DESIGN OF TAPPING FUME EXTRACTION SYSTEMS FOR FERROALLOY FURNACES

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ABSTRACT

A significant portion of new air pollution control equipment in the ferroalloy industry is installed to capture secondary fumes generated by tapping processes. The trend is that legislation requires extraction from the taphole and specifies a minimum opacity for building emissions. In response to this, many old plants are being retrofitted with hoods, ducting and control devices and new plants are automatically fitted with extraction equipment. However, capacities are often inadequate and particle capture devices inefficient.

Traditionally, design of fume extraction canopy hoods used correlations based on thermal updraft caused by convective heat transfer from hot surfaces. Shortcomings of these correlations when applied to the ferroalloy environment include:
Geometry around tapholes and hot metal handling areas are always complex and installation of a standard overhead canopy hood is frequently not possible. The correlations do not provide any guidance of extraction volumes required for practical hood arrangements.
Heat generation by hot metal can be significantly higher than merely predicted by standard hot surface convection correlations. Higher heat generation in real situations can lead to significantly undersized extraction volumes.

In response to the above, a design method was compiled, which focuses on the following aspects:
Site test work is done to evaluate energy and particle generation aspects.
Computational Fluid Dynamics (CFD) techniques are utilized to evaluate impact of hood geometry and extraction volume on fume capture efficiency.

The article presents results of site test work, CFD modeling results, a comparison of conventional design results with the proposed design method as well as equipment selection criteria for fume capture devices.

1 INTRODUCTION

Secondary fumes are generated around the smelting process by oxygen lancing, drilling and metallic fumes in areas where hot metal is handled: the tap hole, transfer launders, ladles and casting areas. The fumes are mainly oxides of the metals involved in the smelting process and constitute a significant occupational health risk. Manganese has a relatively high vapour pressure, resulting in significant fume generation during tapping at ferromanganese and silicomanganese facilities. Manganese aerosols generated during tapping contain significant amounts of respirable particles (<5μm), which may be more harmful than other sources of manganese particulate.

On the positive side, tapping fumes at silicon metal facilities have been identified as a high value product and some facilities collect and sell these separately from furnace off-gas particulate.

2 LEGAL REQUIREMENTS

European Commission Reference Document on Best Available Techniques (RDBAT) [1] considers the installation of appropriate hooding systems connected with a bag filter as best practice in the capturing and treating of tapping and casting fumes. The RD BAT future considers the use of high performance fabric filters (e.g. membrane fabric filters) with an associated particulate matter emission concentration of <5 mg/Nm^3 as preferable due to the possible presence of metals in these emissions. Changes to South African legislation are currently being effected with the publication of the Minimum Emission Standards [2] on 24 July 2009 for public comment. This document stipulates a national minimum requirement that must be enforced by the relevant licensing authorities. The document requires that existing Ferro-alloy production facilities must achieve a particulate matter emission concentration of < 100 mg/Nm^3 and that new facilities must achieve an emission concentration of < 50mg/Nm^3. No reference to technology is made.

3 EXTRACTION DESIGN METHODS

Canopy hood design techniques are generally based on the assumption that conduction and convection from a hot surface cause buoyant air flows [3], [4]. A canopy hood is installed directly above the source to capture the contaminant plume. These design techniques have the following limitations when applied to ferroalloy fume generating areas:

- Energy release from the hot metal surfaces is not only via convection from a hot surface furnace, as the test results will indicate.
- The layout at tap hole areas is complicated, with drills, mud guns and crane access required. Canopy hood positioning and sizing is frequently non-optimal due to space constraint factors.
- The effect of building cross-draughts, doors and other openings as well as external wind conditions cannot be taken into account.

In response to these factors, Computational Fluid Dynamics (CFD) modelling is used to provide a more comprehensive evaluation of secondary fume extraction design.

4 TEST RESULTS

Tests were conducted at two producers of high carbon ferrochrome. The tests consisted of volumetric flow, temperature and particulate sampling either directly above the taphole (via a sampling probe) or at ducting of an existing extraction system. In addition, video analysis was done of the tapping fume plume to identify the rise velocity of fumes. The purpose was to determine energy release rates from hot metal, particle generation rate and particle size distribution.

Table 1: The results indicated the following characteristics:

Parameter	Unit	Value range
Fume rise velocity	m/s	3 to 4m/s
Average particulate concentration	mg/Nm^3	176 to 418
Emission factor	kg fume / t metal	0.19 to 0.24
Peak energy generation	kW/m^2 hot metal	1400 to 1800

High variability of results can in general be expected, due to the variability of the tapping process. Convective energy transfer from a hot metal surface at 1600°C is calculated as only 30kW/m^2, so the above peak energy generation value indicates that further energy generation processes are present:

- Combustion of iron during lancing,
- Oxidation of metal to generate fumes and
- Combustion of carbon from the high-carbon metal.

The tested fume size distribution is also illustrated in the log-probability graph below.

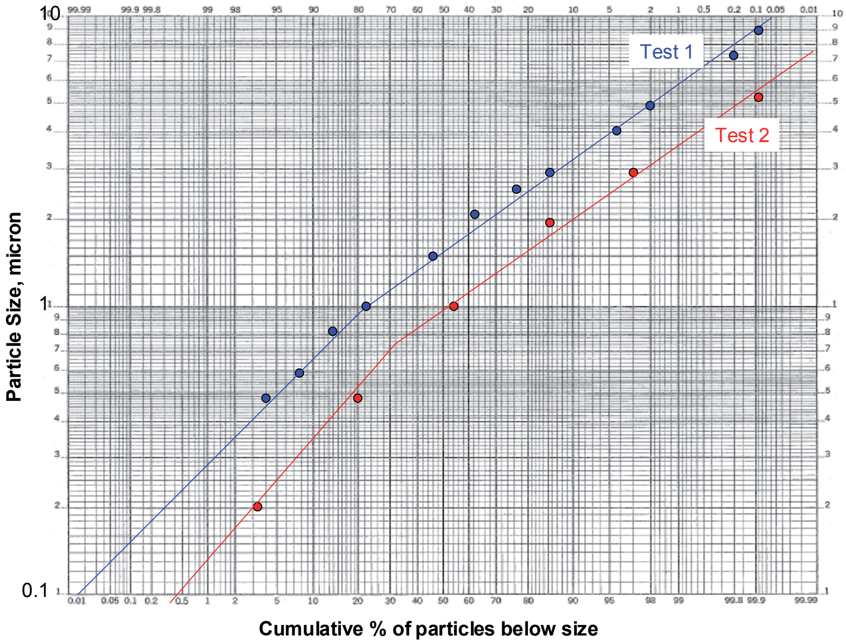

Figure 1: Log-probability plot of the emission size distribution

The fume particulate had a D50 (50% of particles smaller than) of between 0.95 and 1.69µm.

5 AIR POLLUTION CONTROL EQUIPMENT SELECTION

A number of new ferroalloy projects have been commissioned with scrubbers as the control device for fume collection. The European Union Best Available Technology indicates that the preferred technology for fume collection is a bag filter. In order to evaluate equipment selection, scrubber modeling was done, based on existing correlations [5], [6] and using the coarser size distribution from test work (D50 of 1.69µm).

An average fume concentration over the period of a tap of 176 to 418mg/Nm^3 was measured. In order to accommodate peak fume generation, an inlet dust load specification of 1 to 3g/Nm^3 is realistic. Below, venturi scrubber efficiency and emission are plotted versus throat differential pressure.

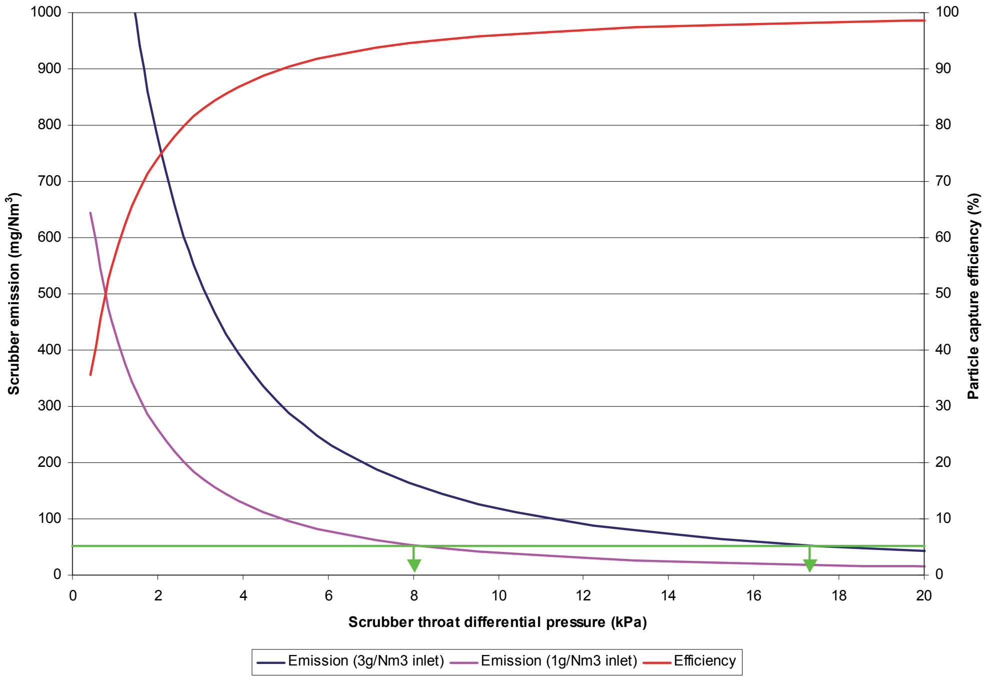

Figure 2: Scrubber efficiency and predicted emission for inlet loads of 1 and 3g/Nm^3

In order to meet an emission limit of 50mg/Nm^3, a scrubber throat differential pressure of between 8 and 17.5kPa is required. Assuming an inlet and interconnecting duct pressure loss of 2kPa, the scrubber power consumption will be at least 2.5 times that of a bag filter. As volumetric flows required to capture all generated fume are significant, power consumption can be very high. A bag filter is therefore the preferred control device. Given the very fine particle size distribution, a multi-compartment bag filter (allowing off-line cleaning) with PTFE membrane-type bags is generally preferred.

6 CFD MODELLING

In general, Computational Fluid Dynamics (CFD) modeling provides an excellent tool for design of fume extraction systems. Input parameters are obtained by site test work as above or video analysis of an existing installation. A good way of providing input parameters is by specifying gas flow rates and temperatures at each fume source. Lancing operations can be shown modeled by including a high velocity disc at the tap hole, with a flow and temperature based on the oxygen flow and iron combustion energy.

It is important to include wind effects in buildings which are not completely enclosed. Various cases can be modeled for calm, average winter and summer conditions. A worst case is determined by determining the ninety-percentile wind condition (i.e. wind speed not surpassed during 90% of time).

6.1 Tap Hole Fume Extraction

An overhead hood above a tap hole is in general the most effective way of capturing fume generated during tapping. An example of such an arrangement is shown below, with a temperature plot indicating good capture. In general, a temperature profile is an effective way of evaluating fume capture – generated fume and hot air will follow the same path. Particle studies can also be used to evaluate capture efficiency.

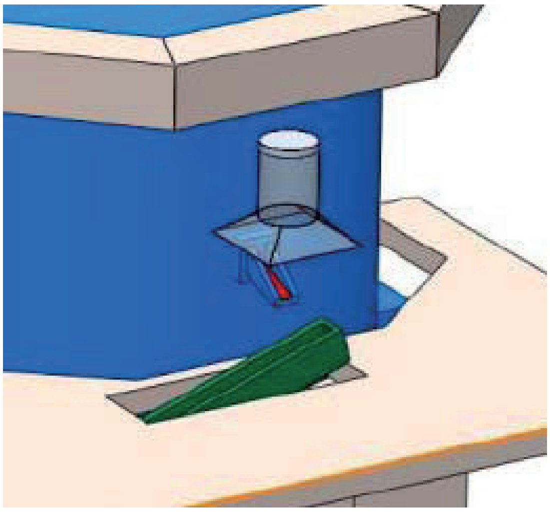

Figure 3: Isometric view of tap hole overhead hood

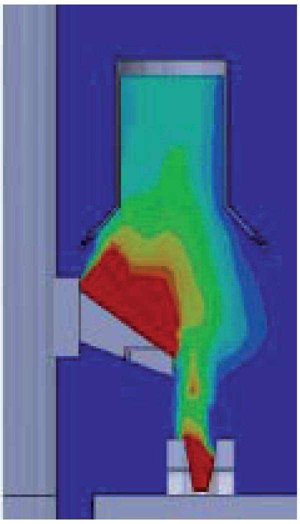

Figure 4: Temperature plot – vertical section through tap hole

The area around a tap hole is in general quite constrained by drills, mud guns and other equipment. In order to allow this type of equipment access and to limit the effect of cross-winds, a shallow high velocity hood can be constructed around the taphole. While the hood can capture all fume generated at the taphole, it is not effective further along the launder.

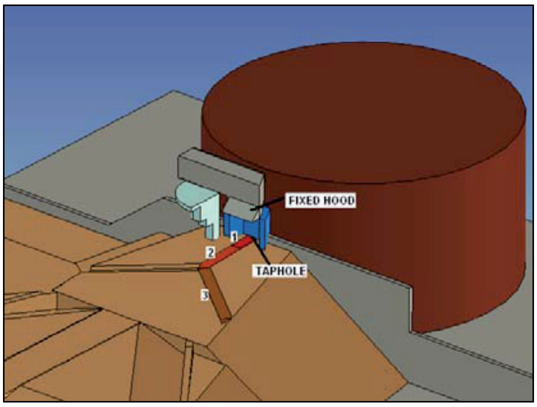

Figure 5: Tap hole hood arrangement

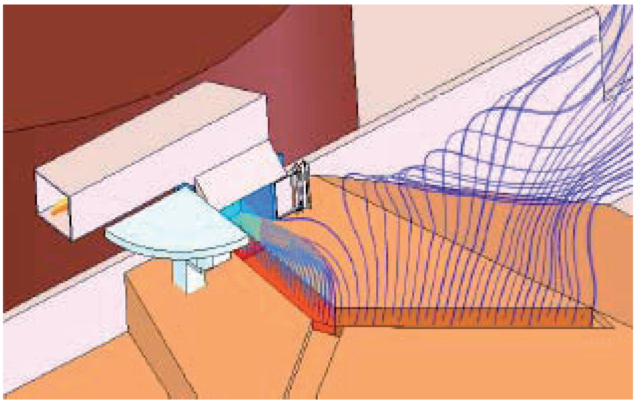

Figure 6: Particle study

6.2 Launder fume extraction

Fume from launders can be captured by use of an overhead hood. This is frequently not possible, given the crane and other access required for launder maintenance. Below, the lack of launder generated fume capture at a tap hole hood is shown. In this arrangement the launder runs through a floor and down to a ladle.

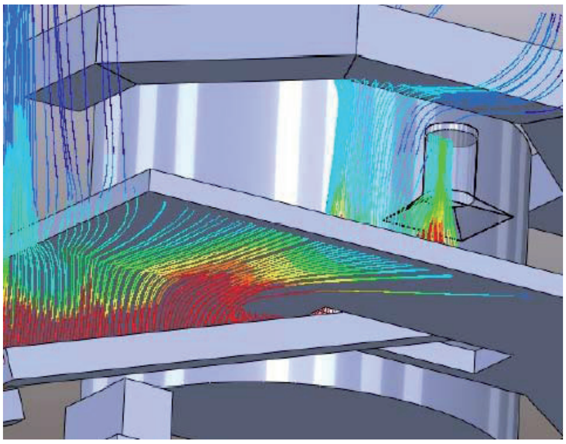

Figure 7: Particle study of fume flow below floor level

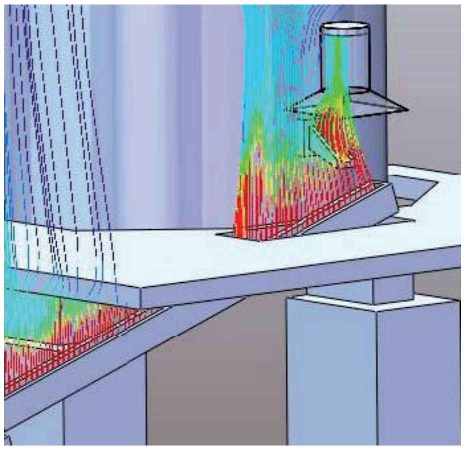

Figure 8: Particle study indicating lack of launder capture efficiency at tap hole hood

This problem can be remedied by use of either:

- A launder cover, slightly raised to allow access as well as visual inspection. The cover can be used to direct fume flow to the tap hole hood. The cover is normally fitted with refractory lined hinged top doors to allow maintenance access.
- An air curtain or push head with lateral subdivisions to move the generated fume to the tap hole or other hood.
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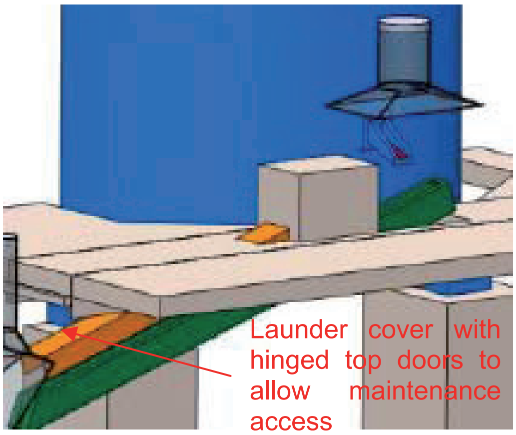

Figure 9: Isometric view of launder cover arrangement

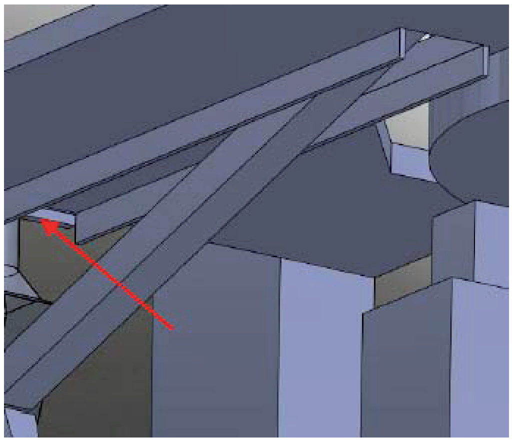

Figure 10: Isometric view of push head and side divisions

Fume capture using a launder cover is shown below. On the left, a temperature profile indicates good fume capture efficiency while on the right the particle study indicates the direction and good capture of fume.

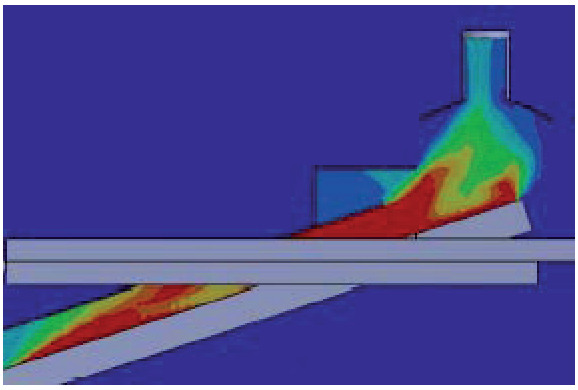

Figure 11: Vertical temperature plot along launder

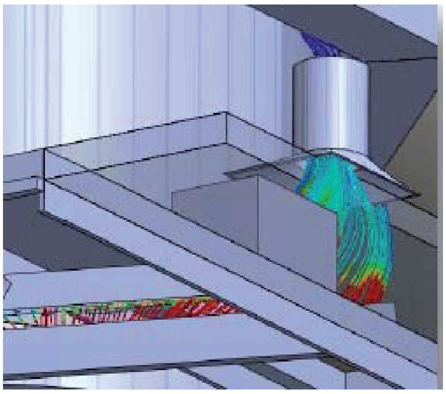

Figure 12: Particle study of launder cover fume capture efficiency

Over a longer distance, the air curtain concept is not as effective as the ladle cover, but still improves fume capture efficiency significantly, as shown below.

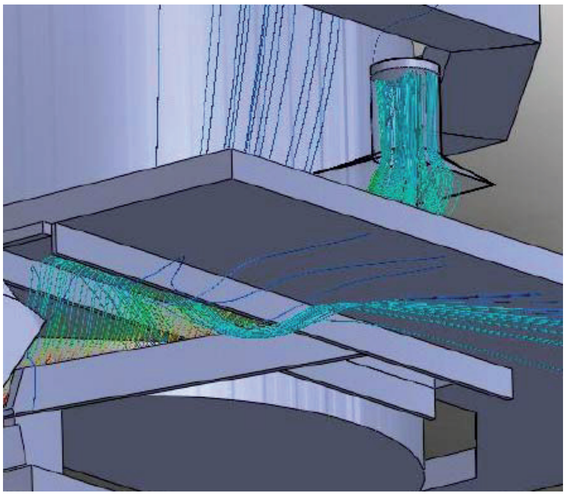

Figure 13: Particle study of launder air curtain arrangement fume capture efficiency

6.3 Ladle fume extraction

Extraction of fume generated at a ladle during tapping generally requires enclosure of the ladle and either an overhead hood or if overhead space is constrained, a side extraction hood. Below, a ladle enclosure arrangement is shown with either option:

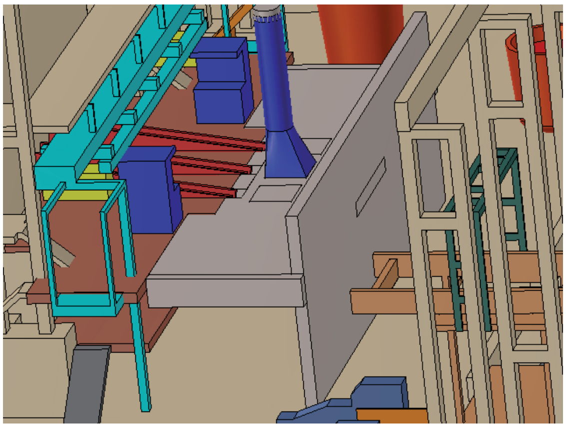

Figure 14: Overhead hood arrangement

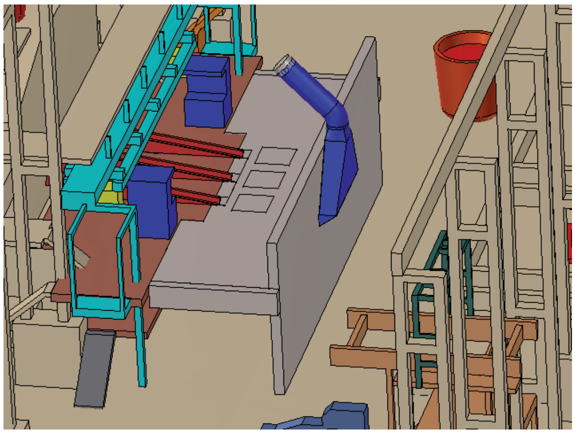

Figure 15: Side extraction hood arrangement

An overhead hood is the most effective, as the fume buoyancy is used. Full fume capture is achieved in the temperature plot below.

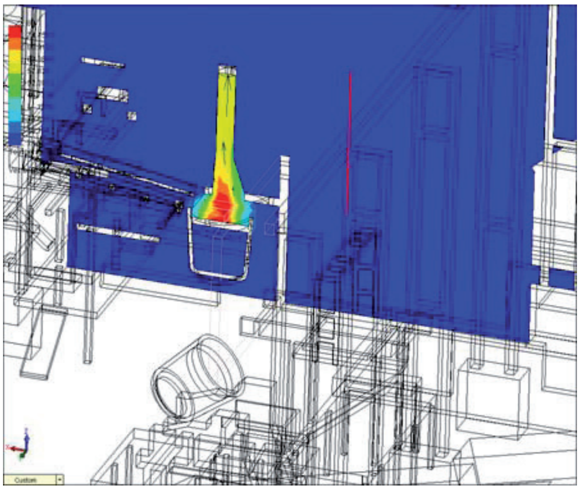

Figure 16: Vertical temperature cut plot of overhead hood

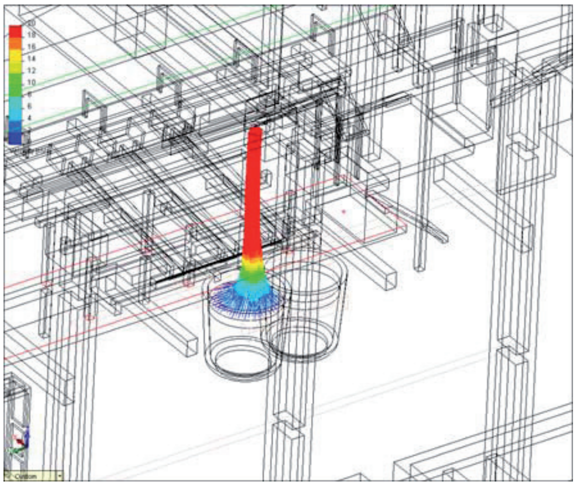

Figure 17: Particle study of overhead hood fume capture

A side extraction hood is less effective, as the reach of a high velocity hood is limited. Buoyant fume tends to escape via any open pathways upwards – as shown on the left below. On the right, the situation is rectified by introducing an air curtain or push header from the opposite side and by installing subdivision sections to limit lateral fume movement.

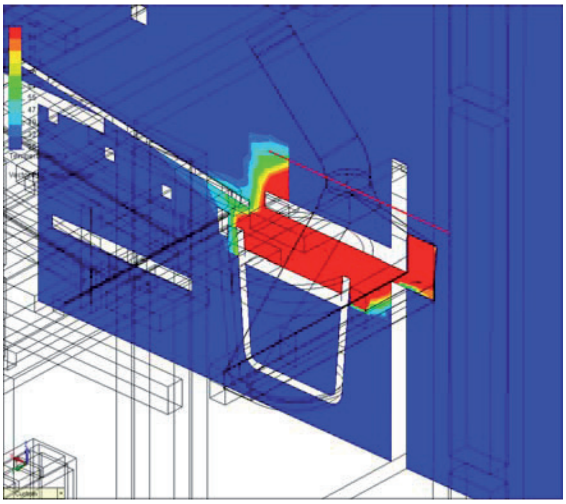

Figure 18: Temperature cut plot of side extraction

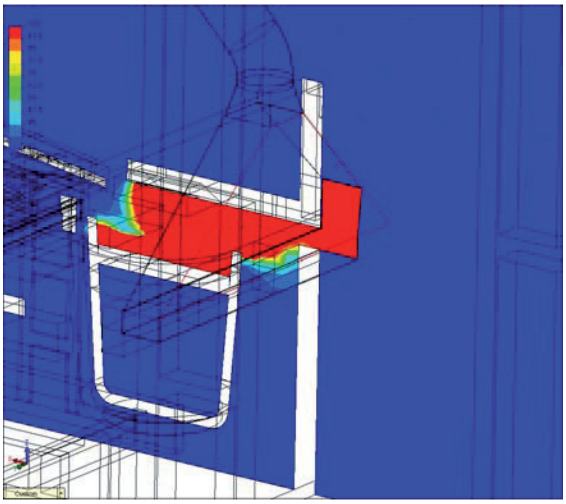

Figure 19: Temperature cut plot of side extraction – with air curtain

6.4 Casting

Casting to either a pit area (dry casting) or to a casting machine can be difficult in terms of fume capture and the amount of extraction flow required can be very high. As these areas are difficult to enclose due to the amount of casting area required as well as the access required by overhead cranes or front end loaders. The effect of wind on a ladle tilter at a casting machine is illustrated, with the improvement made by installing some enclosures.

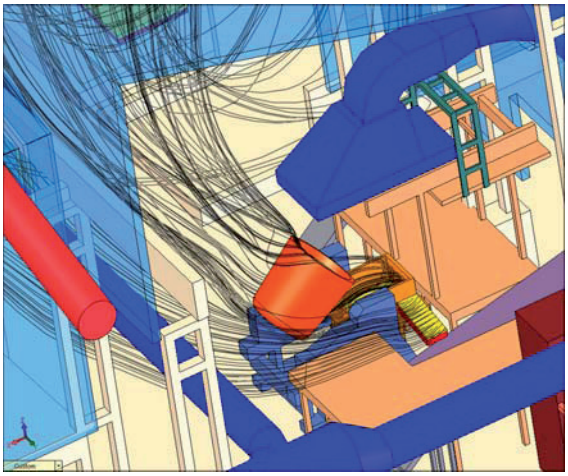

Figure 20: Particle study of casting machine hood with wind effect

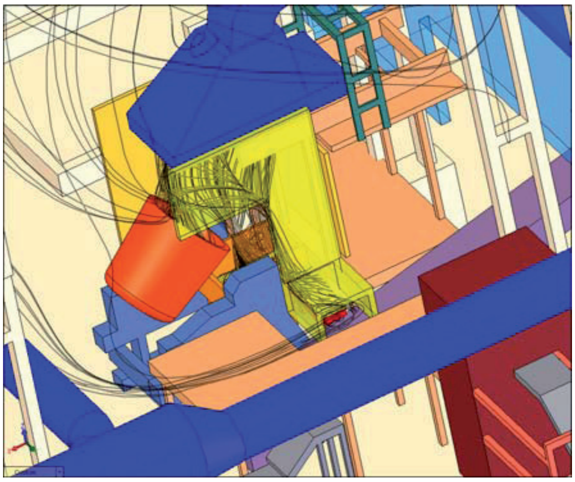

Figure 21: Particle study of casting machine hood with enclosure

Below, the effect of wind is shown on a casting pit without any covers (no fume capture) and with a partial cover. An overhead hood is used in both cases.

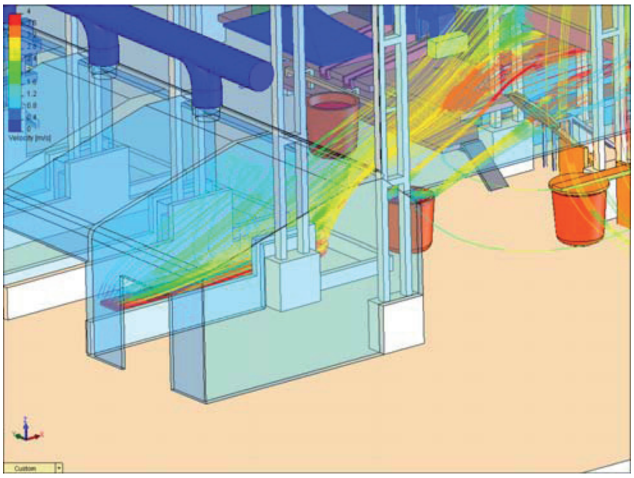

Figure 22: Particle study of casting bay lack of fume capture – wind included

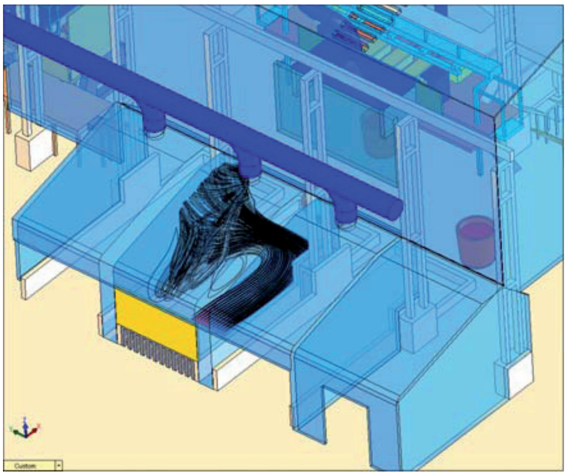

Figure 23: Particle study of improved casting bay fume capture with partial enclosure

The fume generated at the casting ladle (casting pit) or at a position of hot metal transfer between ladles for ladle reactions can be captured using either an overhead hood (shown on the right below) or a high velocity side extraction hood.

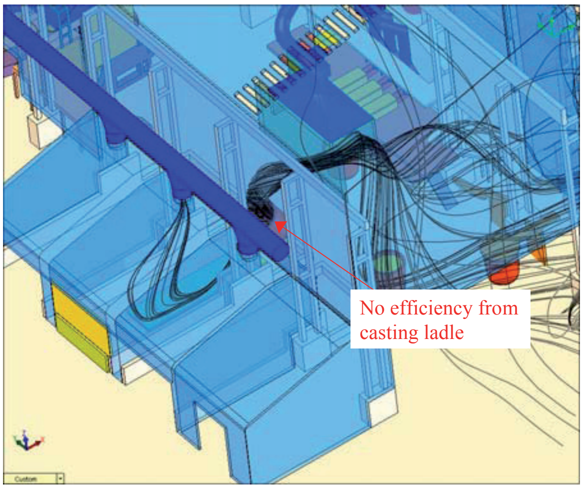

Figure 24: Particle study of lack of fume capture at casting ladle

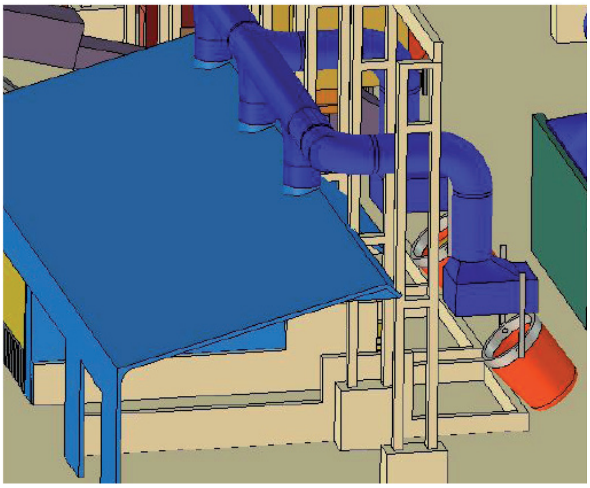

Figure 25: Casting ladle overhead hood arrangement

6.5 Cost-effectiveness evaluation

The cost-effectiveness of sizing fume extraction can be evaluated using CFD by plotting fume capture efficiency as a function of extraction rate. An example is shown below for a casting pit extraction point. This also allows demonstration of the effect of enclosing areas and other upgrade options.

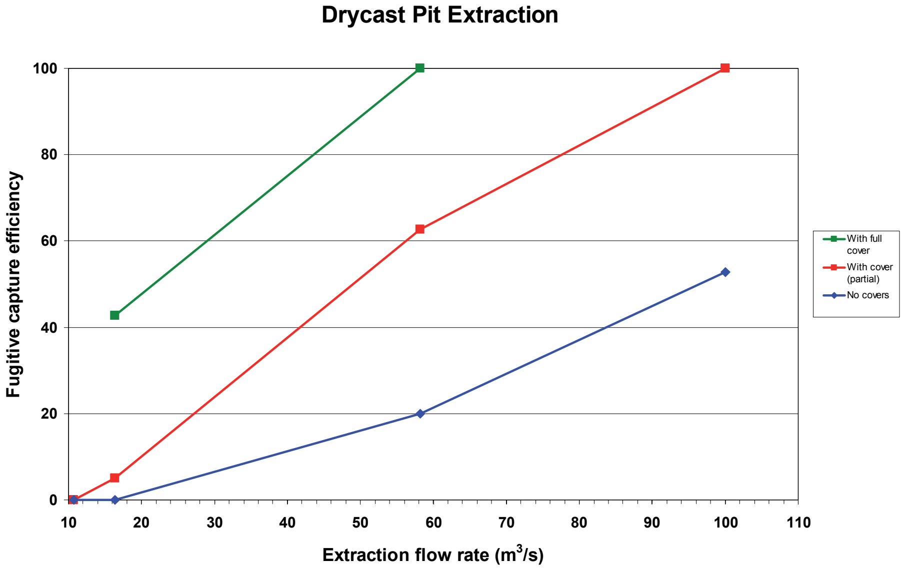

Figure 26: Fume capture efficiency vs Extraction flow rate for various enclosures

7 CONCLUSIONS

Conclusions of this article are:

- Due to the fineness of fume particulate generated at hot metal handling areas, a bag filter is preferred for fume collection.
- Test work and video analysis is important in generating input parameters for engineering design actions.
- Fume extraction layout is a compromise between process requirements and enclosures required for optimal capture efficiency. In general, a change in operating procedures is required to limit extraction equipment sizing and associated capital costs:
  - Launders have to be limited in length and hoods in conjunction with air curtains installed above launders to adequately contain fume.
  - Hot metal and slag have to be contained and cooled in small areas, which can be fully enclosed and extracted from.
- Given proper input parameters, CFD is an excellent design tool to ensure optimum fume capture efficiency can be achieved at the minimum capital cost. CFD can be used to compare extraction layout options, generate ideas around enclosures and air curtains, optimize design and ensure overall design cost-effectiveness.

8 REFERENCES

[1] Reference Document on Best Available Techniques in the Non Ferrous Metals Industries, December 2001, European Commission

[2] Listed Activities and Associated Minimum Emission Standards Identified in terms of Section 21 of the National Environmental Management: Air Quality Act, 2004, 24 July 2009

[3] ACGIH, “Industrial Ventilation – A manual of recommended practice”, 24th edition, 2001

[4] Goodfellow, H and Tähti, E., “Industrial ventilation design guidebook” Academic Press, 2001

[5] Calvert, S. et al, “Wet Scrubber System Study”, Ind Eng Chem, Vol 46, 1954

[6] Yung, S.C., Calvert, S., Barbarika, H.F. and Sparks, L.F., Venturi Scrubber Performance Model, Env Sci Tech, Vol.12, 1972