Project Report

February 27, 2020

AK Steel

Dearborn Works - Ladle Refining Furnaces

Computational Fluid Dynamic Modeling

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1. Introduction

Hatch was retained by AK Steel's Dearborn Works to perform an evaluation of the capture efficiency at their Ladle Refining Furnaces known as LRF No. 1 and LRF No. 2. This evaluation/modeling is required by AK Steel as part of their permit.

AK Dearborn operates two (2) 250 ton ladle refining furnaces at its Dearborn Works in Dearborn, Michigan. Each LRF is equipped with emission control ductwork, its own baghouse and fans and all necessary equipment for the refining of molten steel.

The molten steel is transported in a ladle by a Klein Carrier from the basic oxygen furnace shop to the Caster building. Once the Klein Carrier sets the ladle down, the overhead crane picks up the ladle and places it in a transfer car at either one of the LRF's. The transfer car is then moved into position, beneath the emission control hood, where the molten steel is further refined. When the process is completed, anywhere from 30 to 120 minutes depending on the refinements, the ladle is moved to either one of the two casters.

This report summarizes the Computational Fluid Dynamic modeling for both ladle refining furnaces.

2. Computational Fluid Dynamic (CFD) Modeling Methodology

2.1 Introduction to CFD Modeling

Computational Fluid Dynamic (CFD) Modeling is the science of predicting fluid flow and heat and mass transfer. CFD models are used to simulate flow conditions for a variety of applications by numerically solving coupled balance equations for mass (Conservation Equation), flow (Navier-Stokes Equation of Motion) and heat (heat transfer equations).

The numerical approach taken by CFD modeling is to break a given geometry (in this case, the geometry of a ladle refining furnace) into many smaller, geometrically simple pieces or elements. The equations can then be solved for each element with each element communicating with its neighboring element. The individual solutions for each element are then combined to give a solution for the overall volume (or domain).

2.2 Model Geometry

The first step in developing this CFD model is to set up the geometry of the ladle refining furnace shop to describe the physical boundaries and internal blockages to fluid flow. The geometry of the model includes the physical bounds of the ladle refining furnace building, the LRF's, ladle, transfer car and associated ductwork. Figures 2-1 through 2-5 represent the geometry for the models run for this project.

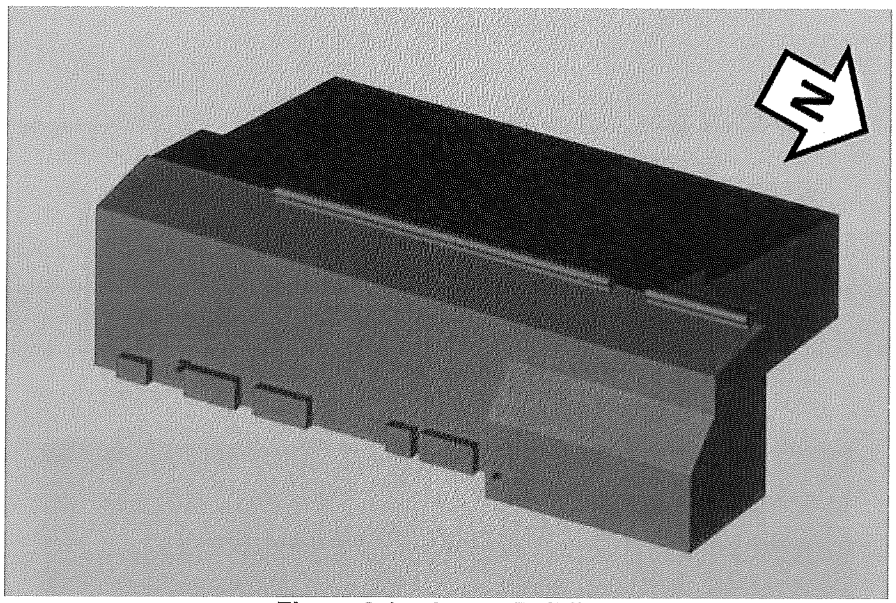


Figure 2-1 – Caster Building

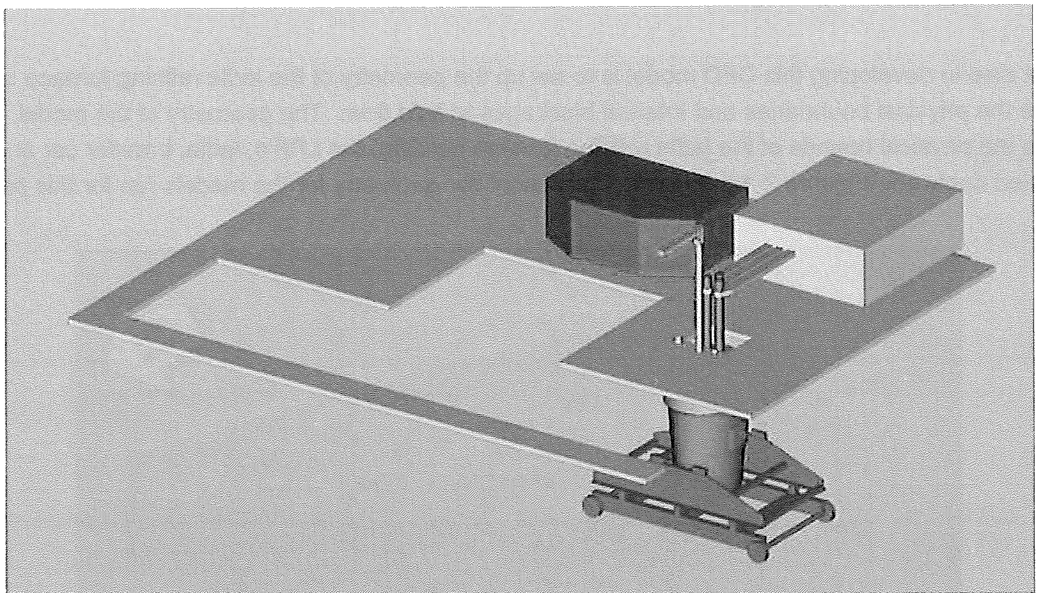


Figure 2-2 – LRF No. 1 (Some items not shown for clarity)

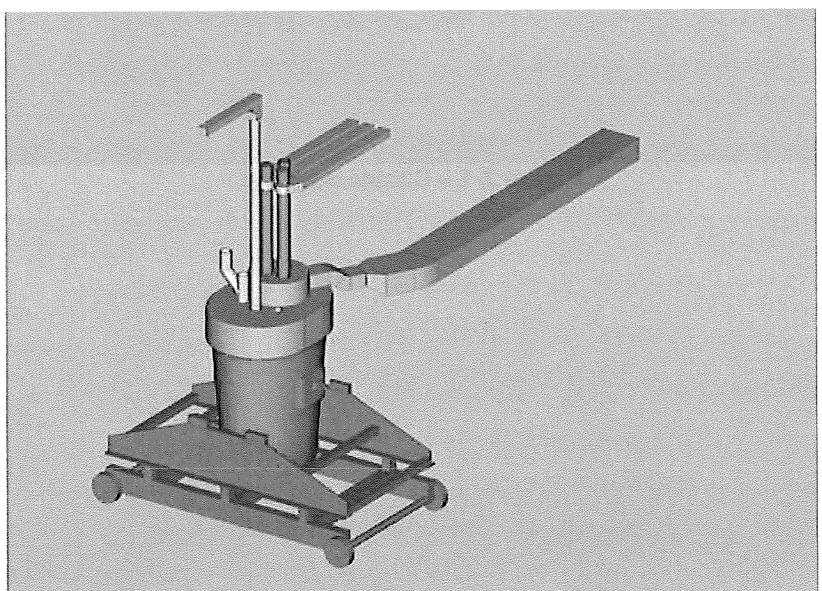


Figure 2-3 – LRF No. 1 (Some items not shown for clarity)

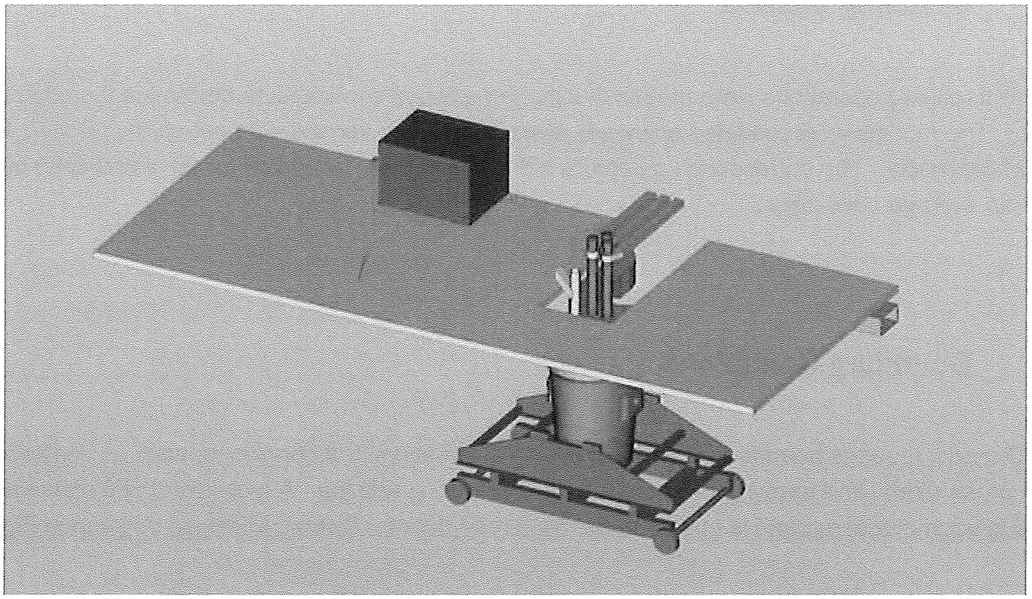


Figure 2-4 – LRF No. 2 (Some items not shown for clarity)

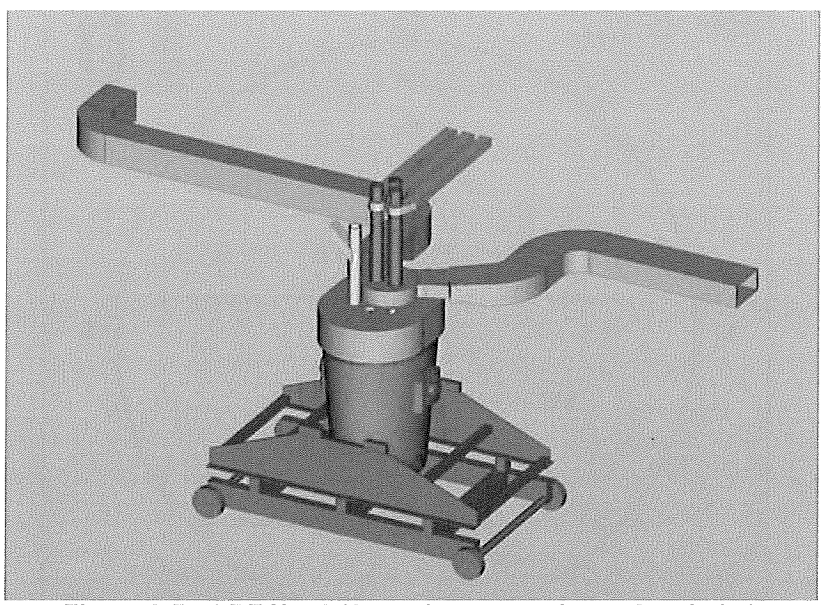


Figure 2-5 – LRF No. 2 (Some items not shown for clarity)

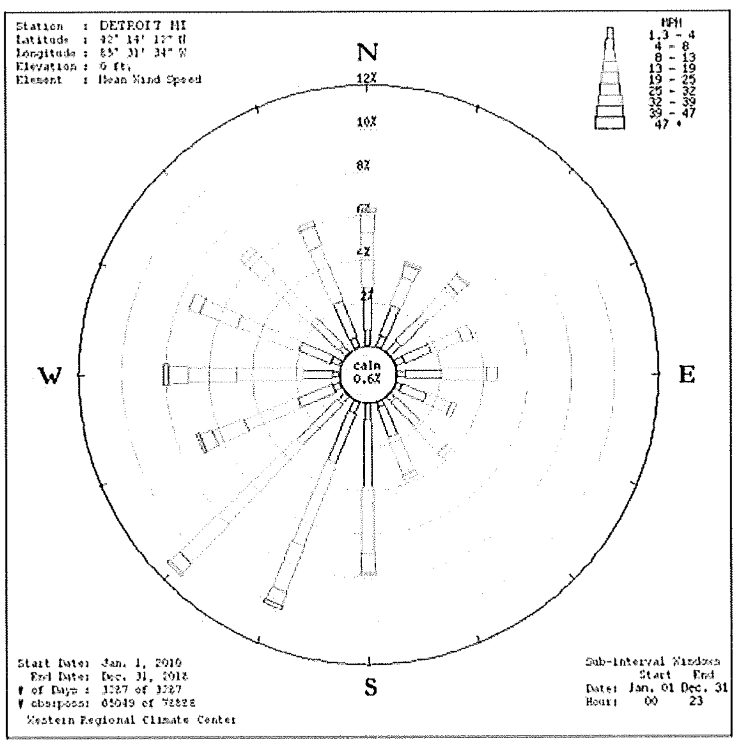
2.3 Modeling Method

The current refining operations were modeled using the existing conditions to determine the capture efficiency. The models were modeled as steady state, that is, the variables do not change during the course of the model. The corresponding capture efficiency is then calculated for the worst-case condition rather than average conditions.

2.4 Boundary Conditions

The CFD model requires boundary conditions, that is, a starting set of conditions, such as ventilation volume, cross winds, and temperature from the furnace during refining. A cross wind of 8 mph was included in each model run and is based on the wind rose data for Detroit, Michigan as seen in Figure 2-6.

DETROIT MI



DETROIT MI - Wind Frequency Table (percentage)

Figure 2-6 – Wind Rose for Detroit, Michigan

The only open doors are on the east side of the building, therefore a wind from the east was used in the model. An ambient temperature of 70 deg F was assumed for all model runs. The roof monitors were defined as open to the atmosphere.

The ventilation volume was measured at each LRF's stack during normal production the week of November 11, 2019. The lowest recorded volume measured is shown in Table 2-1.

The volume measured at the LRF No. 1 stack included the LRF and alloy storage bins. An alternate point, closer to the LRF, was measured and a volume of 88,565 and a temperature of 132 deg F were recorded. For the purpose of the modeling, a volume of 88,500 acfm was used as the input to the CFD model.

As seen in Photo 2-1 (taken from Google Earth®), the stack for LRF No. 2 is a considerable distance from the LRF. Given this distance, approximately 180', the flow measured at the stack is considerably less because the temperature drops significantly through the duct, spark box and baghouse. The test results, presented in Table 2-1, show that the temperature at LRF No. 2 stack is approximately 20% higher than that of LRF No. 1. Applying this 20% factor to the temperature measured near LRF No. 1 (132 deg F), we can conservatively estimate that the temperature in the LRF No. 2 duct as it exits the building is approximately 160 deg F. Applying Charles' Law, we can correct the volume to be more representative of the ventilation volume as it exits the building as seen in Equation 1.

$$\text{Volume}_1 / \text{Temperature}_1 = \text{Volume}_2 / \text{Temperature}_2 \qquad \text{Equation No. 1}$$

$$(61{,}828 \text{ acfm}) / (112.4 \text{ deg F} + 459.67) = (\text{Volume}_2) / (160 \text{ deg F} + 459.67)$$

$$\text{Volume}_2 = 66{,}755 \text{ acfm}$$

This flow of 66,755 acfm was used in the CFD model. In the case of both LRF's, it was felt that taking the measurement of flow at the stacks and subsequently correcting for temperature differences or flow related to the alloy storage bins was the best approach since the sampling location at the stack satisfied USEPA Method 1 criteria and alternative points closer to the furnaces did not.

Table 2-1 – Lowest Measured Ventilation Volume at Stack Exhausts

Ladle Refining Furnace	Measured Volume at Stack	Temperature
LRF No. 1	81,695 acfm	87.4 °F
LRF No. 2	61,628 acfm	112.4 °F

Table 2-2 – Flowrates Used in CFD Modeling

Ladle Refining Furnace	Flowrate
LRF No. 1	88,500 acfm
LRF No. 2	67, 755 acfm

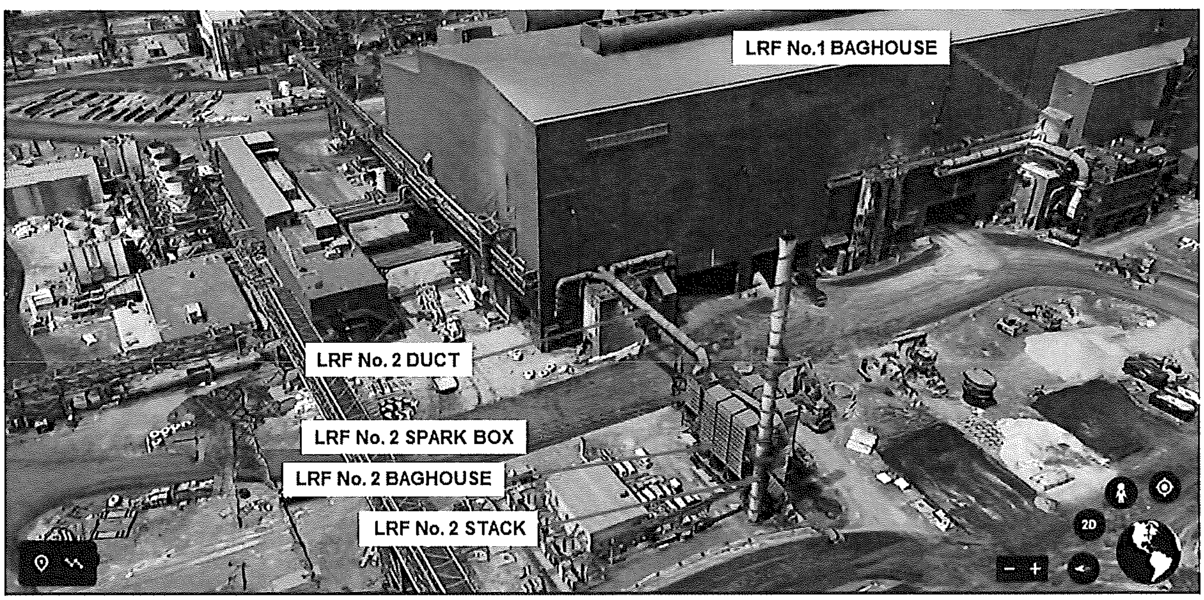


Photo 2-1 – LRF No. 2 Baghouse Location

Additionally, a fume exhaust rate of 75,000 acfm from the LRF's was calculated based on heat sheets from the LRF. This value was assumed for both furnaces.

2.5 Mesh

The CFD modelling software breaks down the complex geometry of the melt shop into smaller pieces, typically referred to as the mesh or grid. Here, the calculations are performed to solve the equations for velocity, temperature, pressure, etc. Figure 2-7 illustrates the typical mesh for this model. As seen in the figure, a tighter mesh is defined around the LRF hood (both inside and outside) to ensure an accurate solution to the model.

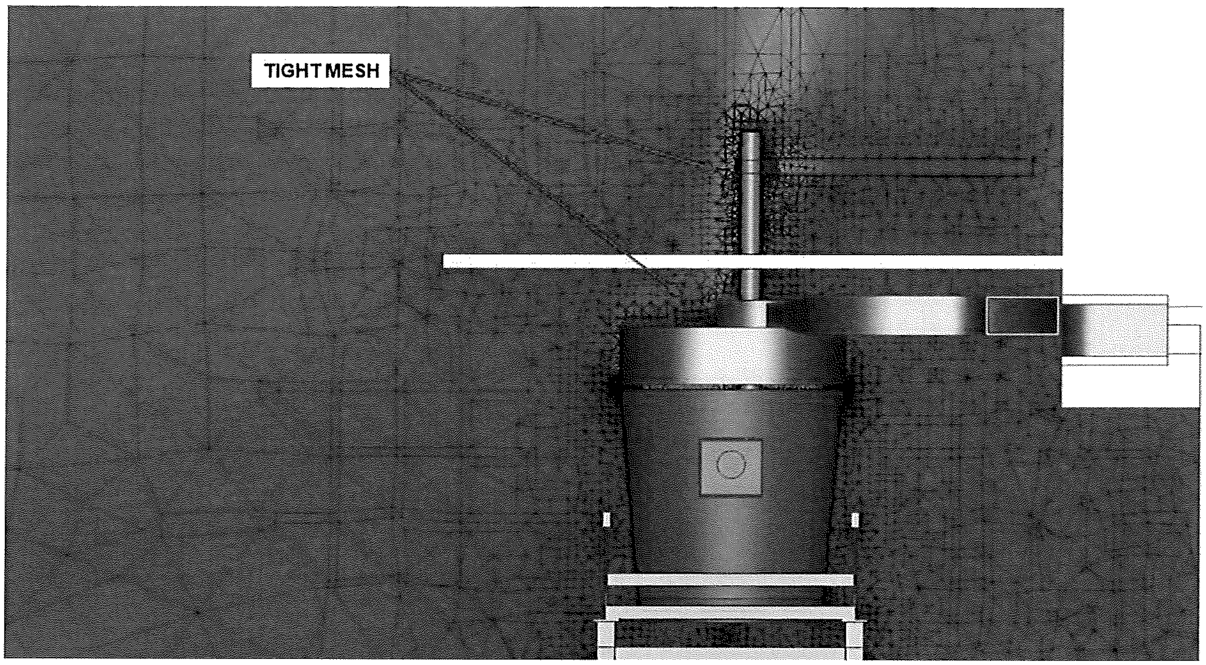


Figure 2-7 – Typical Mesh

2.6 Turbulence

The turbulence model used for all AK Dearborn models is k-epsilon. The k-epsilon model is one of the most common models used in CFD analysis to represent mean flow characteristics for turbulent flow. This model is a two equation model which accounts for turbulent kinetic energy and dissipation of turbulent kinetic energy. The k-epsilon model was developed and used to better predict the turbulence in a mathematical model and is often considered the "workhorse" of the CFD models.

2.7 Capture Efficiency

The capture efficiency is calculated by inserting particles of various sizes ranging from 0.5 microns up to 100 microns into the model just above the source of interest. For example, when calculating the capture efficiency during refining, particles are placed just inside the ladle and then assigned size and density. The model will then calculate their trajectory based on their properties and other various conditions such as the thermal properties from the ladle, cross winds entering the shop and influence from the emission control system. Figure 2-8 represents an abbreviated particle trace for LRF No. 1.

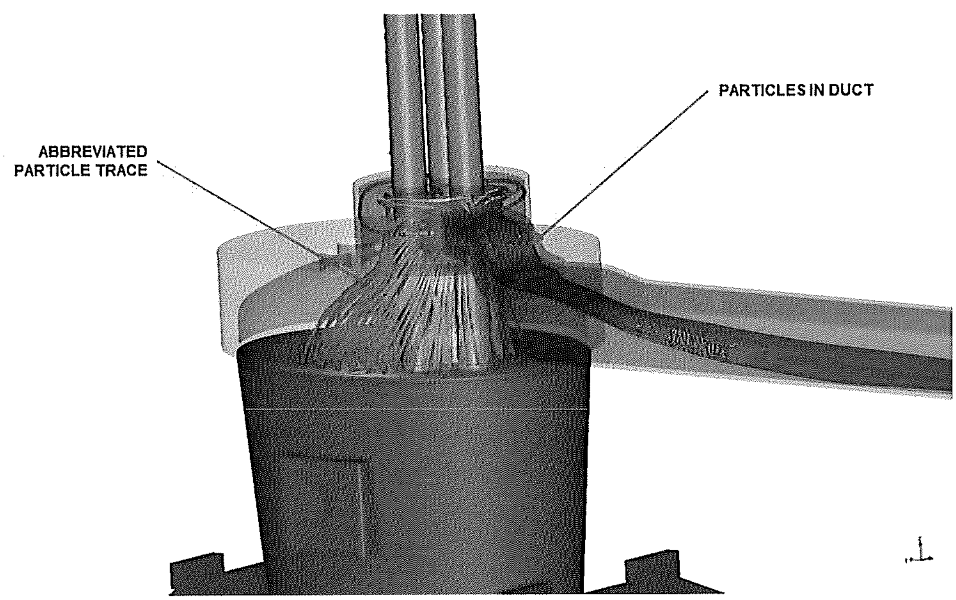


Figure 2-8 – Abbreviated Particle Trace

A particle trace whose trajectory ends inside the duct is considered captured by the baghouse. Any other particles not counted in the duct are then assumed to have either exited the building or settled within the shop. The particle size distribution (the percent of each particle size that makes up the off-gas sample) is based on data supplied by the US EPA for an uncontrolled Electric Arc Furnace. Although not an exact match, this distribution closely resembles the ladle refining process. This distribution is used in the determination of the capture efficiency. Figure 2-9 represents the particle distribution as published by the US EPA.

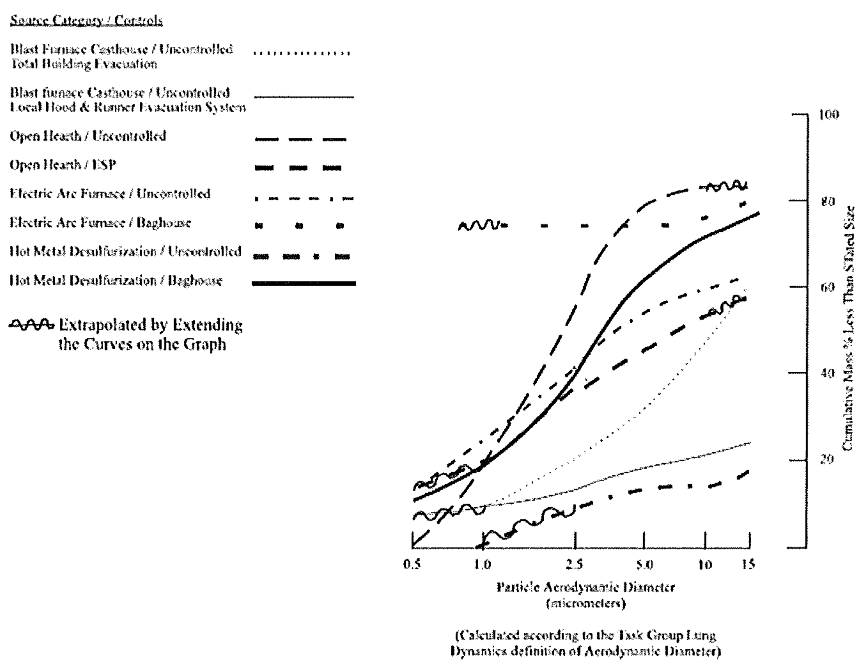


Figure 2-9 – Particle Distribution

3. Computational Fluid Dynamic Modeling Results

3.1 Ladle Refining Furnace No. 1

Figure 3-1 is a plan view of LRF No. 1 showing the negative pressure inside the hood and the reach of the influence of the emission control system.

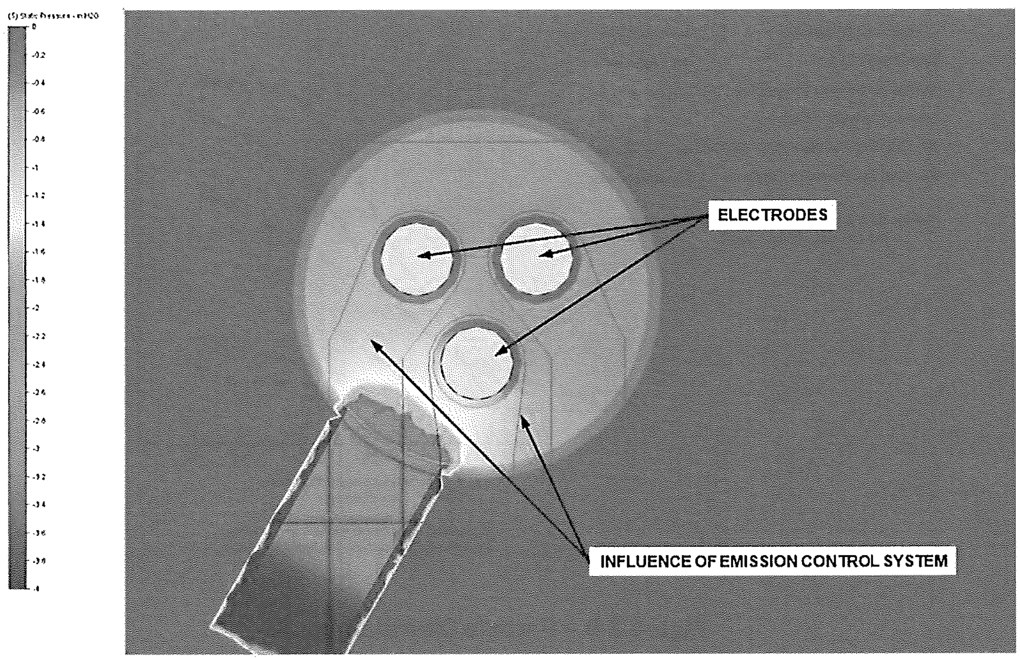


Figure 3-1 – Plan View – Static Pressure – LRF No. 1
(Some items not shown for clarity)

Figure 3-2 is an elevation of LRF No. 1 again showing the influence of the emission control system. As seen, the negative pressure generated by the system extends about halfway through the top hat section of the hood and into the main body of the lower hood.

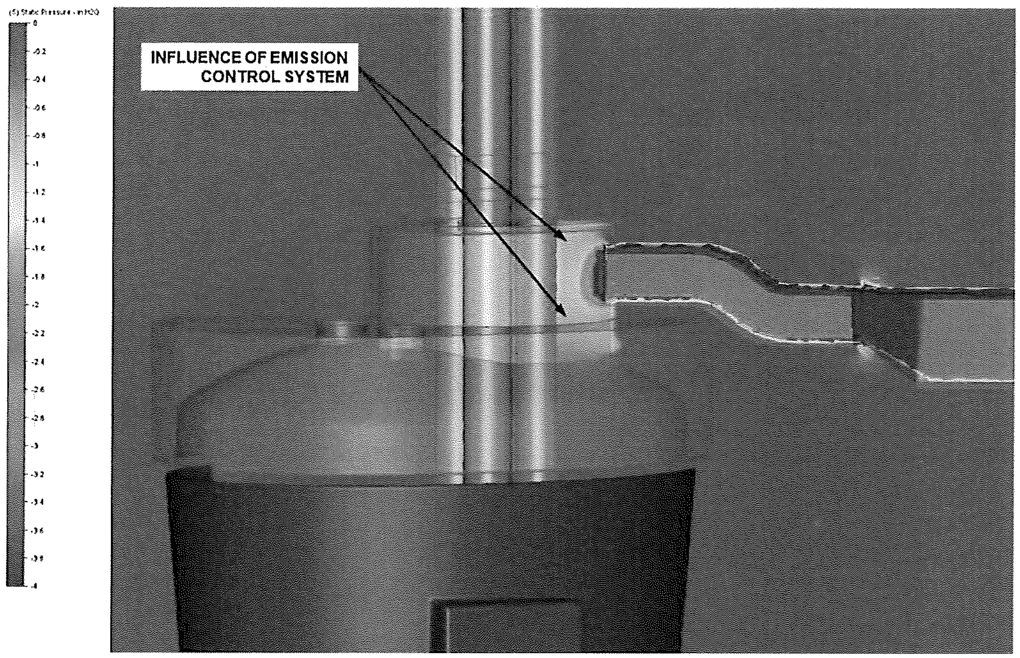


Figure 3-2 – Elevation – Static Pressure – LRF No. 1
(Some items not shown for clarity)

Looking at the vectors, as seen in Figure 3-3, we see that the vectors are pointing towards the duct which is a key indication of where the air is moving to and is representative of the capture efficiency generated by the emission control system.

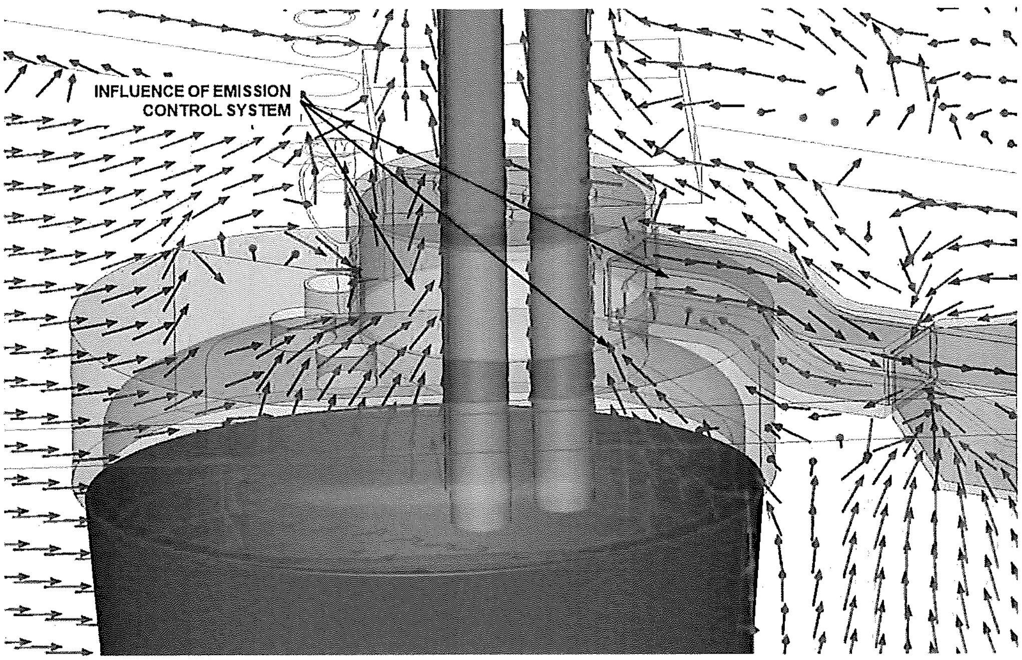


Figure 3-3 – Elevation – Velocity Vectors – LRF No. 1
(Some items not shown for clarity)

3.2 Ladle Refining Furnace No. 2

Figure 3-4 is a plan view looking down on LRF No. 2. Notice that LRF No. 2 differs from LRF No. 1 in that LRF No. 2 utilizes two duct off-takes to ventilate the emissions from the hood.

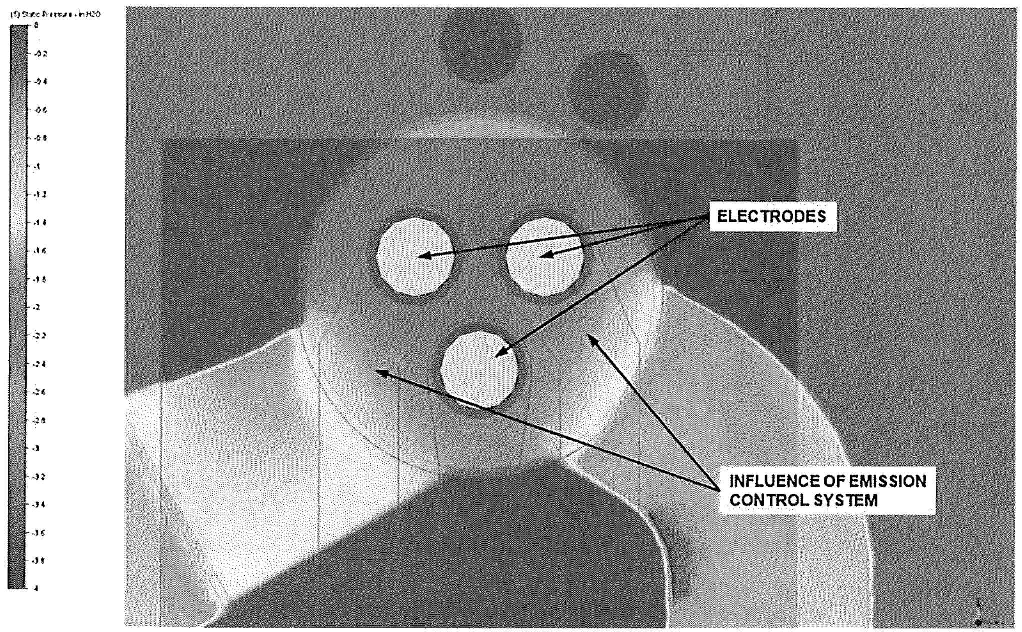


Figure 3-4 – Plan View – Static Pressure – LRF No. 2
(Some items not shown for clarity)

Figure 3-5 is an elevation looking at the influence of the emission control system. Here we see the influence reaching from both off-takes towards the center of the top hat section of the hood.

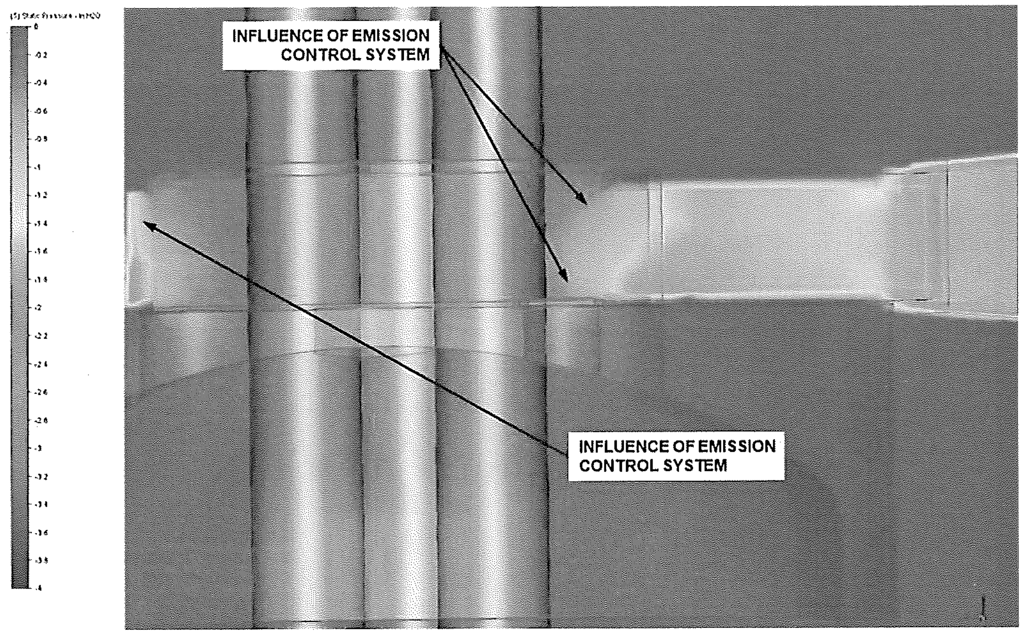


Figure 3-5 – Elevation – Static Pressure – LRF No. 2
(Some items not shown for clarity)

The vectors, seen in Figure 3-6, can be seen moving towards the off-take duct. This vector representation is indicative of the capture efficiency of the hood.

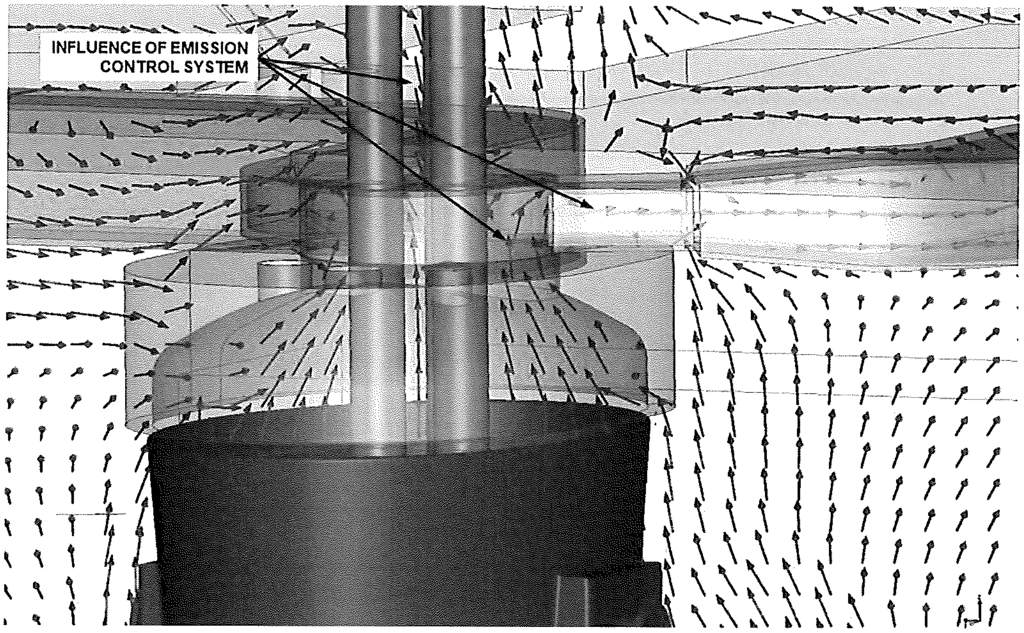


Figure 3-6 – Elevation – Velocity Vectors – LRF No. 2
(Some items not shown for clarity)

4. Summary of Results

Table 4-1 – Capture Efficiency

Ladle Refining Furnace	Capture Efficiency
LRF No. 1	100%
LRF No. 2	100%

5. Timeline of Modeling

Key Dates	Description
September 10, 2019	Submitted Notification to State
November 11, 2019	Site Visit and Observation
January 29, 2019	Start of CFD Model Runs
February 10, 2019	End of CFD Model Runs
February 27,2019	Report provided to AK Steel

Brian Bakowski
BB: