EFFECTIVE DESIGN OF CONVERTER HOODS

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Abstract

The primary source of fugitive gas emissions in most copper smelters is Peirce Smith converter operations. The modern trend is towards installation of secondary gas collection systems, which are intended to collect fugitive gases from charging, stand-by, and skimming operations. These have been installed with varying degrees of success. Often, the major source of emissions from the converter area is leakage of process gas from the primary hoods when the converter is blowing. This gas is typically collected by the secondary system and discharged to atmosphere or scrubbed with an alkaline agent. Those smelters considering installation of secondary hoods, or scrubbing of gases from secondary systems should first address the issue of gas leakage from the primary hoods. Improving the primary hood gas collection efficiency will often be more cost-effective than installing secondary hooding. In the case of secondary gas scrubbing, it will significantly reduce the reagent consumption and operating cost of the scrubbing system. This paper examines the parameters that determine whether or not a primary hood will effectively collect process gases without leakage and demonstrates, using computational fluid dynamics (CFD), the effects of variations in these parameters on the overall performance of the hood. It also looks at the application of CFD techniques in the design of secondary hoods.

Introduction

Despite the introduction of new smelting technologies such as the flash converter and the Mitsubishi converter, the Peirce-Smith converter is still the dominant technology for production of blister copper and nickel-copper matte.

Many smelters were built in the days when it was environmentally acceptable to discharge the converter gases to atmosphere without removing the SO_2. These smelters were able to draw in large quantities of infiltration air at the converter hoods and the hood suction would be sufficiently high to prevent leakage of gas from the hood. Typically, infiltration would be 300 to 400% of the process gas flow. Gases are cooled by infiltration at the hood and water cooled hoods are usually not necessary.

Modern smelters have to send the converter gases to the acid plant. This requires that the gas system operate at much lower rates of infiltration to maintain a high SO_2 concentration in the acid plant and to limit the total off-gas volume at the acid plant. Infiltration rates of 80 to 120% are more typical in these smelters, hood temperatures are in the region of 700 degrees C. Water cooled hoods are required along with some method of gas cooling downstream of the hood.

At the low infiltration rates, designing a hood that captures all of the process gas is much more difficult. Traditionally hoods have sliding doors that need a small gap between the door and the hood to allow the door to slide. As the gases leaving the converter mouth are hot and buoyant this region of the hood tends to be under positive pressure and the process gases leak from this joint.

Many smelters have installed secondary hoods which capture some of this leakage. Typically these secondary fumes are not treated for SO_2 removal so the secondary hooding does not reduce the overall smelter SO_2 emissions. Smelters that do scrub the secondary gases use reagent-based scrubbers whose operating costs are proportional to the SO_2 content of the gas stream. In this case it is uneconomical to allow excessive leakage from the primary hoods during converter blowing.

Secondary hood designs vary from simple fixed hoods mounted above the primary hood, to complete enclosures with complex door arrangements. A common problem with all of these designs is ineffective capture of fugitive emissions from the ladle when charging the converter. During charging, the hood doors have to be open and the hood with sliding doors is no more effective than the fixed hood.

Computational fluid dynamic modeling, verified by actual operating data, has been used to examine the parameters which govern the effectiveness of the primary hood. Design options and collection efficiencies for secondary hoods are also presented.

Development of the Computational Fluid Dynamic Model

The assumptions made during the investigation are summarized below:

- Steady state conditions
- Ideal gas behavior, density and viscosity properties of air
- Buoyancy effects due to density differences
- k-ε turbulence model
- No energy transfer to hood walls
- Atmospheric conditions of 101.3 kPa and 25ºC

The capture of process gas by the primary hood during blowing and the capture of charging fumes by the secondary hood are events that last for a long enough time to be modeled as steady-state. The temperature of the gases that are interacting during blowing and charging vary from 25ºC (ambient) to 1200ºC, so the effect of temperature on density must be included in the model. The temperature and pressure effects on gas density are incorporated into the model using the ideal gas law. In both the primary and secondary CFD models the buoyancy due to density differences are included.

The k-ε turbulence model is used to model flow turbulence. It is a two-parameter turbulence model that is widely used in the CFD field. Energy transfer, although significant in both situations, is omitted to reduce model complexity and computation requirements. In all simulations, atmospheric conditions of 101.3 kPa and 25ºC are used.

Primary Hood Design

Gas leakage from a converter hood during blowing can be reduced or eliminated by increasing the suction at the hood. However, increasing the suction will also increase the infiltration rate. The maximum achievable infiltration rate is normally limited by the volume of gas that can be taken to the acid plant, this in turn limits the suction which can be applied to the system.

The efficiency of converter hoods in collecting off-gases during blowing varies widely between smelters. At some smelters there is virtually no leakage from the hood during blowing, whereas other apparently similar smelters have a continuous stream of gas leaking from the primary hood. Many smelters have tried to solve this problem by installing secondary hoods when the real solution lies in providing an effective primary hood design.

Factors affecting gas collection efficiency of primary hoods include:

- Mouth angle
- Hood/door configuration
- System draft
- Infiltration rate
- Apron plate/hood gap
- Door/hood gap
- Hood geometry
- Downstream infiltration
- Physical condition of the hood

The effect of the converter blowing angle, the gaps between the apron plate and the primary hood, and the door arrangement will be shown using CFD. Based on GCT/HGE's experience, a great portion of the smelter's total sulfur release can be attributed to the leaking of the joint between the primary hood door and the primary hood. A positive relative pressure at the door joint drives the process gas to leak from the primary hood. Although this joint is impossible to seal completely, steps can be taken to promote a negative pressure at the door joint and achieve minimal leakage.

Figure 1 shows the major components of the geometrical configuration used for the CFD simulation of the converter primary hood.

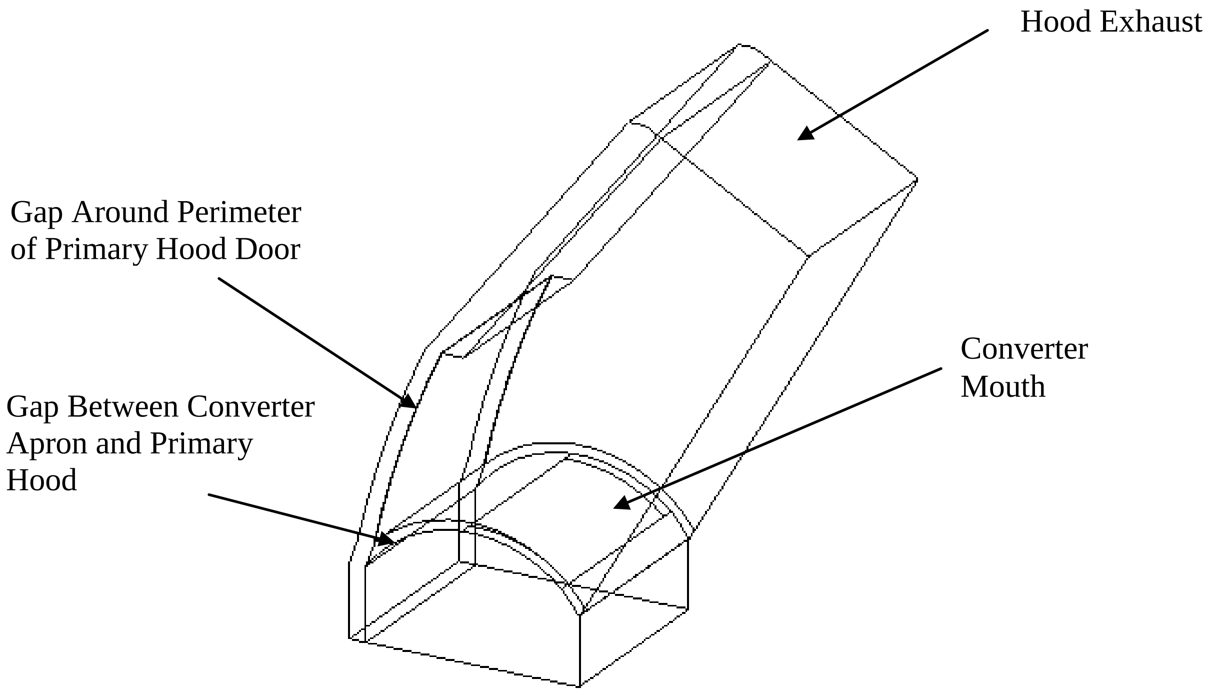


Figure 1: Primary Hood CFD Geometrical Configuration

Converter Mouth Orientation and Infiltration Ratio

Hot, buoyant gases exit through the converter mouth at velocities of 12 to 15 meters per second. If the mouth is oriented to direct the gases into the hood and away from the door joint, the gas collection will improve. It is surprising how many smelters operate their converters with the mouth pointing directly upwards causing the process gas to spill into the converter building.

Changing the blowing angle is often possible with little or no changes to the converter or primary hood. Directing the converter mouth off-gas directly into the hood, and away from the door joint, will reduce the pressure at the door joint and therefore the process gas leak rate.

Figure 2 shows the effect of the infiltration ratio and the blowing angle on the leak rate from the door joint. Most primary hoods have door joints measuring about 1 inch (25 mm), but for illustration purposes Figure 2 uses a four-inch (100mm) door joint. The figure shows that rolling the converter into the hood decreases the door joint leak rate.

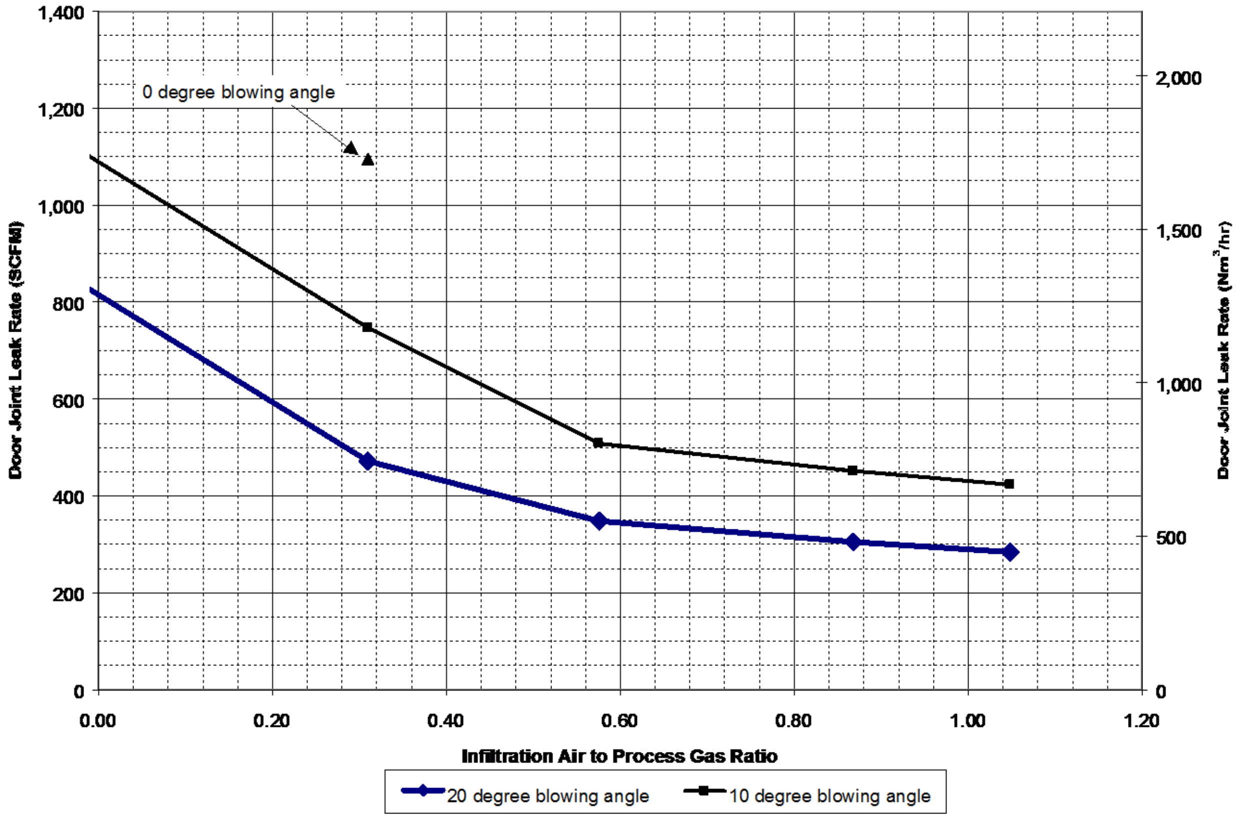


Figure 2: Door Joint Leak Rate vs. Infiltration Ratio for Different Blowing Angles
183mm side and front gaps; 102mm door joint gap;
35,200 Nm^3/hr process gas flow rate; 1,200ºC gas temperature exiting mouth

In Figure 3, which has been run with smaller side gaps than those in Figure 2, the effect of changing the blowing angle on the pressure, temperature, and velocity profiles inside of the primary hood is clearly shown. In the pressure profiles, the CFD results indicate a positive pressure at the door joint for the 10º blowing angle case and a negative pressure at the door joint for the 20º blowing angle case, rotating the mouth in this case eliminates the leakage.

The temperature and velocity profiles in Figure 3 show increased contact between the process gas and the rear portion of the primary hood when blowing at a 20º blowing angle. The increased contact must be matched with adequate water velocities in the cooling panels at the rear of the hood to avoid panel failure.

Changing the blowing angle can cause an increase in the amount of solid build-up on the rear portion of the primary hood. Increasing the water velocities in the rear cooling panels and re-configuring the mouth to allow large solids to roll back into the mouth will decrease the build-up problems associated with increasing the blowing angle.

Rotating the converter so that the mouth directs the gases into the hood is an effective way of reducing spill gas but it needs to be done by reconfiguring the mouth rather than by simply rotating the mouth. Otherwise the amount of splashing and the build up on the back of the mouth can be excessive.

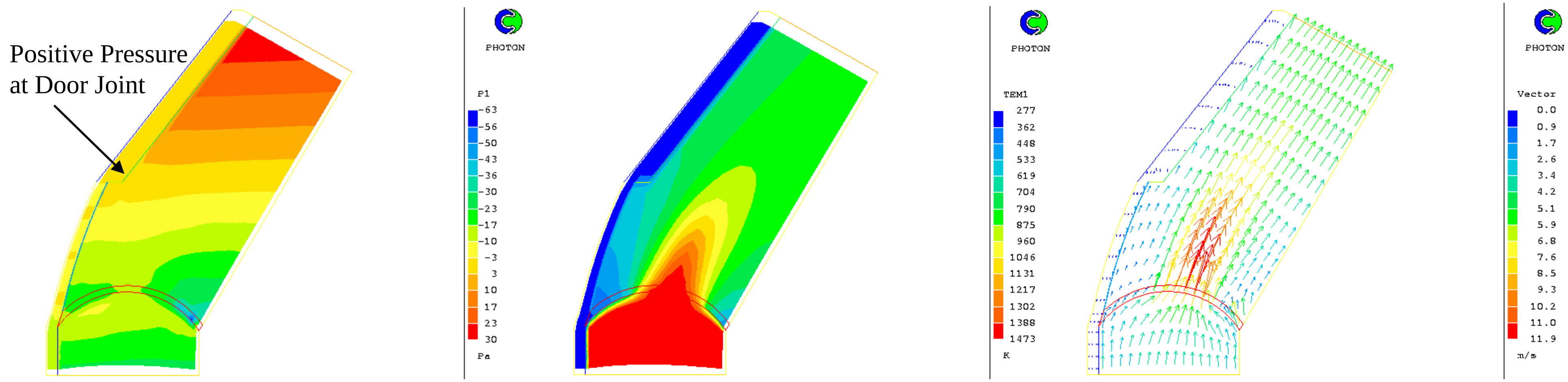


Figure 3a: 10º Blowing Angle

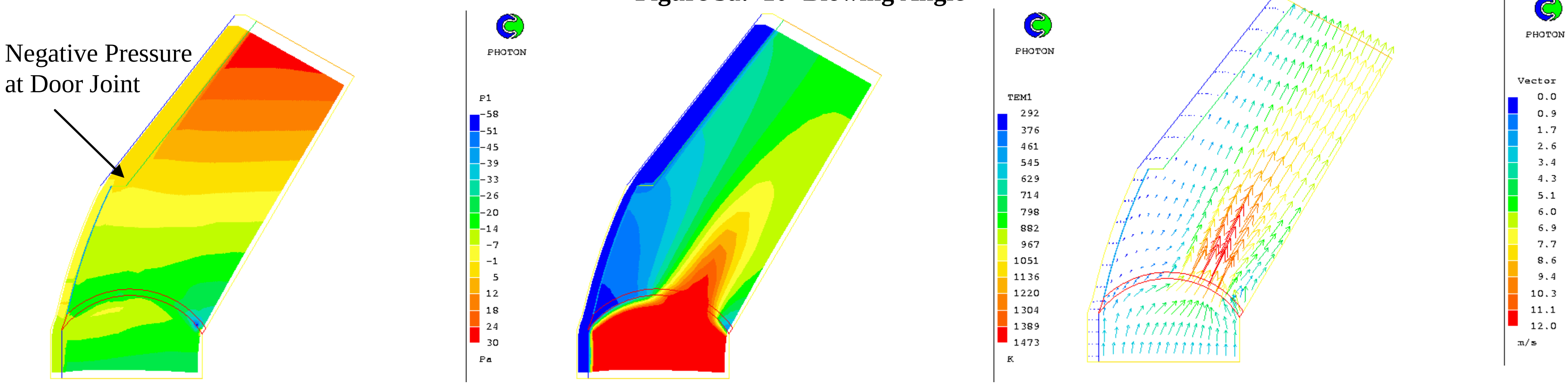


Figure 3b: 20º Blowing Angle

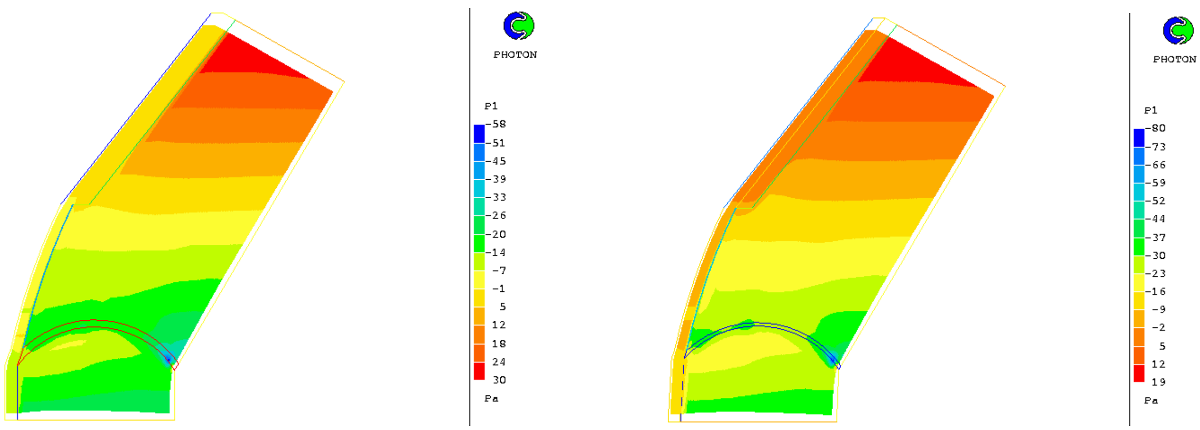
Figure 3: Pressure, Temperature, and Velocity Profiles

50mm side gaps; 400mm front gap; 25mm door joint gap; 1.4:1 infiltration ratio; 35,200 Nm^3/hr process gas flow rate; 1,200ºC gas temperature exiting mouth

Gap Between Converter Apron and Primary Hood

Closing the gap between the converter apron plate and primary hood, for a constant infiltration ratio, will increase the draft in the primary hood.

Figure 4 compares the pressure profiles for apron-to-hood gaps of 7.2 inches (183mm) and 3.6 inches (91mm). Under both cases the door joint is under negative pressure, but the infiltration rate through the door joint increases for the case with the smaller (3.6 inch, 91mm) gap.



Gap Size: 7.2 inches (183mm)
Door Joint Static Pressure: -2.7 to -4.0 Pa
Door Joint Infiltration Rate: 1,400 SCFM (2,200 Nm^3/hr)

Gap Size: 3.6 inches (91mm)
Door Joint Static Pressure: -7.0 to -11.0 Pa
Door Joint Infiltration Rate: 3,300 SCFM (5,200 Nm^3/hr)

Figure 4: Effect of Gap Between Converter Apron and Hood on Door Joint Infiltration
400mm front gap; 25mm door joint gap; 1.4:1 infiltration ratio;
20º blowing angle; 35,200 Nm^3/hr process gas flow rate; 1,200ºC gas temperature exiting mouth

It is not necessary to completely close this gap, some air infiltration under the hood helps to keep the apron plate cool and prevent sticky build-up.

Hood and Door Geometry

Bringing the hood door joint forward out of the direct flow of gas will also improve the gas capture. The first exercise when designing a new hood is to lay out the crane during ladle charging and scrap charging operations in order to determine the maximum distance the hood can be extended.

Smelters who charge scrap while the converter is blowing have to bring the crane cables closer to the converter during this operation. This places an extra design constraint on the hood and may reduce the effectiveness of the hood.

Figure 5 shows the effect of changing the hood/door geometry. This usually requires a curved door rail, or a special door mechanism such as the quadrant door or the Noranda swing arm door to fit into the layout of the building.

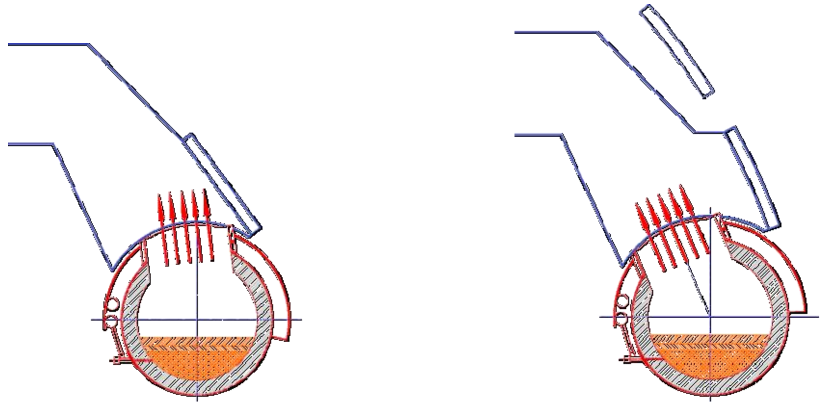


Figure 5: Converter Mouth Rotation and Primary Hood Door Modification

Secondary Hood Design

After the emissions associated with the primary hoods, the largest source of SO_2 emissions from smelters is often the hot metal transfers to and from the Peirce-Smith converters. GCT has measured instantaneous SO_2 release rates from 22 to 111 lb/hr (10 to 50 kg/hr) during matte charging at various smelters around the world. The particulate released during the charging and pouring operations can potentially push a smelter into the "major source" category for hazardous air pollutants (HAPs). Once effective primary hoods are installed, the next logical step toward reducing the emissions associated with the converter operation is to install secondary hoods.

The secondary converter hood design must have the following characteristics:

- It must ensure effective fume collection during the following operations:
  - matte charging
  - scrap charging
  - slag skimming
  - blister pouring
- The secondary hood in conjunction with the automated blast air control system should serve as an effective method of fume control for the converter roll in/out emissions
- Secondary hooding must be capable of capturing any leaks from the primary hood during blowing
- Secondary hooding should not interfere with the process activities, especially the ability of operators to view operations directly.
- Secondary hooding should not interfere with the maintenance activities, including mouth chipping and re-bricking.
- Secondary hooding should have good mechanical reliability and minimum moving parts.

CFD is useful as a design tool when used in combination with operating knowledge, prior experience, and engineering judgement. The results from CFD simulations must be used for relative comparisons rather than absolute predictions of performance since it is impractical to include all possible disturbances and operating scenarios in the model.

Figure 6 shows the major components of the geometrical configuration used for the CFD simulation of the converter secondary hood.

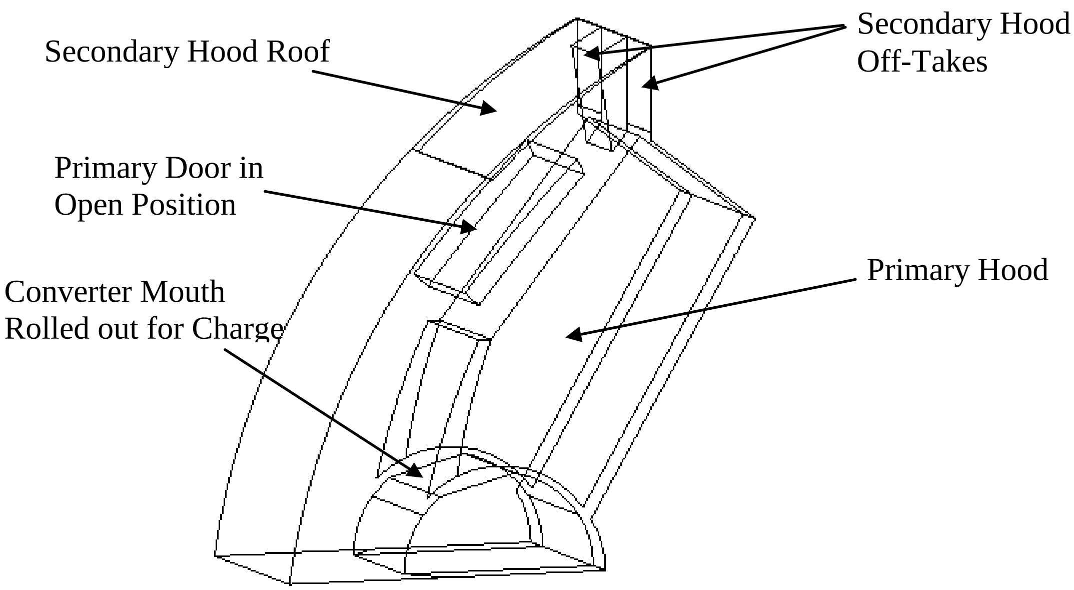


Figure 6: Secondary Hood CFD Geometrical Configuration

For this analysis, the fume capture efficiency of the secondary hood is predicted for a matte charging operation. The fume mass flow rate and heat release rate are input to the CFD model based on estimates of the radiative and convective energy release during the operation.

Figure 7 illustrates the effect of secondary hood exhaust rate on the capture efficiency for a matte charging operation. The velocity profile in Figure 7a shows the fume velocity vectors turning slightly toward the secondary hood off-takes as they rise upward, which indicates an inadequate hood exhaust rate. Figure 7b shows that most fume velocity vectors are entrained and carried to the secondary hood.

Figure 7b shows that the fume capture increases by a factor of 2.7 (from 35% to 94%) when the secondary exhaust rate is tripled to 112,400 SCFM at 255ºF (177,400 Nm^3/hr at 124ºC). Additional CFD simulations using higher secondary hood exhaust rates determined that the exhaust rate required in order to achieve 100% fume capture is 158,000 SCFM at 210ºF (250,000 Nm^3/hr at 100ºC). These results demonstrate the difficulty in capturing fugitive emissions within practical limits.

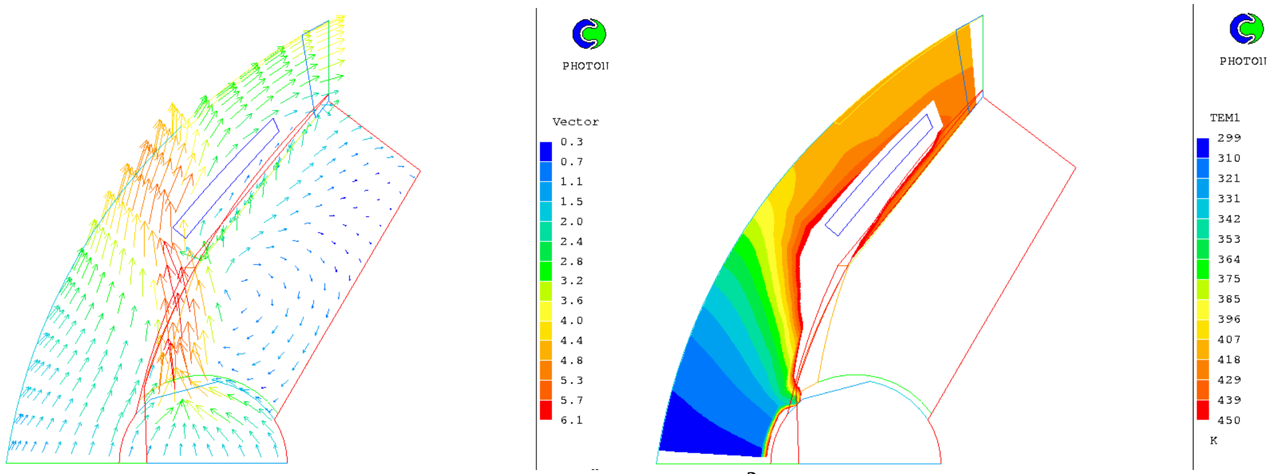


Figure 7a: 36,100 SCFM at 284°F (57,000 Nm^3/hr, 140°C) Exhaust Rate, 35% Capture Efficiency

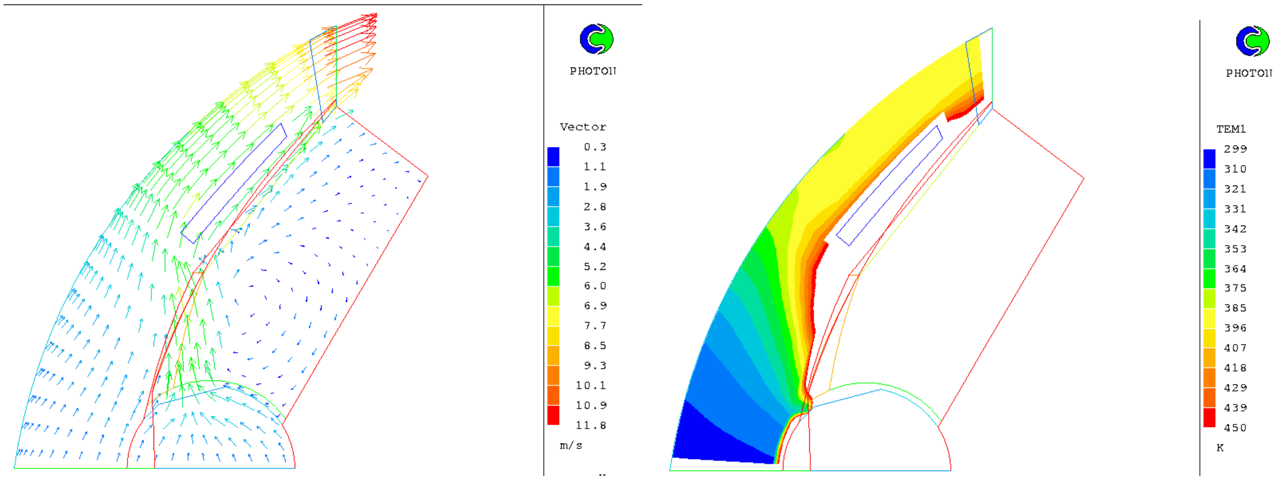


Figure 7b: 112,400 SCFM at 255°F (177,400 Nm^3/hr, 124°C) Exhaust Rate, 94% Capture Efficiency

Figure 7: Velocity and Temperature Profiles for Ladle Pour Fume Capture Efficiency
400,000 Btu/min (7,000,000 W) Heat Release Rate; 13,800 SCFM (21,800 Nm^3/hr) Fume Release Rate

In an attempt to improve the secondary hood performance, the CFD model was modified to extend the secondary hood roof outward as far as the crane cables allow. This modification improves the capture efficiency of the hood by only 2%.

Conclusions

This paper provides an overview of the major factors to be considered when designing primary and secondary hoods for Peirce Smith converters and examines the parameters' effects using computational fluid dynamic modeling.

Mouth Orientation: For a given infiltration ratio, reconfiguring the converter mouth so that the process gas is directed into the hood and away from the door joint can improve primary hood capture significantly with minimal changes to other operating parameters.

Gap Between Converter Apron and Primary Hood: Tighter gaps between the converter apron and primary hood increase the suction in the primary hood and reduce or eliminate leakage at the door joint for a constant infiltration ratio.

Primary Hood and Door Geometry: Designing the hood so that the door joint is out of the path of the process gas improves the draft at the door joint and the gas capture efficiency. The distance the door joint can be moved is determined by the crane cable location during charging operations.

Secondary Hood Design: Performance of the primary hood must be maximized before secondary hoods are installed. CFD is a useful design tool for optimizing secondary hood capture configuration and minimizing the off-gas handling system size to achieve the acceptable gas collection performance.