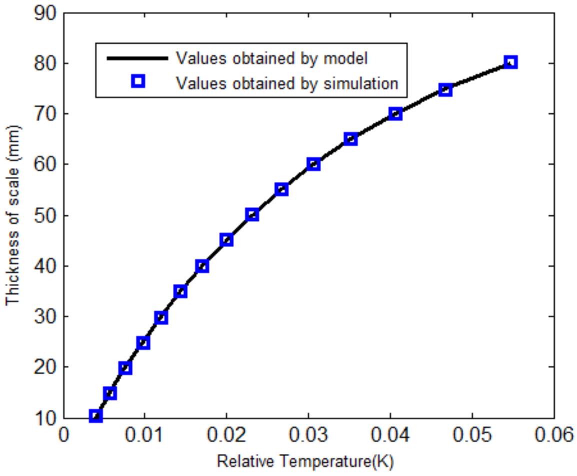

Figure.6-b: Comparison of the proposed model results with reference. Pipe thickness ep=12mm

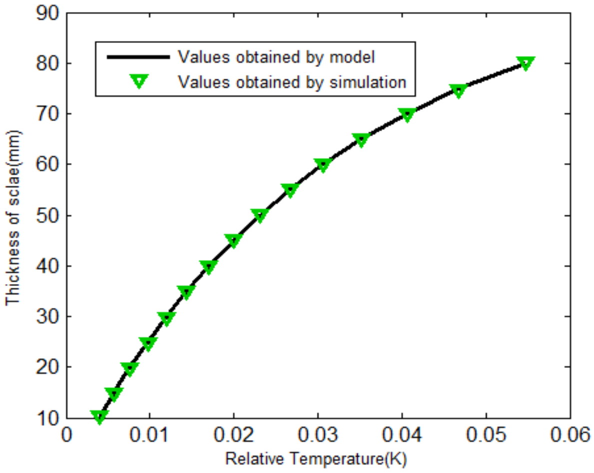

Figure.6-c: Comparison of the proposed model results with reference. Pipe thickness ep=14 mm

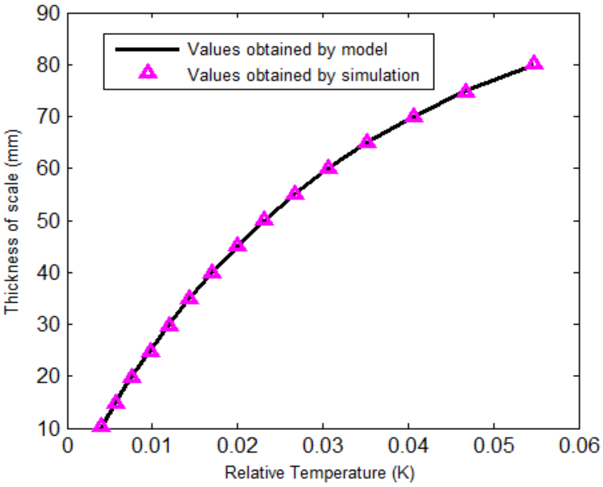

Figure.6-d: Comparison of the proposed model results with reference. Pipe thickness ep=16 mm

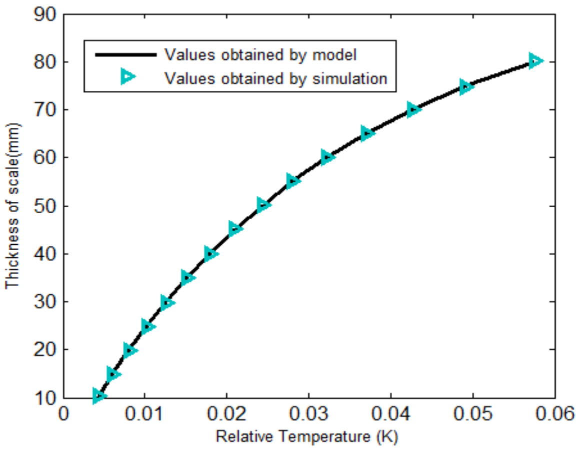

Figure.6-d: Comparison of the proposed model results with reference. Pipe thickness ep=16 mm

To evaluate the precision of the model results, we defined the difference (error) by the following arithmetic average:

$$error = \frac{\sum_{i=1}^{n} \left| e^{i}_{sim} - e^{i}_{c} \right|}{n}$$

Where :

- e^{i}_{sim} is the thickness of the scale obtained by simulation
- e^{i}_{c} is the calculated thickness by the proposed model by relationship (2),
- n is the number of considered points,

Table 2 shows the obtained errors (gap) values

Table 2*:* Gaps values

Thickness of pipe	ep=10mm	ep=12mm	ep=14mm	ep=16mm	ep=18mm
Error(mm)	0.1286	0.1395	0.1427	0.1392	0.1402

The proposed model can estimate the scale thickness from the relative temperature of the steel pipe heated surface. The obtained values deviations remain low for all thicknesses pipe. This shows the ability of the proposed model for inspection in the case of steel pipes with various scale thicknesses.

V. CONCLUSION

In this article, we highlighted the ability of the 3D finite element method to simulate the scale thickness detection. We studied the geometrical parameters effects on the inspected pipes thermal response. Indeed, we found that the pipe diameter has no significant influence on the inspected pipes thermal distribution. The scale deposits may cause harmful environmental accidents. We proposed a new model to estimate the scale thickness from the relative surface temperature. The obtained gaps values remain low for all thicknesses pipes.

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