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Optimum Air Feed Locations on Medical Waste Incineration Rotary Kiln by Computational Fluid Dynamics (CFD)

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Abstract

Twenty-four tons of medical waste is combusted every day in Istanbul. The plant is operated by ISTAÇ AŞ and combustor type is rotary kiln. The air was being fed manually along with the waste being introduced to the kiln. This case caused some problems regarding the combustion efficiency. The administration staff decided to open holes to supply air to the combustor. In this study, CFD was utilized in order to determine the optimum places for air inlets. Flow geometry of the air was prepared and then meshed for calculations. k-ε turbulence model was utilized in the calculations. Four air inlet pipes were placed on the edges of the circular inlet area. Different locations were tested. When the air was fed from the top, waste could not completely contact with the air. Additionally, different inlet angles were tested from zero degrees to thirty degrees. The degree of the inlet did not distinguishably change the combustion characteristics inside the kiln. Piping holes were burrowed from the bottom at zero degree angle.

Keywords: Incineration; rotary kiln; CFD; medical waste

1. Introduction

Medical waste is produced firstly from medical treatment and secondly from medical research [1]. The generated medical waste amount was reported as 50 600 kg per day in Istanbul in 2010 [2]. The amount of waste per bed in one day is 2.35 kg. Infectious waste is a large portion of the medical wastes and handling of this waste type should be very sensitive due to its pathogenic ingredient [3].

There are several methods in order to dispose medical waste. Incineration and sterilization are the most preferred methods worldwide. The first plant installed was the incineration process in Istanbul, which has 24 tons per day waste capacity [4]. The plant was started accepted taking wastes in 1995. Later, sterilization plant was constructed in addition to incineration system. Sterilization plant has an operating capacity of 110 tons per day [5]. It is expected that this system is going to be able to accept medical wastes of Istanbul in a 30 year time.

Incineration is the ultimate point of the elimination of the pathologic wastes. The kiln is operated at 900°C for 2 hours. This serves a volume reduction of 75 to 95 percent of the total waste volume [3].

Heat distribution is a critical part of the incineration operation. There are several studies on the evaluation of the heat distribution in a furnace [6-8]. This study was conducted in order to i) investigate the current state of a medical waste rotary kiln that is being operated, ii) investigate the effect of auxiliary air supply on waste combustion, and iii) place the auxiliary air pipes to the kiln.

2. Materials and Method

Ansys Fluent v15 was used in this study for the computation of the fluid dynamic [9]. Calculations of this study were executed in five steps. At first, the geometry of the flow volume was regenerated in AutoCad and converted to “iges” file which can further be applied in the DesignModeller of Ansys. In the second step, the generated volume was meshed. The calculations were executed at each generated mesh. In the third step, model parameters were defined. The defined parameters are given in Table 1.

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Table 1. Fluent model configurations

Parameter	Value
Mesh Quality	
Mesh Elements	206830
Mesh Size Method	Proximity and Curvature
Minimum Mesh Size	1.25600 e-03 m
Minimum Orthogonal Quality	2.01889 e-01
Maximum Aspect Ratio	2.33404 e+02
Turbulent Model	
Reynold Stress	Linear Pressure-Strain
Near-Wal Treatment	Standart Wall Fuctions
Operating Conditions	
Operating Temperature	1000 °C
Operating Pressure	101325 Pa
Solution Methods	
Formulation	Implicit
Flux Type	Reo-FDS
Spetial Discretization Method	
Grandient	Least Squares Cell Based
Flow	Second Order Upwind
Boundary Conditions	
Rotationary Wall Speed	0.3 rad/sec
Roughness Height	0.001 m
Mass Flow Inlet Flow Rate	2 kg/sec

In the fourth and fifth step, solution results were acquired and their results were shown on figures.

2.1. Geometry Design

Inner section of the rotary kiln, where air flow is occurred, is generated as a 3D plot in AutoCad. The flow field is given in Figure 1.

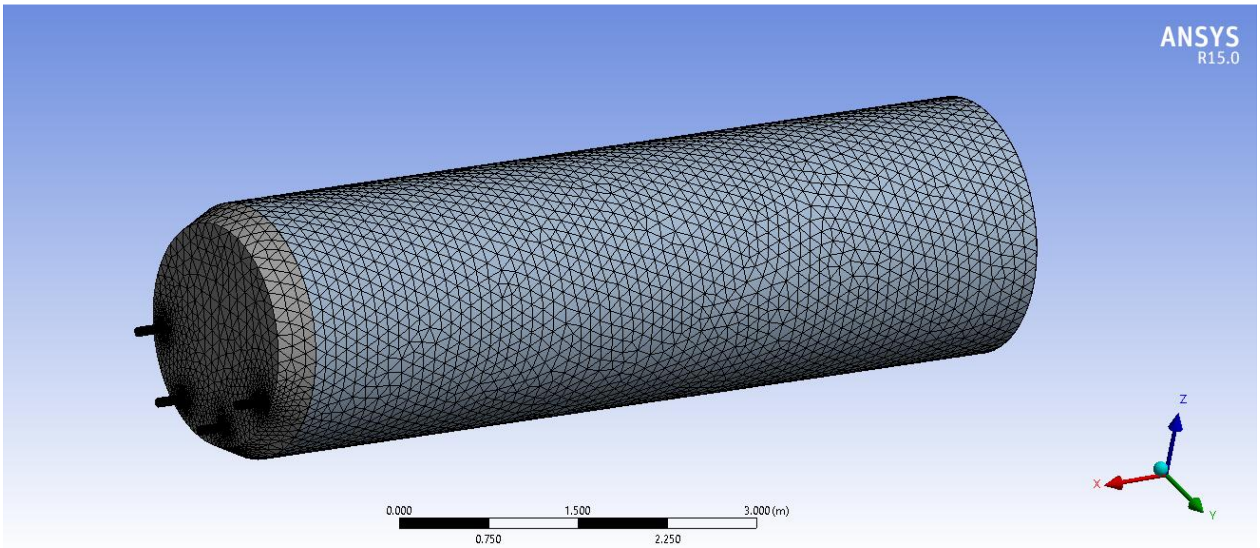


Figure 1. Modelling volume

Figure 1 was drawn by the actual kiln parameters. The length of the kiln is 7.5 m. Inner diameter, between the refractory material, is 2.70 m. The thickness of the refractory material is 20 cm. The rotary kiln has an incline of 3^o. In the previous design of the kiln, there was no inlet for auxiliary air feed. The air introduced along with the waste being fed to the kiln. When the feeding door is closed, contact with the air from the upstream of the kiln was stopped. This causes some inefficiencies such as high unburned content of the waste in the ash and high CO amount in the flue gas. For that reason, it was decided to include four pipes to the inlet wall of the kiln. The diameter of these pipes was 75 mm. The position of those pipes was approximately decided by the result of the CFD model. The actual system now being operated in the plant is the one shown in Figure 1.

2.2. Theory/calculation

Some assumptions are present in order to solve the numerical problem. These are the conservation of mass and momentum. These two equations were taken from Yaghmaelian et al. [10]. The mass conservation is given in Eq 1.

$$\frac{\partial(\rho u)_i}{\partial x_i} = 0 \qquad (1)$$

The conservation of momentum is given in eq 2.

$$\frac{\partial \rho u_i u_j}{\partial x_j} = \frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\mu_{eff}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{2}{3}\mu_{eff}\frac{\partial u_k}{\partial x_k} + \rho g_i \qquad (2)$$

The effective viscosity is calculated as follows (3):

$$\mu_{eff} = \mu_l + \mu_t \qquad (3)$$

where, μ_l is the absolute viscosity of the laminar flow, whereas μ_t is the absolute viscosity of the turbulent flow. μ_t is calculated according to Eq(4).

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \qquad (4)$$

The solution was executed by Reynolds stress turbulent model. For this turbulent model, C_μ is 0.09. The Reynolds stress from k and ε can then calculated as follows (5):

$$-\rho\overline{u_i' u_j'} = \mu_t\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{2}{3}\rho k \delta_{ij} = 2\mu_t E_{ij} - \frac{2}{3}\rho k \delta_{ij} \qquad (5)$$

$$\delta_{ij} = 1 \ if \ i = j \ and \ \delta_{ij} = 0 \ if \ i \neq j$$

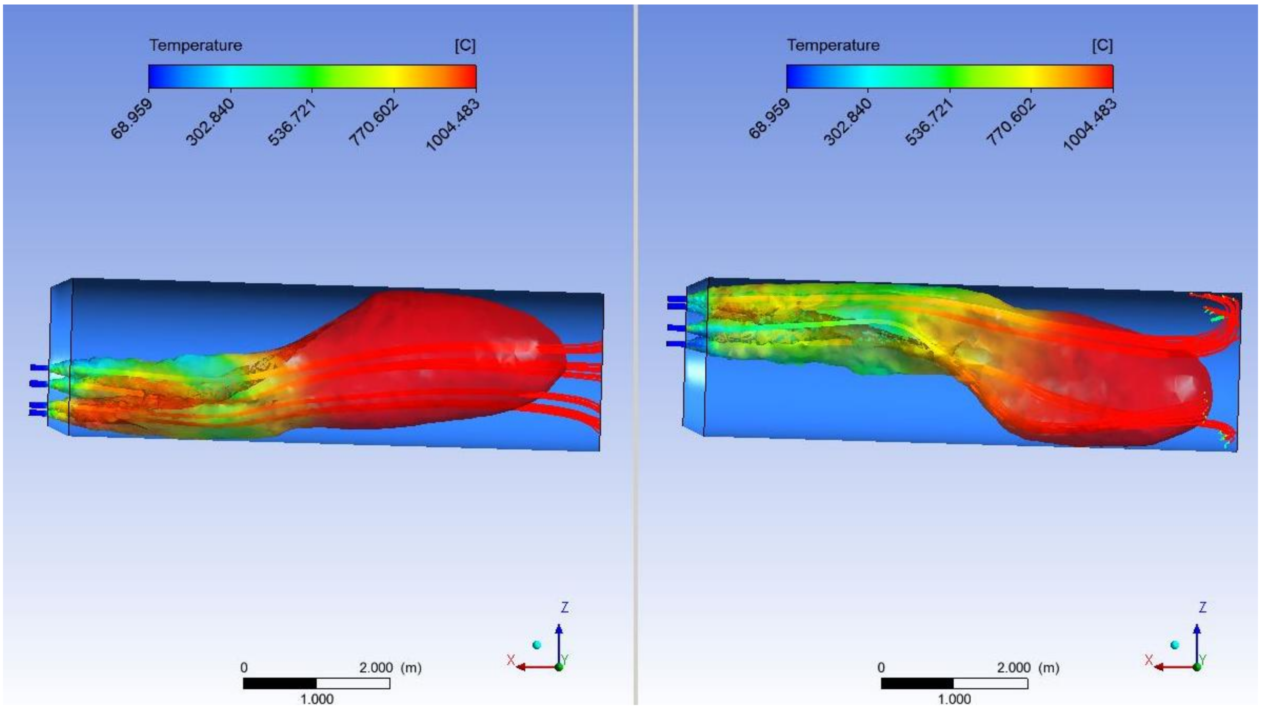
Above equations from 1 to 5, were given in one dimension. In the actual processing of the model these were executed in three-dimensions.

3. Results

The study was conducted in two steps. In the first one, the positioning of the inlet pipes was determined. In the second one, inlet pipes were placed at different angles. Effect of different inlet angles was investigated.

3.1. Positioning of the inlet pipe holes

In this section, optimum height of the inlet air that is introducing to the kiln is decided. Four holes were located at the top first and at the bottom next. The model was executed for both of these different geometries. Results of these two studies are shown in Figure 2.



(a) (b)

Figure 2. (a) Auxiliary air inlet from below (b) Auxiliary air inlet from top

These results suggest that, if the air is fed from the top of the kiln, air would not contact with the waste homogenously. It is obvious that due to temperature different of the waste and the air being fed leads to a temperature layering. Air is being mixed after traveling some distance within the kiln. This may cause to oxygen-lean burn in some parts of the furnace. Thus, elevated carbon fraction in the ash and CO in the flue gas can be measured. In the previous configuration of the kiln, the air was being fed from between the center and top of the kiln. In this case, revision is mandatory for this system, in order to increase the combustion efficiency and to lower pollutant emissions.

When air is fed from the bottom, it is can contact with the waste, where it did not have possibility in the other configuration. Additionally, air is gradually being heated with the waste as can be seen from Figure 2. So that, layering does not occur. Further calculations at different angles were studied from the bottom-feeding configuration.

3.2. Effect of inlet angle

Different angles from 0^o to 30^o were studies at five different stages, which were 0^o, $5\ ^o$, $10\ ^o$, $15\ ^o$, and 30^o, respectively. The aim of this was to determine whether the inlet angle has a significant effect on the temperature distribution or not. Volume rendering results are shown in Figure 3.

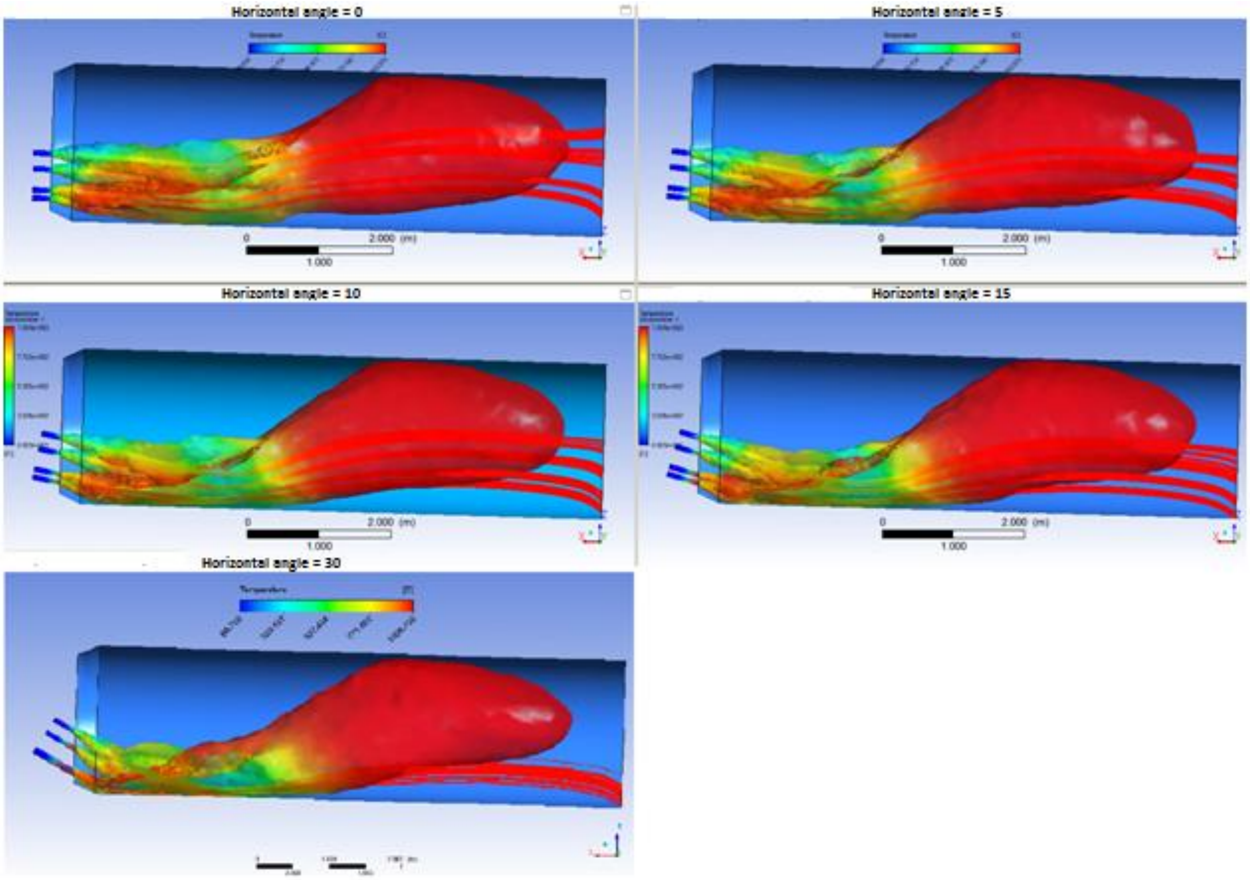


Figure 3. Temperature distribution at different inlet angles

According to the plots in Figure 3, any significant visual variation was not achieved. Apart from 0^o angle, the inlet with 15^o and 30^o seems to have a better temperature distribution. However, in the inlet with 30^o contact with the waste is lesser in the downstream of the kiln. Inlet with 15^o is somewhat more preferable than inlet with 30^o. Inlet with 0^o and 15^o were compared in Figure 4.

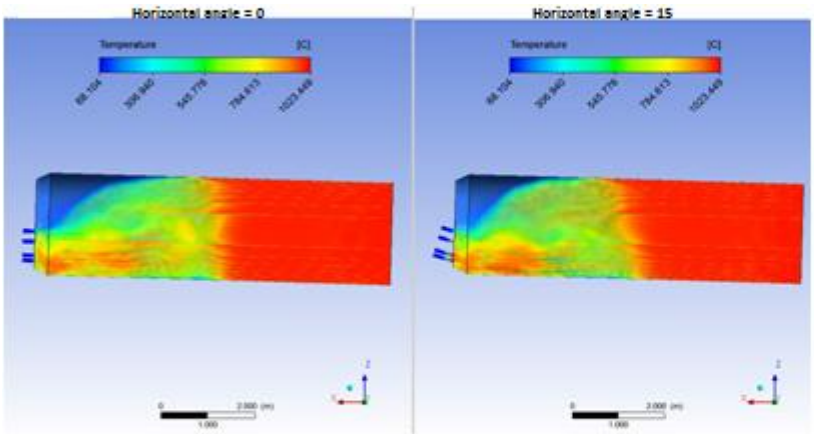


Figure 4. Comparison of inlet angles of 0^o and 15^o

Figure 4 shows the temperature distribution on a planar surface which is vertically placed in the kiln. The temperature difference at the waste contact level is not significant. Thus, considering this insignificancy and ease of engineering application for hole opening, 0 ^{o} angle was selected for the inlet angle. That means auxiliary air pipes are parallel to the surface of the kiln.

4. Discussion

In the previous configuration of the kiln, there was no auxiliary air feed channel. This study helped us to find the accurate places for more efficient combustion. It is decided to open holes for auxiliary air pipes at the bottom of the kiln. Thus, the air had opportunity to contact with the waste at any part of the kiln.

Secondly, different geometries with varying inlet hole angles were prepared. It was decided that there was not a significant difference between different configurations. So the inlet pipes were placed parallel to the kiln.

The plant is now being operated with the proposed configuration suggested in this study.

5. Conclusions

Air feed from the middle or the top of the kiln is not appropriate for the operational purpose. Temperature layering occurs between the air and the waste. This prevents the complete combustion in the upstream of the kiln. The best place for air feed was the bottom of the inlet wall, which is perpendicular to the kiln. Furthermore, the variations in the inlet angles didn't make significant changes. Pipes were placed parallel to the kiln.

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