Study on Air Tubes Failure in Sponge Iron Rotary Kiln

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Abstract: The rotary kiln process is a commonly practiced method in the industry for producing sponge iron using coal. In the industry, there have been recent reports of premature failures of certain air tubes in a rotary kiln. Most of those cases have concentrated on those air tubes which run into the kiln around the middle portion of the kiln. This research work aims at identifying the probable cause of the failure. Two different types of kiln models (Front view and Side view 2-D models) were constructed and a temperature profile and an air-flow velocity profile were obtained. It is found that there are two main causes of thermal failure: i) due to steep changes in the overall temperature of an air tube with respect to time, and ii) due to the internal temperature gradient changes within an air tube with respect to time.

Keywords: Sponge Iron, Heat Transfer, Rotary Kiln

1. Introduction

In Rotary kiln, carbon is charged from either end, in one end in the form of coal particles and in another in form of coal lumps. The coal reacts with air to form carbon monoxide which then reduces iron oxide (ore) to iron. So, in a kiln, there are two sources of energy, one in the lance injecting coal particles from one end and the second is the coal in charge bed where reduction of iron ore occurs. The air tubes are located along the length of the kiln and they inject air into the kiln. A section of air tube is located inside the kiln and rest of the machine/blower is outside of the kiln. There have been some cases in industry where, the air tubes failed before the end of the life cycle. The failure is more prominent in the air tubes located around the central region. The temperature in the kiln is in the higher side of 1500 K and varies along the length of the kiln. The kiln also rotates at a fixed RPM about the central axis.

2. Use of COMSOL Multiphysics

Conjugate heat transfer module was used in the study. Two different types of 2-D kiln models (Front view and Side view) were constructed and a temperature profile and an air-flow velocity profile were calculated. There were three domains; the innermost was the air which contained the heat source, the second was the refractory layer and the third was the steel shell. The heat source was defined based on the heat of reactions in the kiln. The boundary conditions were defined as the outside temperature of the kiln.

3. Governing Equations

Conjugate Heat Transfer Module Interface in COMSOL was used for the study. The following set of equations was used:

$$\rho C_p\left(\frac{\partial T}{\partial t}+(\mathbf{u}.\nabla)T\right)=\nabla.(K\nabla T)+Q \quad ..(1)$$

$$-\mathbf{n}.(K\nabla T)=h.(T_{ext}-T) \quad \ldots (2)$$

$$-\mathbf{n}.(K\nabla T)=\varepsilon\left(G-\sigma T^4\right) \quad \ldots (3)$$

Heat conduction, flow of gases, surface to surface and surface to ambient radiations was considered in the system. The heat source was taken as constant and time dependent solver was used to solve the equations.

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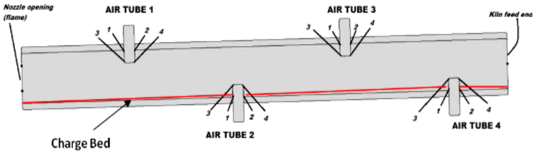
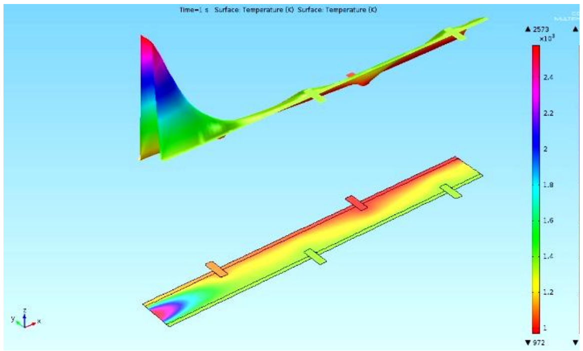


Figure 1.Geometry of the cross-sectional model.

5. Results

The simulation was run for 2000 seconds to study the initial stages of the kiln. The heat sources were fixed at one end of the kiln and the charge-bed.



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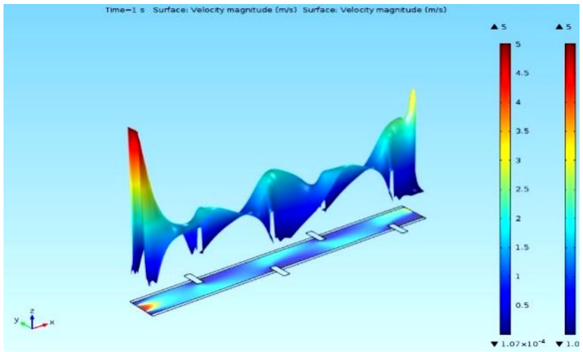
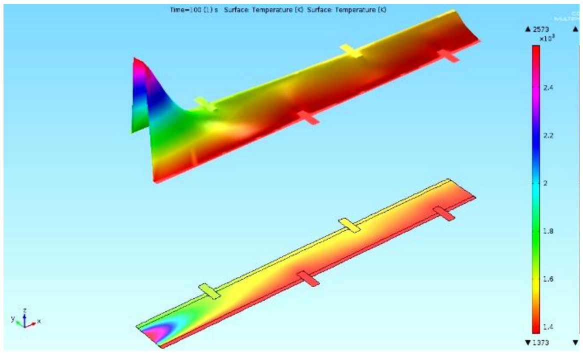


(b)

Figure 2. At t = 1 s of the kiln cross-sections viewed from the side, across the length (a) Temperature profile (b) Air flow velocity profile

In figure 2(a) and 2(b), the plots shown are for temperature and velocity respectively at t = 1s. In figures 3(a) and (b), the same is shown at time t = 100 s.



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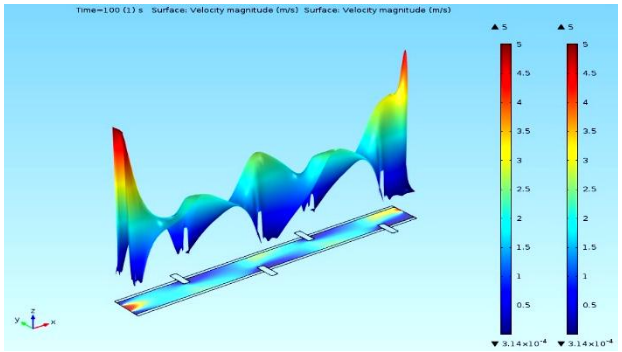
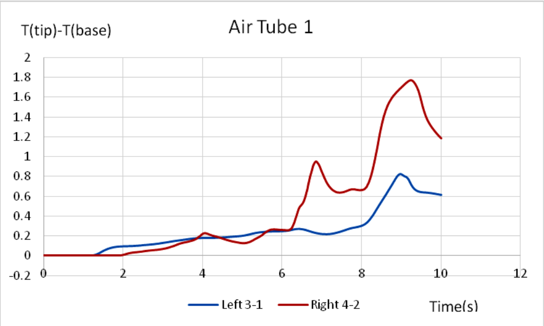


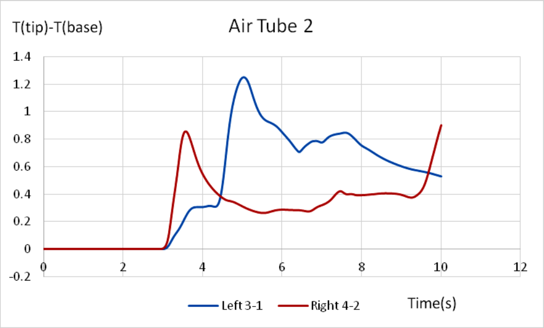
(b)

Figure 3. At t = 100 s of the kiln cross-sections viewed from the side, across the length (a) Temperature profile (b) Air flow velocity profile

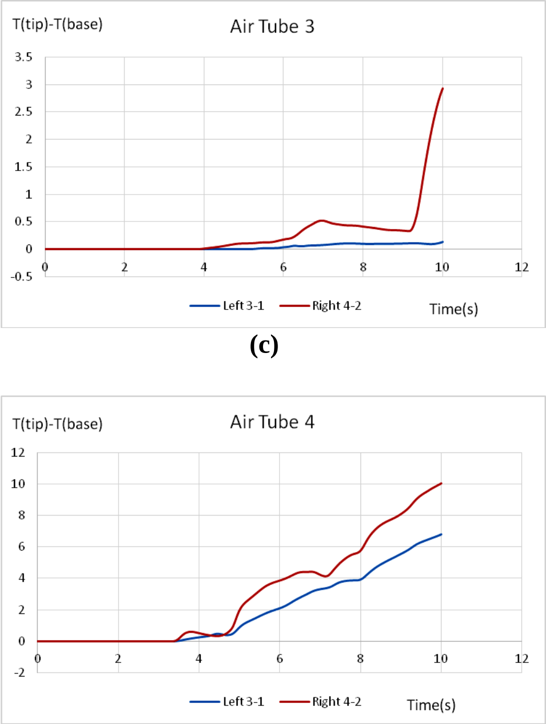
As shown in figure 1, probes were used at different points on the sirtubes to evaluate the temperature evolution with time.



(a)



(b)



(c)

(d)

Figure 4: Side view model: Difference in temperatures of the tip and the base of (a) Air Tube 1 (b) Air Tube 2 (c) Air Tube 3 (d) Air Tube 4: Left side (probes 1 and 3) and Right side (probes 2 and 4)

4. Discussion

The temperature evolutions shown in figure 4 were plotted as difference in temperature in probes shown in figure 1. As seen from figure 4(b), in air tube 2, there is some steep change in temperature. Similar, but less intense changes are visible in Air tubes 1 and 3 too.

There are two causes of thermal shocks which can affect the air tubes.

i) The first one is a steep change of the temperature of the air tube surface as a whole in a short time interval, which might induce thermal shocks in the air tube. This kind of thermal shock when repeatedly experienced in cycles over a long duration (a rotary kiln is operated continuously for months) can induce thermal wear and fatigue but it is for this reason that the air tubes are given appropriate surface protection before being installed in the rotary kiln. So, it is highly possible that the air tube surfaces withstand this and it might not be the major factor in the failure of certain air tubes well before their estimated life.

ii) Secondly, across the air tube surface, the temperature difference between any two points on the surface might vary between a low value and a high value either in a cyclic manner or abruptly in a short time interval. This will introduce a high thermal stress in that region during that time interval. When this time interval of high thermal stress occurs periodically over a long duration, it will lead to thermal fatigue across many small parts of the surface and might be a significant factor in the premature failure of certain air tubes.

Similar study was conducted for front view of the rotary kiln as shown in figure 5 and 6.

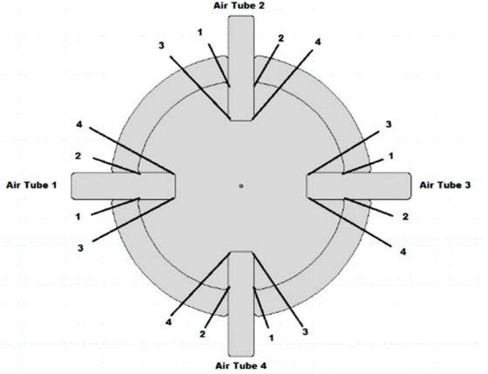
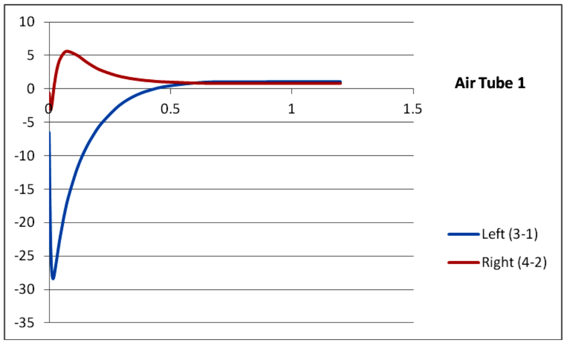
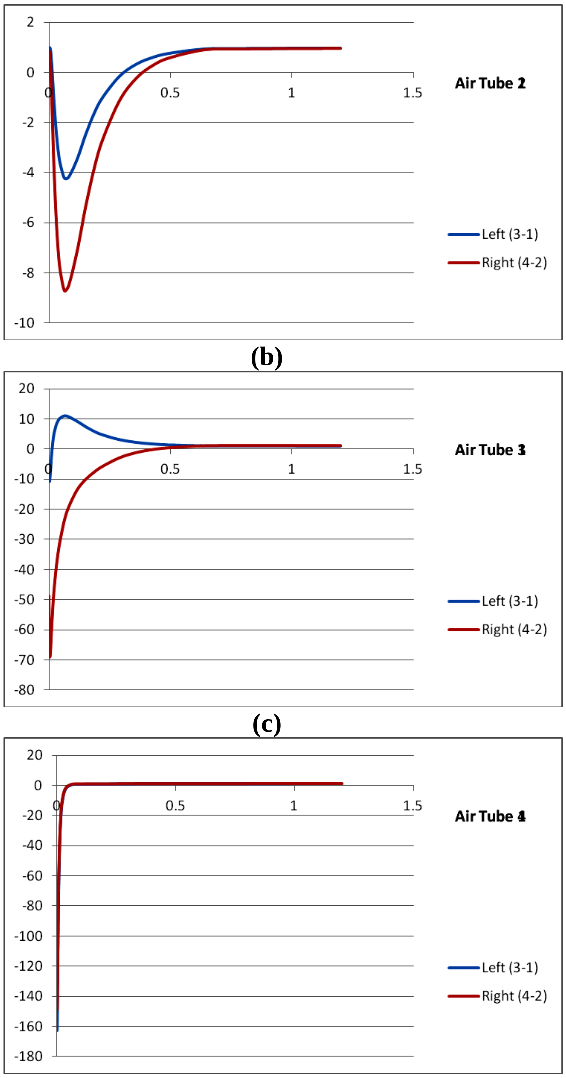


Figure 5. Front view model of the kiln showing the placement of temperature probes on the tips and the bases of each air tube



(a)



(b)

(c)

(d)

Figure 6: Front view model: Difference in temperatures of the tip and the base of (a) Air Tube (a)1 (b)2 (c) 3 (d) : Left side (probes 1 and 3) and Right side (probes 2 and 4)

Just like the previous case, in this case too we are compelled to consider two kinds of thermal shocks: the first due to the overall temperature change of an air tube with respect to time and the second due to internal temperature differences within the air tubes changing with respect to time causing localized damage.

5. Conclusions

In the present study of the temperature profile of the side view model, it was found out that the susceptibility to thermal shocks and thermal failure is high for the air tubes around the middle portion of the kiln due to steep changes in internal thermal gradient within the tubes. This in combination with the rotation of the kiln might lead to thermal fatigue in the longer run. The surface of the central portion air tubes is the most susceptible to failure than other air tubes in the present design of the kiln. It is consistent with the failure reports from the industrial plant which stated that the air tubes around the central portion have cracked originating from the surface very prematurely. Thus knowing that thermal action is most probably behind the premature failure of these central air tubes and thus further analysis is direct in this area. The design flaw was identified in this study and corrective actions are under research

6. References

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