PEIRCE-SMITH CONVERTER HOOD DESIGN ANALYSIS USING COMPUTATIONAL FLUID DYNAMICS MODELING

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Abstract

Computational Fluid Dynamic (CFD) modeling provides a powerful tool to assist with the design of ventilation and fume control systems in smelters and other high temperature metallurgical facilities. For this paper, this tool has been used to analyze the off-gas flow pattern exiting the mouth of a Peirce-Smith converter into a water-cooled hood and drop out box. The effects of various process and physical plant design parameters on process gas and fume capture and potential build up on the converter hoods was examined, and the optimum design and operating parameters were determined.

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Introduction

Despite the commercialization of various new converting technologies for copper matte such as Ausmelt Technology[1], Mitsubishi's continuous converting technology[2], the Kennecott-Outokumpu flash converting process[3], and the continued use of Hoboken converters at several installation, the Peirce-Smith converter is still the dominant converting technology for the production of blister copper and nickel-copper matte.

A Peirce-Smith converter consists of a horizontally orientated refractory lined cylinder as shown schematically in Figure 1.

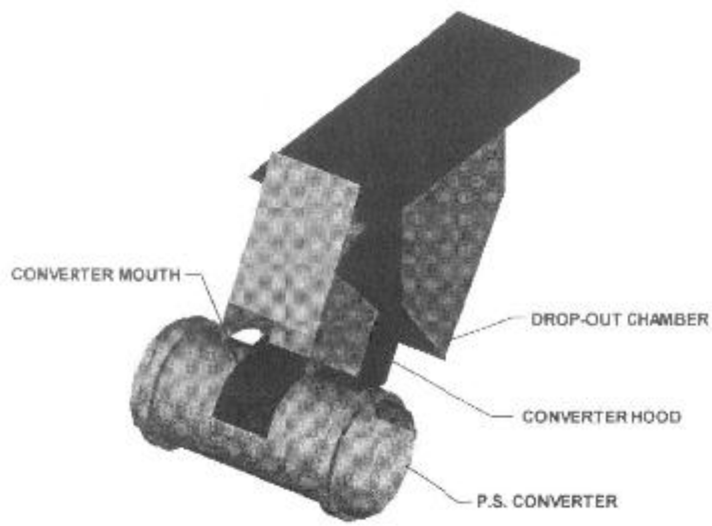


Figure 1: Schematic of a Peirce-Smith Converter.

The large mouth of the converter is a critical region for the vessel. Molten material is poured into the converter from large ladles to fill the vessel. Molten material is also later skimmed from the converter through the mouth into ladles. Fluxes, reverts, and scrap are also fed through the converter mouth often while the vessel is in the blowing position[4].

All process gases also exit the vessel through the mouth and are captured in hoods that are designed to fit over the converter mouth. Because the mouth is located so close to the molten bath within the furnace and intense splashing is caused by the injection of air through the tuyeres, the off-gas contains a great number of molten particles. These molten particles can cause both very high localized heat transfer to the hood surface when they impact on the surface of the hood and accretions that increase the weight of the hoods and impede the gas flow into the gas handling system. The molten particles and pouring of molten material also result in the formation of accretions around the converter mouth.

The off-gas also contains a number of volatile metallic species such as lead, arsenic, and cadmium that are present as metallic vapor. These elements in particulate are heavily regulated due to their impact on the environment if they escape as fugitive emissions. In the US, all copper smelters with

Peirce-Smith converters are working diligently to minimize the emissions of these elements to avoid the regulatory impact of being declared a "major" source for these "Hazardous Air Pollutant" (HAPs) elements and to minimize exposure of their workforces.

Asarco El Paso had taken the approach sealing the entire converter aisle to minimize impact on the environment but this had resulted in poor working conditions for plant operators. Most other plants have attempted to prevent fugitive emissions at the converter mouth. As noted by Drummond and Deakin[5], there is a clear movement within the industry from air-cooled hoods to water-cooled hoods in an effort to improve the capture of the converter off-gases. In some European smelter, plants have been designed with tertiary hooding systems to ensure very low emissions to the environment. However, the design of the hoods and associated gas handling equipment immediately adjacent to the converter is critical to ensure that full benefit is gained from the investment in the water-cooled hoods.

Computational Fluid Dynamic (CFD) Modeling for Metallurgical Plants

Computational fluid dynamic (CFD) modeling is a powerful tool that can be used to develop velocity, temperature, and contaminant concentration profiles to assist in designing ventilation and fume control systems. It can be used to predict and evaluate:

- Performance of ventilation systems
- Airflow pattern and contaminant migration paths
- Hood designs and configurations for optimum capture of contaminants
- Worker heat and contaminant exposure levels
- Combustion efficiency for a given geometry

To implement the modeling technique, a three-dimensional model of the heat and mass transfer and fluid flow occurring in the system is developed. Appropriate thermal, momentum, and mass transfer boundary conditions and the domain of calculation are chosen to mirror physical reality. The transport equations are then solved numerically using a control volume finite difference method based on commercially available codes such as PHOENICS® or FLUENT®. These packages are also then used to graphically display the solution so that calculation results can be visualized. In some cases, physical measurements are undertaken on an existing process so that the model can be "calibrated" to mirror the existing conditions before it is modified to predict the behavior of the process when operating parameters or the design of the equipment is changed.

CFD modeling can provide:

- A tool for evaluation of design alternatives by calculating the effect on the design objectives as each design parameter is modified
- In-depth understanding of the problem by graphical display of the air flows that help the user understand the mechanisms by which contaminants and heat migrate through a process or the building in which the process is housed
- Verification of measurements by supplying data to check and explain unusual measurement results
- Reduce costs by reducing the need for scale and physical model testing
- Shorter design times by reducing the need for scale model testing

In this application, CFD modeling provides an integrated analysis of environmental impacts, worker comfort, and indoor air quality that results in optimized process and building fume and contaminant control.

Case Study: CFD Modeling of a Copper Converter Off-Gas System

To illustrate the results that can be obtained by CFD modeling, a case study has been completed. In this case study, a CFD model has been constructed and used to study the off-gas flow pattern exiting a Peirce-Smith converter mouth into a water-cooled hood and dropout box.

Present Conditions

The model was calibrated under the existing conditions that are summarized below:

Converter:	Blast rate: 23,420 Nm^3/hr (13,785 scfm)
	Process gas temperature: 1,200°C (2,200°F)
	Mouth opening 2.28 m^2 (75% of the original 1.7 m x 1.8 m mouth)
	Hood apron gap: 15.2 cm (6 in)
Sliding Door Gap:	3.8 cm (1.5 in)
Dropout Hopper:	Opened (air infiltration: converter process gas = 1 : 1)
Dropout Box:	Outlet off-gas flow rate of 176,750 m^3/h (actual) (104,000 acfm)

The CFD model results are shown in Figure 2 and the following observations can be drawn from these results:

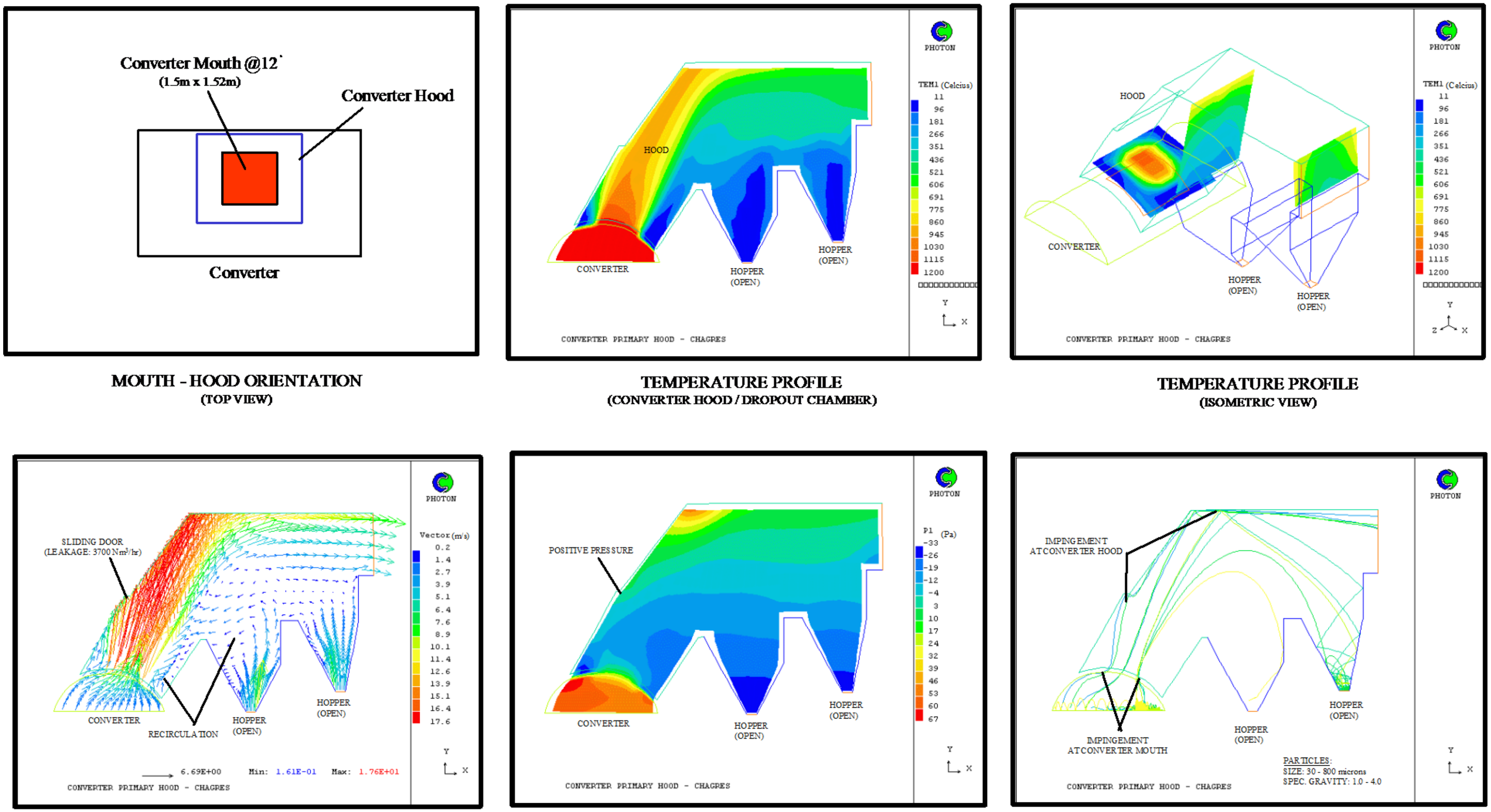
- Velocity profile: The velocity profile shows a high converter process gas velocity of 15.8 m/s (3,110 fpm) exiting the converter mouth directed toward the hood sliding door area. Recirculation in the dropout hoppers is predicted, leading to impaction on the surfaces by molten particles. Both of these phenomena will cause accretions to form on these surfaces.

- Temperature profile: The off-gas temperature profile at the converter water-cooled hood shows a significant heat load at the front (sliding door) and the roof of the hood. The off-gas temperature at the outlet of the drop out box is predicted to be well mixed at about 445°C (830°F). This predicted temperature is close to the field measurement of 433°C (812°F).

- Pressure profile: The pressure profile shows that there is insufficient draft at the converter hood uptake. The gap area between the sliding door and the water-cooled hood is under positive pressure and a fugitive emission of 3,700 Nm^3/h (2,300 scfm) is predicted.

- Particle tacking: Particles in the range 30-800 µm and specific gravity of 1.0 to 4.0 are spread around the converter free board area. The CFD model predicts that some particle flow with the gas and hit the edge of the converter mouth. At the operating temperature of between 600 and 750°C (1,100 and 1,380°F), some of these particles are still semi-molten and are likely to stick at the converter mouth. The profile also shows some impingement of particles at the front sliding door area. As noted above, both of these phenomena will lead to the formation of accretions that will result in operating difficulties.

FIGURE 2
COMPUTATIONAL FLUID DYNAMIC (CFD) MODEL
(PRESENT CONDITION)



MOUTH - HOOD ORIENTATION
(TOP VIEW)

TEMPERATURE PROFILE
(CONVERTER HOOD / DROPOUT CHAMBER)

TEMPERATURE PROFILE
(ISOMETRIC VIEW)

VELOCITY PROFILE
(CONVERTER HOOD / DROPOUT CHAMBER)

PRESSURE PROFILE
(CONVERTER HOOD / DROPOUT CHAMBER)

PARTICLE TRACKING

Evaluation of Various Configurations

Given the predicted operating difficulties associated with the first design of both accretion formation and the production of fugitive gases, several configurations were evaluated to seek a more optimum operating and design strategy. Three strategies that are expected to improve the present situation have been investigated. They are:

1. Close the dropout hopper openings to reduce air infiltration into the system.

2. Close the dropout hopper openings and change the orientation of the converter mouth from the current 12° to 20°. In practice, this would require altering the tuyere line position relative to the mouth so that the converter is rolled further to get it "into stack". However, the implementation of water-cooled hood systems is usually associated with rebuilding of the converter so both changes can be implemented at the same time.

3. Close the dropout hopper openings and enlarge the converter mouth to 1.9 m x 2 m, which assumes only 20% buildup at the converter mouth.

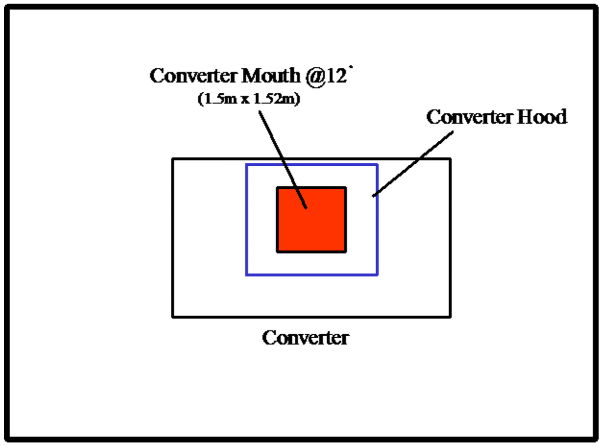
The results of the CFD calculations for each of the three (3) new configurations are shown in Figures 3 through 5 respectively and are summarized in Table 1.

Configuration No. 1: The process parameters for this configuration are similar to those for the present configuration except that air infiltration into the system is reduced by closing the dropout hoppers. The model predicts high converter off-gas flow directed upwards onto the front sliding door area but no fugitive emissions will be observed. This will result in high heat flues to the water-cooled hoods that must be incorporated in the thermal design of the hood. The draft at the converter hood uptake is improved for this configuration with a predicted air infiltration through the sliding door gap of around 2,660 Nm^3/h (1,650 scfm). Elimination of the air flow into the dropout hopper through the open bottom will result in more gas recirculation in the hopper. Particle impingement at the converter mouth and on the hood is still observed.

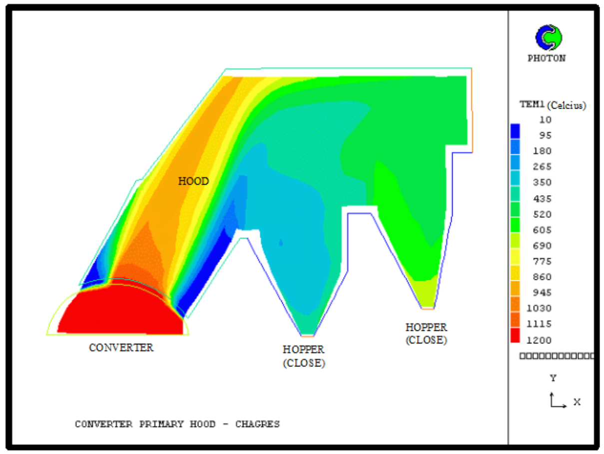
Configuration No. 2: This configuration is similar to the last configuration except that the angle of the converter mouth is changed to more closely align the process off-gas flow with the available angle for the converter hood. The model predicts an increased air infiltration rate of 7,260 Nm^3/h (4.500 scfm) through the sliding door opening. The velocity profiles show less impingement on the front and roof of the water-cooled hood, which will reduce the heat fluxes in these regions. Particle tracking predicts less particle impingement on the water-cooled hood but more impingement at the converter mouth. This will require more cleaning of the converter mouth with associated poor refractory performance in this region as will as difficulties skimming molten material from the converter.

Configuration No. 3: In this configuration, the converter mouth is enlarged to 3.06 m^2. All other parameters are similar to those in configuration No. 1. The CFD model predicts an air infiltration rate of 4,350 Nm^3/h (2.700 scfm) through the sliding door opening. The velocity profile shows that the converter process gas exits the converter mouth at a lower velocity of 11.8 m/s (2.332 fpm), which helps increase the draft at the hood uptake. The pressure profile also shows better draft than for configuration No. 1. Because the overall velocity is lowered, there is less particle impingement at both the converter mouth and the front and roof of the water-cooled hood.

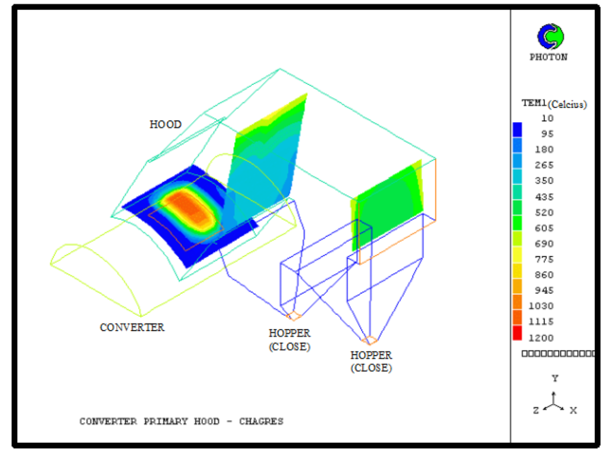
FIGURE 3
COMPUTATIONAL FLUID DYNAMIC (CFD) MODEL
(CONFIGURATION #1)



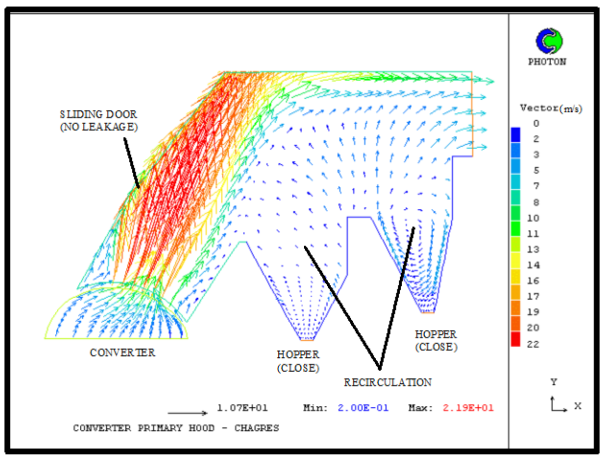
MOUTH - HOOD ORIENTATION
(TOP VIEW)



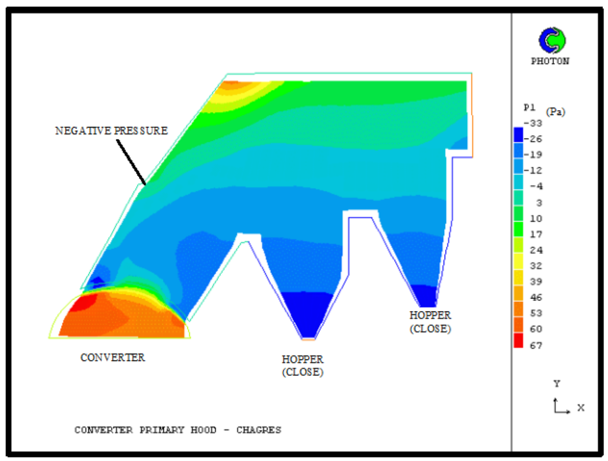
TEMPERATURE PROFILE
(CONVERTER HOOD / DROPOUT CHAMBER)



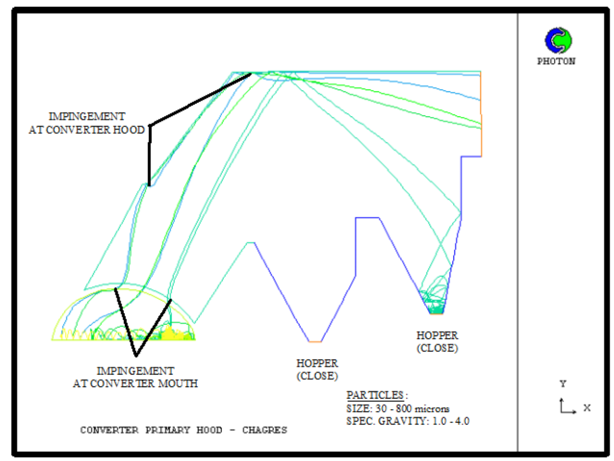
TEMPERATURE PROFILE
(ISOMETRIC VIEW)



VELOCITY PROFILE
(CONVERTER HOOD / DROPOUT CHAMBER)

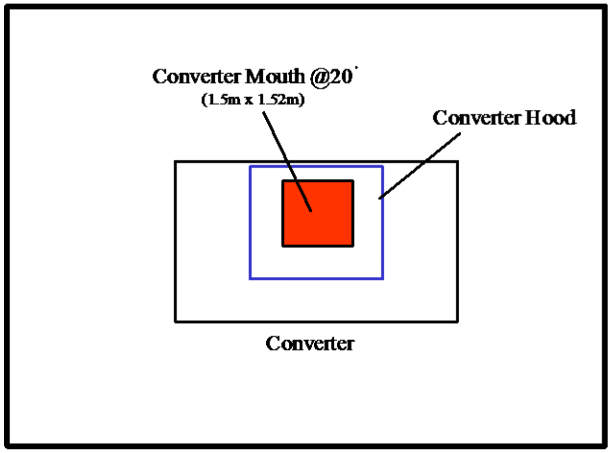


PRESSURE PROFILE
(CONVERTER HOOD / DROPOUT CHAMBER)

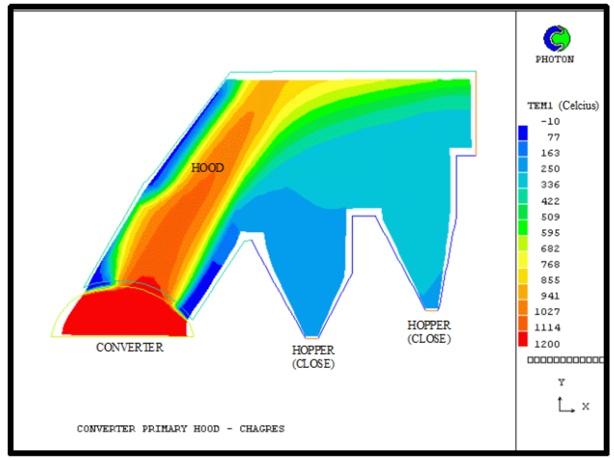


PARTICLE TRACKING

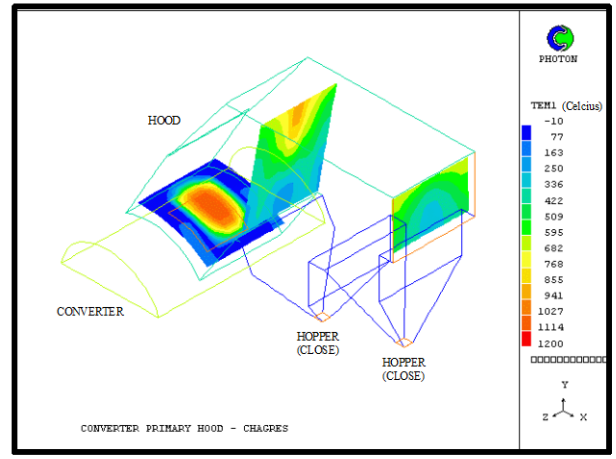
FIGURE 4
COMPUTATIONAL FLUID DYNAMIC (CFD) MODEL
(CONFIGURATION #2)



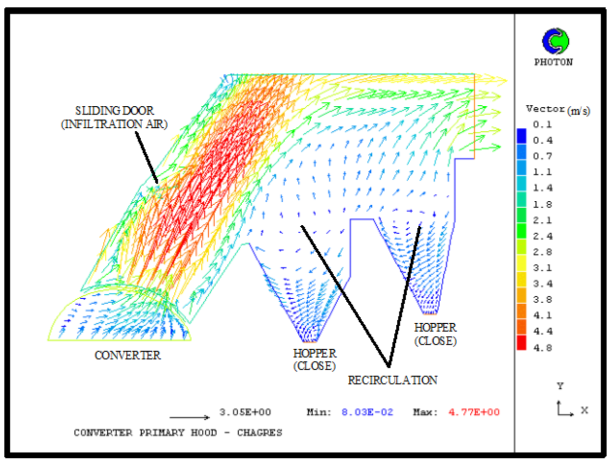
MOUTH - HOOD ORIENTATION
(TOP VIEW)



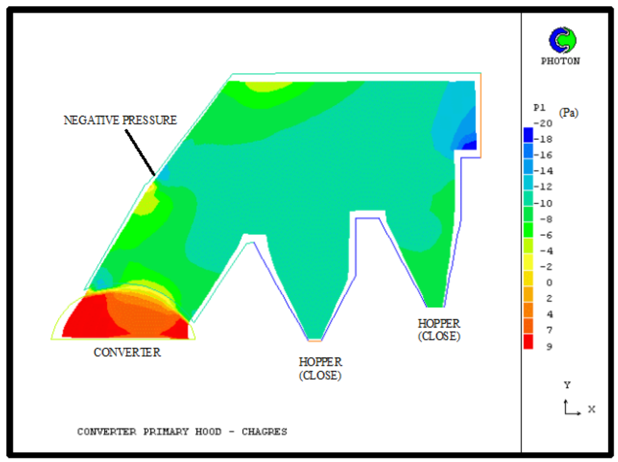
TEMPERATURE PROFILE
(CONVERTER HOOD / DROPOUT CHAMBER)



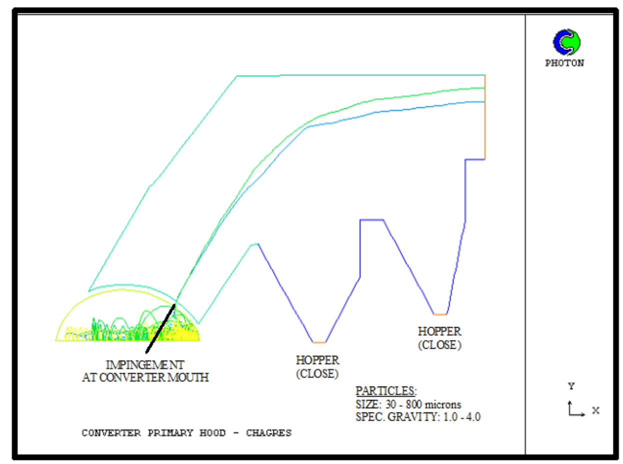
TEMPERATURE PROFILE
(ISOMETRIC VIEW)



VELOCITY PROFILE
(CONVERTER HOOD / DROPOUT CHAMBER)

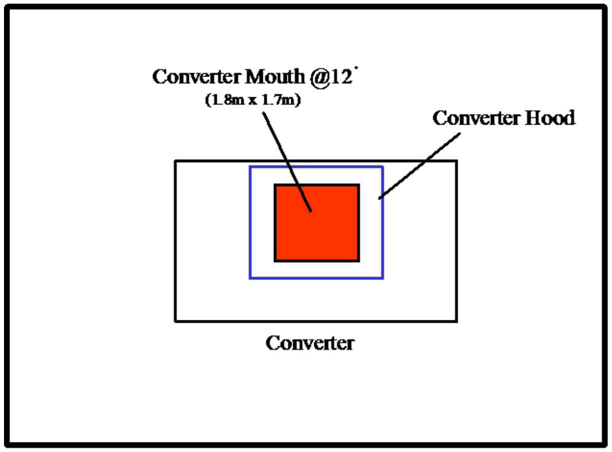


PRESSURE PROFILE
(CONVERTER HOOD / DROPOUT CHAMBER)

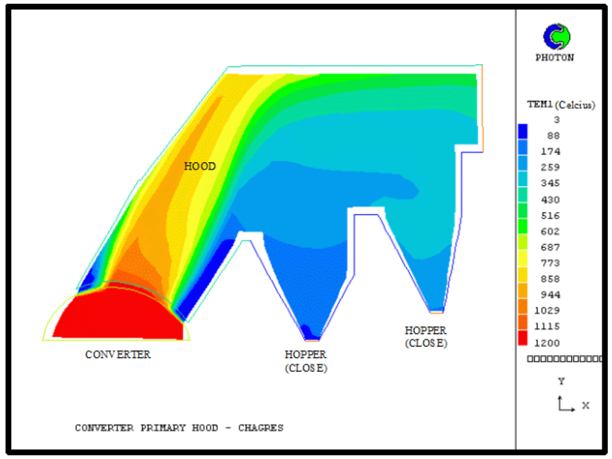


PARTICLE TRACKING

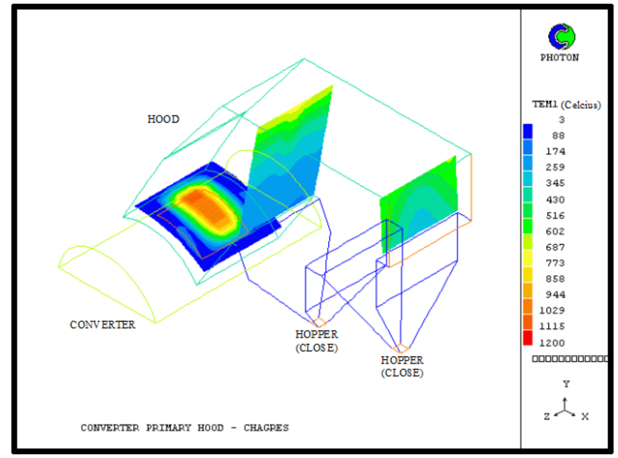
FIGURE 5
COMPUTATIONAL FLUID DYNAMIC (CFD) MODEL
(CONFIGURATION #3)



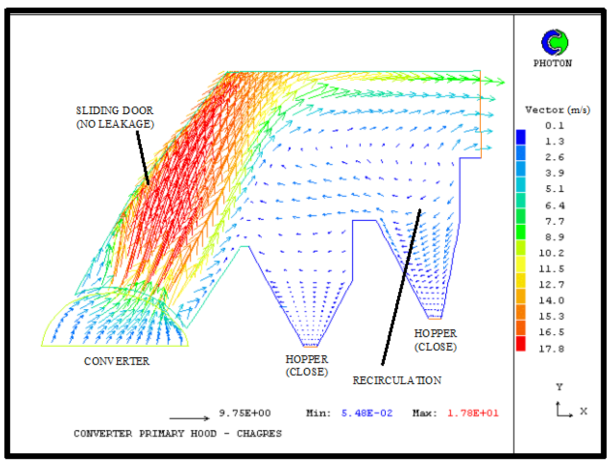
MOUTH - HOOD ORIENTATION
(TOP VIEW)



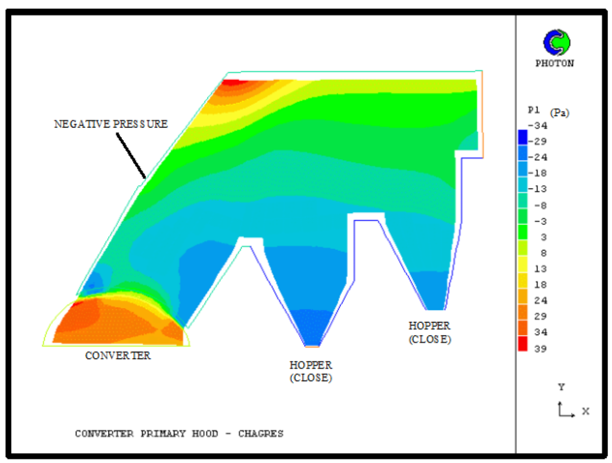
TEMPERATURE PROFILE
(CONVERTER HOOD / DROPOUT CHAMBER)



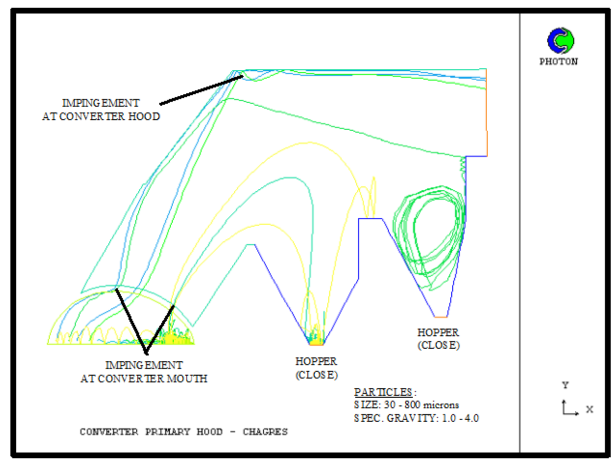
TEMPERATURE PROFILE
(ISOMETRIC VIEW)



VELOCITY PROFILE
(CONVERTER HOOD / DROPOUT CHAMBER)



PRESSURE PROFILE
(CONVERTER HOOD / DROPOUT CHAMBER)



PARTICLE TRACKING

TABLE 1
CFD MODEL – SUMMARY OF VARIOUS CONFIGURATIONS

PROCESS PARAMETERS		PRESENT CONDITION	CONFIGURATION #1	CONFIGURATION #2	CONFIGURATION #3
~~CONVERTER:~~					
Blast Rate	[Nm^3/hr]	23,420	23,420	23,420	23,420
	[scfm]	14,500	14,500	14,500	14,500
	[acfm]	76,400	76,400	76,400	76,400
Process Gas Temperature	[°C]	1200	1200	1200	1200
	[°F]	2200	2200	2200	2200
Mouth Size	[m^2]	3.06 (1.80m x 1.70m)	3.06 (1.80m x 1.70m)	3.06 (1.80m x 1.70m)	3.8 (1.90m x 2.0m)
Available Mouth Opening	[m^2]	**2.28**	**2.28**	**2.28**	**3.06**
Process Gas Velocity @ mouth	[m/s]	15.82	15.82	15.82	11.78
	[fpm]	3110	3110	3110	2320
Mouth-Hood Orientation / Angle		**12°**	**12°**	**20°**	**12°**
~~SLIDING DOOR GAP:~~		3.8 cm (1.5in)	3.8 cm (1.5in)	3.8 cm (1.5in)	3.8 cm (1.5in)
~~HOPPER:~~		**opened** (100 % air infiltration)	**closed** (no air infiltration)	**closed** (no air infiltration)	**closed** (no air infiltration)
~~DROPOUT BOX~~					
Exit Off-gas Flow Rate	[Nm^3/hr]	66,000	49,500	54,100	51,190
	[scfm]	41,000	30,700	33,550	31,750
	[acfm]	104,000	104,000	104,000	104,000
Exit Off-gas Temperature	[°C]	445	677	596	648
	[°F]	830	1250	1105	1200
~~CFD RESULTS:~~					
Leakage @ sliding door gap	[Nm^3/hr]	3700	none	none	none
Infiltration @ sliding door gap	[Nm3/hr]	none	2660	7260	4350
Mouth Velocity and Buildup		- High process gas velocity at the converter mouth (15.82 m/s) - Inadequate draft at the hood uptake - moderate dust impingement at converter mouth	- High process gas velocity at the converter mouth (15.82 m/s) - Adequate draft at the hood uptake due to closing the dropout hoppers - moderate dust impingement at converter mouth	- High process gas velocity at the converter mouth (15.82 m/s) - Adequate draft at the hood uptake due to closing the dropout hoppers - High dust impingement at converter mouth	- Low process gas velocity at the converter mouth (11.78 m/s) - Adequate draft at the hood uptake due to closing the dropout hoppers - Lowest dust impingement at converter mouth
Gas Impingement on Water-cooled Hood		- High gas impingement at the sliding door area at the water-cooled hood	- High gas impingement at the sliding door area at the water-cooled hood	- Lowest gas impingement at the sliding door area at the water-cooled hood	- Moderate gas impingement at the sliding door area at the water-cooled hood

Conclusions

For the case study presented in this paper, it was predicted that:

- Sealing the dropout box hopper openings will significantly improve the converter draft to the point that there is no fugitive emissions

- Sealing the dropout box hopper opening and changing the mouth angle to 20 from the current 12 will reduce process gas impingement on the sliding section of the converter hood. However, since the mouth will be closer to the bath level, particle impingement at the mouth of the converter will be increased. No process gas fugitive emissions are predicted.

- Sealing the dropout box hopper opening and increasing the mouth opening to 1.9 m x 2.0 m while keeping the current mouth angle of 12 will result in improved converter draft and reduce particle impingement at the mouth. As with the previous two (2) configurations, no fugitive process gas emissions are predicted.

This case study also demonstrates the opportunities offered by applying CFD modeling techniques to the design and optimization of process gas handling and building ventilation systems for metallurgical industries.

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