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RESEARCH ON LIFE PROLONGATION FOR TEMPERATURE SENSORS PLACED IN HIGHLY EROSIVE ENVIRONMENT

Ionescu O.N.[1], Ionescu G.C., Minescu M., Nae I.

[1]Petroleum - Gas University of Ploiesti, Romania, e-mail: ionescu_o_ro@yahoo.com

Abstract: *This study is the results of research on technologies suitable for extending the operational life of temperature sensors placed in highly erosive environment. The need for this research resulted from a request received from a dry mortars factory, operating a sand drying plant. The process of sand drying is automated controlled using the information provided by two temperature sensors. One of these sensors is located inside of the exhaust pipe and was severely eroded in about two months by the quartz sand mixed within the exhaust gases. There it was an attempt to shield the sensor by using a segment of steel pipe; however, the change in the transfer rate of heat generated a significant delay in regulating the system. An alternate solution was studied and the sensor was coated through thermal spray coating with a 0.01 mm layer of Titanium – Zirconium. This solution has been operationally tested and the results showed that there were not troubles due to the heat transfer rate and the operational life of the sensor was prolonged to six months.*

Keywords: *sand drier, abrasion, spray coating, temperature sensors*

1. INTRODUCTION

The sand drying plant used in the commissioned factory uses the phenomenon of fluid bed of material for minimizing the amount of electrical and thermal energy for drying materials. The sand drier see Figure 1 consists of two sections, one for drying the sand (1) and the second for cooling the material (2). The fluid bed of material is generated by a complex system which shakes the bottom part of the drier and realizes a balance between the intake pressure and the exhaust under pressure in each of the section of the sand drier. In the sand drying section the fluid bed is the result of action of the pressure of the hot air generated by the burner (3) and the hot air exhaust fan (4). The hot air is filtered by the first section of the filter plant (5) and released in the atmosphere with content of less than 10000 ppm residues. In the second section, the cooling chamber, the cooling agent is generated by the intake fan (6) and after passing through the cooling chamber it is recycled through the second section of the filter plant and through the fan is used to increase the effectiveness of the burner. The optimum value of the module of the differential pressure which generates the desired fluid bed of material should be established at 1 mbar. The sand drying plant includes an automated control system designed to correlate the temperature of the hot gases into the drying chamber with the quantity of the wet sand feed to the system and to maintain the under pressure required for the fluid bed of material. To protect the filter plant was implemented a system to open a cooling air vane when the temperature is getting over 80 ^{0}C and shutting down the dryer when the exhaust hot gases would reach values over 100 ^{0}C . The sensor used to monitoring the temperature of exhaust gases is PT 100.

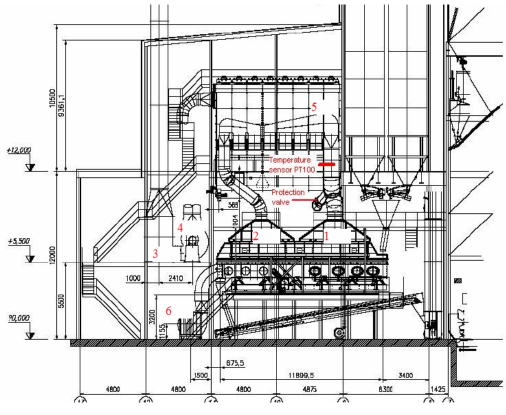

Figure 1. The schematics of Sand drying plant

The experience yielded during the first six months of production and operational tests showed that due to the highly erosive environment the protective tube of PT 100 sensor was severely eroded within 2 months, causing its destruction see Figure 2.

Figure 2. Eroded PT 100 sensor

In order to increase the operational life of the sensor it was studied if possible to add an additional protective tube made off a wear resistant material. To establish the feasibility of this solution the increase of the response time had to be studied. The PT 100 sensor has been already provided with a 4mm protection tube, as presented in Figure 3. According to the PT 100 data - sheet the response time for the 4mm wall thickness protective tube there is a response time of about 6 minutes.

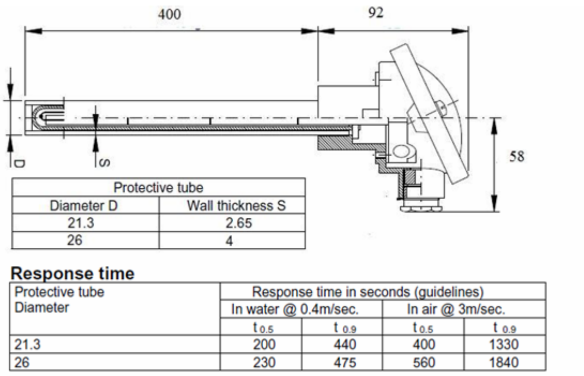

Figure 3. PT 100 temperature sensors technical details [1]

There were conducted mathematical calculations for studying the increase of response time for an additional 4 mm thickness protective tube made of 12Cr 130 (STAS 3583) X 15 Cr 13 (DIN 17440, SEW 400).

Table 1. Chemical composition of steel used for manufacturing the additional shield

Steel	Chemical composition (%)			
	C	Cr	Mn	Si
12Cr130/ X 15 Cr 13	0,09…0,13	12,0…14,0	max. 0,60	max. 0,60

According to the technical documentation [3], there are three methods for calculating heat transmission time, through solid bodies. These methods are considering the main characteristics of heating agent and geometrical characteristics of heated body.

Input data:

a. Thickness of protective tube R = 4 mm;

b. Area of temerature variation for the working environment : $t = (100…400)\ ^0$C;

c. Tipe of material used for protective tube: 12Cr130/ X 15 Cr 13 steel;

1. Calculation method based on heating criterion.

Mathematical formula used for heat transmission time is [3]:

$$\tau_{i,1} = 0.1 \cdot k_f \cdot k_m \cdot k_u \cdot R \text{ (min)} \qquad (1)$$

Where: τ_i is heating time (min), k_f – shape coefficient (based on geometrical shape of studied body – for the studied case- empty cylinder, heated from outside, $k_f = 2$ [3]; k_m – environmental coefficient, characteristic for heating velocity; for this peculiar case the environment consists of gases therefore $k_m = 2$ [3], k_u – coefficient characterizing heating uniformity; for this case $k_u = 1$, [3], R – characteristics related to studied body dimensions (thickness); $R = 4$ mm.

In this specific case heating time calculated with formula (1), is: $\tau_{i,1} = 1.6$ min.

2. Calculation method based on geometrical coefficient of studied body.

Heating time $\tau_{i,2}$ is calculated with formula: [3]:

$$\tau_{i,2} = \frac{(D-d)\cdot l}{4\cdot l + 2\cdot(D-d)} \cdot k_f \text{ (min.)} \qquad (2)$$

Where: D, d are external and internal diameters of cylinder – protective shield - ; in this case D = 34 mm, d = 26 mm, k_f – physical factor characterizing heating, for this case: k_f =35 [3].

In this specific case the result of calculation is: $\tau_{i,2}$ = 6, 93 min

3. Criterial calculation method

Steps of calculations:.

a. Establishment of thermo-phisical parameters as presented in table 2 [2].

Table 2. Value of termo-phisical parameters

Type of material	Value of termo-phisical parameters			
12Cr130 (X15 Cr 13)	Heat transfer coefficient, α $\left(\frac{kcal}{m^2 \cdot h \cdot {}^0C}\right)$	Thermal conductivity λ $\left(\frac{kcal}{m \cdot h \cdot {}^0C}\right)$	Specific heat, C_p $\left(\frac{kcal}{kg \cdot {}^0C}\right)$	Specific weight (density), ρ $\left(\frac{kg}{m^3}\right)$
	13,5	23,8	0,113	7740

b. Calculation of temperature criteria, θ_c [2]:

$$\theta_c = \frac{t_m - t_i}{t_m - t_0} \qquad (1)$$

Where: t_m is the temperature of working environment: t_m = 400^{0}C, t_i – temperature at the end of heating cicle: t_i = 200^{0}C; t_0 – initial temperature of heating agent: t_i = 20^{0}C.

Based on these parameters results that: $\theta_c = 0{,}52$

c. Calculation of Biot criteria value, B_i [2]:

$$B_i = \frac{\alpha \cdot R}{\lambda} \qquad (2)$$

According to the initial data the value obtained for is: $B_i = 2{,}26 \cdot 10^{-3}$

d. Based on the previously calculated criteria ($\theta_c = 0{,}52$; $B_i = 2{,}26 \cdot 10^{-3}$), the value of is Boussinesq criteria is calculated, B_q = 3,0 [2].

e. Time of heat transmission is calculated with formula [2]:

$$\tau_i = \frac{\lambda^2 \cdot B_q}{a \cdot \alpha^2} \qquad (3)$$

For the additional protective tube the increase of the response time will be: $\tau_i = 5{,}75$ min.

The results obtained using all three methods are presented in Table 3.

Table 3. Comparison of results obtained by using the mathematical methods presented.

Nr. crt.	Method of calculation used	Mathematical Formula/results
1	Calculation method based on heating criterion	$\tau_{i,1} = 0.1 \cdot k_f \cdot k_m \cdot k_u \cdot R$ $\tau_{i,1} = 1.6$ min
2	Calculation method based on geometrical coefficient of studied body	$\tau_{i,2} = \frac{(D-d) \cdot l}{4 \cdot l + 2 \cdot (D-d)} \cdot k_f$ $\tau_{i,2}$ = 6,93 min
3	Criterial calculation method	$\tau_{i,3} = \frac{\lambda^2 \cdot B_q}{a \cdot \alpha^2}$ $\tau_i = 5{,}75$ min

Comments

Although the results obtained by using the second and the third algorithms are relatively close, there it is a quite large dispersion of the calculated heating times. Due to the sensitivity of application and in order to protect the filtering cloths there it was decided to verify the mathematical calculation by experimental research.

The calculation was verified by using the One-Dimensional, Transient Conduction Version 3.6b of HTTonedt [3] developed by the staff of Virginia University.

The results showed that the response time would increase from 6 to 11 minutes, which cannot be admissible for this critical application. The exposure of the filter's cloth to temperatures over 100 C ^{0} or long time would destroy the fabric consequently generating environmental issues.

The second option considered was to coat the sensor with a much thinner layer of material which provides a better protection against erosion. One of the most promising alternatives is high velocity oxygen fuel (HVOF) tungsten carbide coatings.

There it was selected the spraying powder produced by Sulzer Metko - WOKA 3901 consisting of 86% Tungsten carbide, 10% Chromium and 4% Chromium. [4].

The coating of the sensor has been performed using the Sulzer Metco Diamond Jet DJ Gun see figure 4 available in the welding laboratory of Petroleum and Gas University. The sensor was coated with a 0.01 mm layer of material.

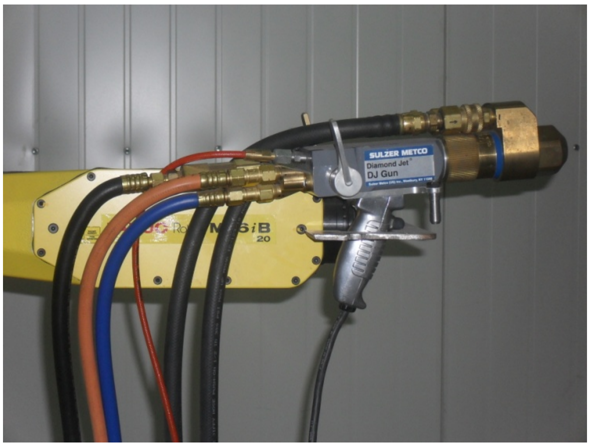

Figure 4. Sulzer Metco Diamond Jet DJ gun

Due to the fact that the thermo-physical parameters of the coating were not known it was not possible to calculate the increase of the response time of the coated sensor. In this regard there were conducted practical measurements using the thermal test chamber ETUVA 100 see Figure 5 housed in the welding laboratory of Petroleum and Gas University. The result of measurements showed that the increase in response time for a 0.01 mm thickness of coating is about 17 seconds.

Figure 5. Thermal test chamber ETUVA 100

2. CONCLUSION

The coated sensor was operationally tested in the sand drying plant. The 0.01 mm thick coating has prolonged the operational life of the sensor to 6 months. Since the increase of the response time due to the 0.01mm coating was relatively small there is still room for applying a thicker layer of Sulzer Metko - WOKA 3901 in order to increase the operational life of sensor.

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