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Determination of Leakages in Blast Furnace Cooling Plates

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A system has been designed and installed in order to confirm the eventual occurrence of leakages in the cooling plates of a blast furnace refractory lining. The system injects a solution of T into the feeding pipeline and determines, by means of liquid scintillation (LS) counting, the concentration of T in the exhausting gases at the top of the blast furnace. The system was tested under different blast furnace operating conditions, and allowed the detection and determination of leakages greater than 0.5 L/min. Following necessary maintenance, the system also confirmed the satisfactory results of the corrective actions.

Introduction

Blast furnace walls are cooled by the circulation of water through Cu plates inserted into the blast furnace refractory lining. Plates are fed by circular pipelines, called distribution rings, installed at different levels of the reactor. Because of normal corrosion, plates wear away and can eventually perforate, allowing the leakage of cooling water inside the blast furnace.

When a given volume of leaking cooling water intrudes into the material undergoing a melting process in the blast furnace, it causes temperature variations all along the reactor level where the leakage is occurring. These temperature variations create reactor control problems, specially regarding homogeneity during the descent of the loading material. In order to avoid this problem, it is convenient to have a method capable of detecting the early stage perforation of cooling plates and to determine the magnitude of the corresponding water leakage.

The system reported here is based on the continuous injection of a tritiated water tracer, into the distribution ring. Due to the existing conditions of circulation, the tracer mixes homogeneously with the cooling water before reaching the reactor. The collection of condensed water samples from the exhausting gases at the top of the blast furnace and their measurement for T activity by the LS counting, allows the leakage to be detected.

Theory

The concentration of T activity in the cooling system solution that circulates through the plates is calculated using equation (1):

$$C = \frac{q_0 C_0}{Q_0 + q_0} \cong \frac{q_0 C_0}{Q_0}, \tag{1}$$

where:

C = concentration of T activity in the cooling system solution,
q_0 = flowrate of the T tracer injection,
C_0 = concentration of T tracer activity in the injected solution,
Q_0 = flowrate of the cooling system water.

Equation (2) allows calculation of the total T activity that flows into the blast furnace during a period of time Δt:

$$A = qC\Delta t = \frac{qq_0 C_0 \Delta t}{Q_0}, \tag{2}$$

where:

q = flowrate of the plate leakage.

The concentration of T activity of the water vapor carried by the exiting gases of the blast furnace is calculated by equation (3):

$$C_2 = \frac{A}{Q_{H_2O}\Delta t} = \frac{qq_0 C_0}{Q_{H_2O} Q_0}, \tag{3}$$

where:

Q_{H_2O} = flowrate of the water vapor in the blast furnace.

Equation (4) allows the calculation of the flowrate of leakages from the plates as follows:

$$q = \frac{C_2 Q_{H_2O} Q_0}{q_0 C_0}. \quad (4)$$

Considering a 25% LS counting efficiency for the T, the detection limit of T A_m will be 60 cpm. Since the volume V_a of water measured was 10 mL, the value of the minimum detectable leaking flow can be calculated using equation (5):

$$C_{2_{min}} = \frac{A_m}{V_a} = 24 \text{ dpm/cm}^3 = 0.4 \text{ Bq/cm}^3. \quad (5)$$

By substituting in equation (4) C_0 for the value derived from equation (2) and C_2 by the value of $C_{2_{min}}$ given in equation (5), the minimum detectable leakage flowrate is calculated by equation (6):

$$q_{min} = \frac{0.4 \text{ Bq/cm}^3 Q_{H_2O} Q_0 \Delta t}{A_0}. \quad (6)$$

Considering the values:

$A_0 = 4$ Ci = 148 GBq (total activity injected during the test),
$\Delta t = 180$ min (time of injection),
$Q_0 = 8 \times 10^6$ cm^3/min (flowrate of water in the distribution ring),
$Q_{H_2O} = 6 \times 10^3$ L/h (flowrate of water vapor),

the minimum detectable flowrate of water leakage entering the blast furnace should be 23.3 L/h.

Because of the limitations imposed by radiological safety rules, it was necessary to calculate the following value to determine if it was possible to use the quantity of T necessary to reach a desirable sensitivity for the test:

$$C = \frac{q_0 C_0}{Q_0} = \frac{A_0}{Q_0 \Delta t} = 103 \text{ Bq/cm}^3 \quad (7)$$

As the acceptable limit for the disposal of T in water is 1.11×10^3 Bq/cm^3 (according to Brazilian national regulation CNEN NE-6.05), the quantity of T necessary for the desirabled sensitivity [cited in equation (7)] can be used.

Considering that the water circulating in the cooling distribution ring mixes at the exit with water with a flux greater than 10^3 m^3/h (coming from other areas outside the blast furnace), the concentration C_1 of T in the effluent is calculated using equation (8):

$$C_1 = \frac{Q_0 C}{Q} < 4.9 \text{ Bq/cm}^3. \quad (8)$$

A maximum 4% of the water vapor released inside the blast furnace, may be dissociated to its components because of the existing physical and chemical conditions (Cardozo, 1993). The calculation of gaseous T concentration found in the exhausting gases was made as follows [equation (9)]:

$$A_T = qC = 3.14 \text{ MBq/min}, \quad (9)$$

where:

A_T = rate of T release in the blast furnace.

The value q used for this calculation was the highest measured during the tests. The gaseous T activity was calculated as follows [equation (10)]:

$$T = \frac{0.04 A_T}{Q_{gas}} = 50.2 \text{ Bq/m}^3, \quad (10)$$

with $Q_{gas} = 2500$ m^3/min. Since the obtained value was lower than 7.4 kBq/m^3 (which is the maximum gaseous T authorized for atmospheric release) there was no impediment for its utilization.

Experimental

Prior to the testing, it was necessary to determine the most convenient place to inject the tritiated water tracer into the pipeline that feeds the distribution ring. Once found, a valve and a pressure gauge were installed in the selected position. A diaphragm-type dosing pump capable of operating at a pressure of 10 kg/cm^2 and with a capacity of 3.5 L/h was used for the injection (Fig. 2). The tritium solution was prepared in a 10 L plastic container, with threaded cap. The injection system is light and compact, allowing an accurate control and an excellent stability of the injection flux.

The system used to obtain samples of the exhaust gases at the top of the blast furnace is composed by a descending pipeline, a gas meter to measure the flux of gas in the pipeline, a cooling system to condense steam, and dry and wet bulb thermometers to determine the moisture remaining in the gas (Perry and Green, 1984). The rate of exhaust gas water condensation in the sampling system from the top of the blast furnace was determined by the volume of condensed water obtained during a fixed period of time. In order to obtain a reference sample of condensed water free of T, the sampling procedure was always initiated 30 min before the beginning of the injection of T tracer into the distribution ring. All the condensed vapor water samples from the exhausting gases at the top of the blast furnace were distilled in order to eliminate any C particles which might cause quenching in the determination of the concentration of T.

As the cooling water flow is not a constant but varies every day, its value had to be determined for each test. An aqueous solution of radioactive bromine (^{82}Br) as a tracer was used to measure the flowrate by its transit time, with the installation of two γ-detectors separated by a distance of 52 m. The inner diameter of the pipeline in the sector selected for the test was 12″ (30.5 cm). The first detector was installed at 25 m from the injection point. This

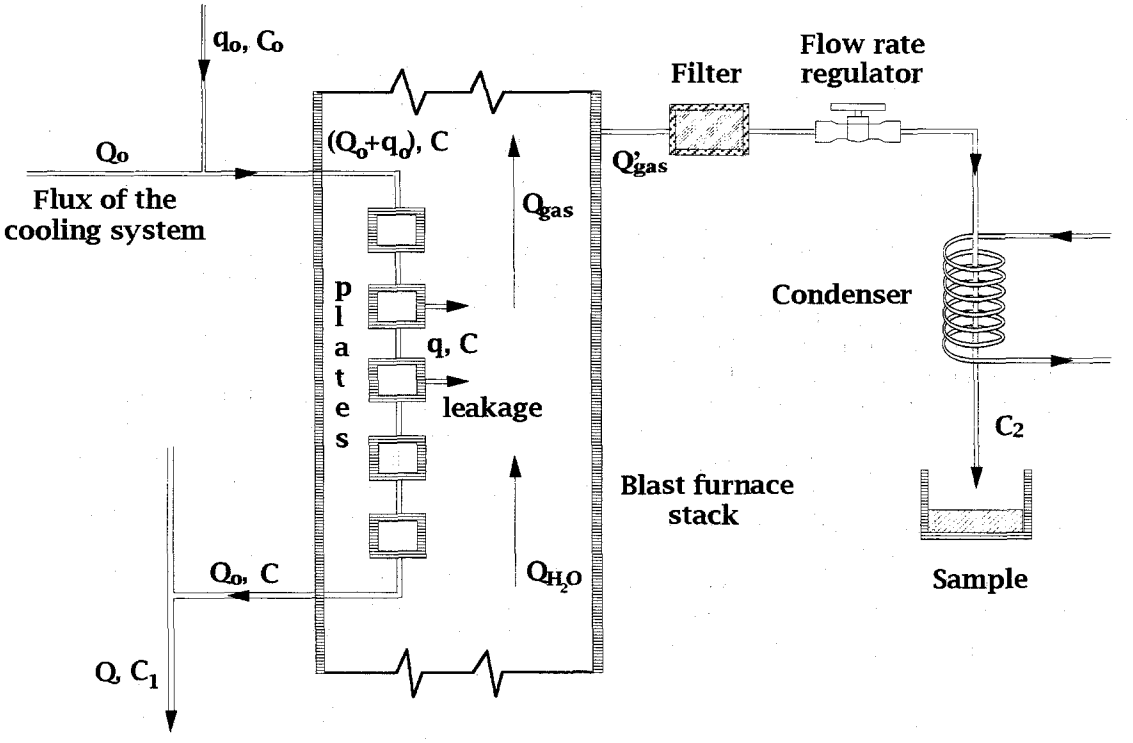

Fig. 1. Scheme and notation of the measurement process.

distance was enough to insure homogenization considering that the Reynolds number was 5×10^5 and that there were elbows in the pipeline. The transit time between the two measuring sections was determined with reference to the centre of gravity of both detection peaks, using a two channel recorder.

The tritiated water tracer injection flowrate varied from 10 to 18.5 mL/min and the activity concen-

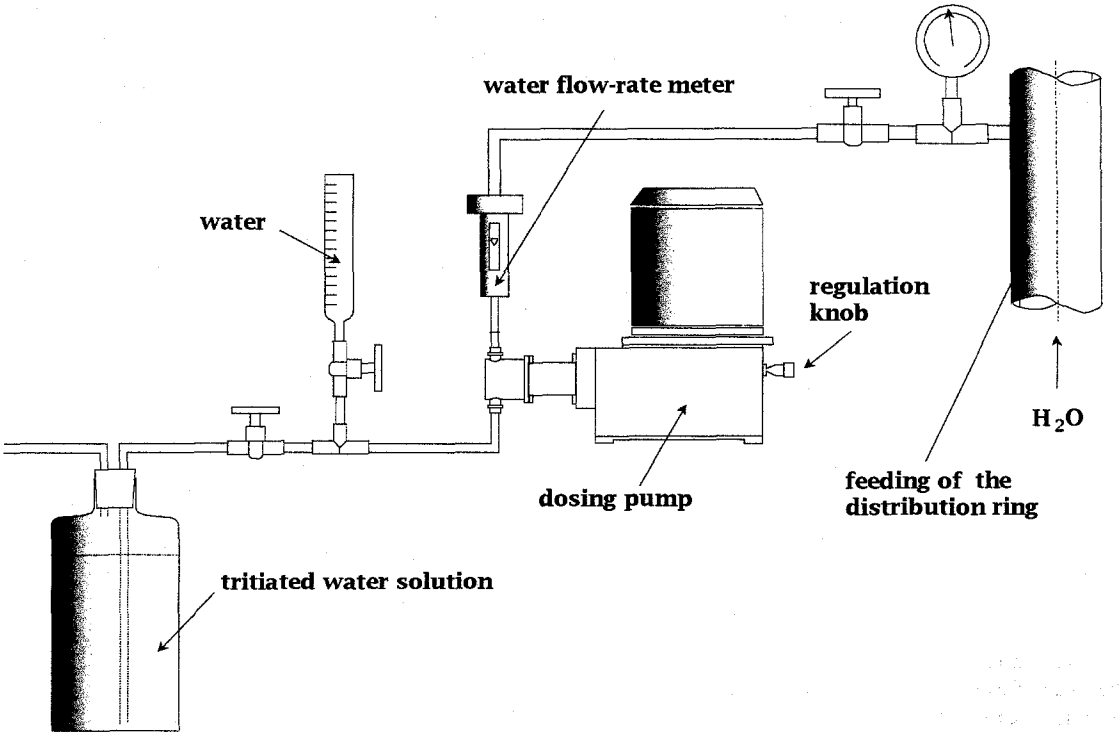

Fig. 2. System for the injection of tritiated water.

Table 1. Values determined

Test		1	2	3	4	5	6	7	8	9	10	11	12	13
Injection flowrate, mL/min	q_0	17.65	18.51	15.87	18.18	18.51	10.48	17.33	17.23	17.23	17.55	17.75	17.65	16.67
Total activity of ^3H injected, GBq	A'	139	100	112	98.5	94.7	72.4	122	122	122	206	208	196	196
Total flux of gases, Nm^3/min	Q_{gas}	3490	3405	2976	3292	3429	2840	2783	2783	2735	2730	2780	2500	2489
Water in exhaust gases, g/Nm^3	f	40.00	38.86	46.70	45.07	62.92	1622.2	119.0	64.55	35.94	44.00	56.00	11.30	43.10
Flowrate of water vapor, L/h	Q_{H_2O}	8376.0	7939.1	8338.8	8888.4	12,961	276,423	19,870	10,780	5897.7	7207.2	9304.8	1699.5	6415.5
Activity of ^{82}Br, GBq	A	1.3	1.1	0.92	0.74	0.93	1.3	1.1	1.1	0.92	0.92	0.92	0.59	0.59
Time between peaks, s	Δt	30.9	35.7	31.2	30.9	32.4	35.4	35.8	41.2	32.0	34.3	35.7	31.5	35.8
Flowrate of water, L/min	Q_0	7367.5	6378.1	7306.1	7367.5	7035.7	6439.2	6367.2	5532.7	7123.4	6645.7	6385.1	7236.4	6367.2
Leakage, L/h	q	1832.0	16.4	17.8	35.0	57.0	1348.2	7.7	11.7	1.9	1.3	1.3	4.3	5.3

tration was between 30 and 65 MBq/mL. The total activity injected was kept between 70 and 200 GBq. The flowrate of the gas exiting the blast furnace was measured with the equipment normally used by the steel plant. The total concentration of water in the exhausting gases was determined taking under consideration the average rate of condensation obtained from the samples plus the moisture that remained in the gas. The listing of values obtained during the experiments is shown in Table 1.

Conclusions

The experiments performed clearly show the possibility of determining, with an acceptable degree of accuracy, the existence of leakages in the blast furnace cooling plates. The main advantage of this method is that it avoids the exposure of workers to dangerous operational conditions and allows quantitative results to be obtained that cannot be measured by traditional methods.

Some important findings can be identified in Table 1:

(a) There was a strong suspicion about the existence of a leakage before the execution of the first test and such a leakage was reconfirmed by the test results;

(b) The series of second to fifth tests show a very interesting sequence of results, which indicates the progressive wearing process of a cooling plate. Initially, there was no external evidence of the existence of a leakage. The leakage was determined for the first time during test number two, and the evolution of the leakage was traced down during subsequent tests;

(c) The series of tests allowed a correlation to be obtained between the blast furnace thermal stability and the magnitude of the leakage flux, supplying parameters of great assistance in technical decisions for troubleshooting;

(d) The sixth test was performed to verify the method's sensitivity under special conditions with the presence of excessive moisture in the blast furnace loading, which in turn increases the dilution of the tracer concentration. Similar to the first test, the existence of the leakage was suspected before performing the test and was reconfirmed by the test result.

Two disadvantages of this method were found:

1. Under the conditions of this study a long response time of approx. 24 h was needed to obtain the results. This period can be greatly reduced by the installation of a small laboratory equipped with an LS counter in the steel work facilities.
2. It was found to be impossible to use this method in the lowest distribution ring since the lowest

ring is located in a level of the blast furnace where maximum temperatures are found. High temperatures cause a chemical reaction between carbon and water which makes the water partially dissociate to oxygen and hydrogen. Because the hydrogen (and consequently the T) in this state cannot be condensed and retained during the test sampling, the tritiated water cannot be used as tracer when quantitative results have to be obtained. However, this technique can still be useful for qualitative purposes or to confirm the presence of a leakage.

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