IMPROVING ENVIRONMENT IN THE TAPPING AREA OF A FERROMANGANESE FURNACE

B. Ravary[1] and S.Grådahl[2]

[1] ERAMET Norway AS, c/o Sintef Materials and Chem., Alfred Getz v. 2, 7465 Trondheim, Norway; benjamin.ravary@erametgroup.com
[2] SINTEF Materials and Chemistry, Alfred Getz v. 2, 7465 Trondheim, Norway; svend.gradahl@sintef.no

ABSTRACT

A main issue for the working environment in plants producing manganese alloys is dust and gas emissions from the slag and metal melts. In particular, under handling of the ladles (tapping, transport, casting), fumes can be produced and need to be collected. To preserve the health of its workers, ERAMET has a very strong focus on limiting exposure to pollutants. In several areas of the plants, a combination of numerical modeling and air flow measurements have contributed to a better understanding and lead to appropriate solutions.

In the present paper, we will present the work performed to improve the ventilation in the tapping area of a high carbon ferromanganese furnace at ERAMET Norway Porsgrunn plant. An exhaustive measuring campaign aimed at quantifying and characterizing the dust and gas emissions in the working environment. Airflow and temperature measurements were collected. An infrared camera allowed measuring wall temperatures that were decisive for the natural convection. The aim with these measurements was to build understanding of the transport and spreading phenomena. Another objective was to gather data for building a Computational Fluid Dynamics (CFD) model. This data was used to set up boundary conditions and validate the model. The CFD model gave results in qualitative agreement with the measurements and with the observations of the fume distribution. Some ideas for possible improvements were tested numerically. Some numerically tested solutions were selected for practical trials. The potential was checked and agreed well with the computational results. Implemented solutions have resulted in a better working environment.

1 INTRODUCTION

In order to improve the working environment in the tapping area of a high carbon ferromanganese furnace, an exhaustive study has been performed that included measurements, modeling and industrial tests.

Firstly, the tapping area has been characterized during a comprehensive measuring campaign. Dust, gas composition, temperature and gas velocities in several locations have been measured in combination with a work environment study based on person held measuring devices [1].

The main focus from a working environment point of view has been SO_2. Sulfur is mostly present in the slag phase according to the slag and metal analysis. The sulphide capacity measures the capacity of a given slag to hold sulfur. It varies both with slag composition and temperature. The sulfur behavior in ferromanganese smelting has been studied experimentally [2]. Though it may be sometimes possible to adapt the slag chemistry to minimize SO_2 emissions, a more robust approach was found to be to improve the ventilation in the tapping area so that other tapping emissions would be solved simultaneously.

The present paper presents the study to understand the problem and improve the ventilation based on measurements, modeling and industrial trials. The final objective is to improve the working environment for the operators.

2 MEASURING CAMPAIGN

The measurement was a part of the EHS (environment, health and safety) work that was done to characterize the working environment in the tapping area. The measurements contribute to identify how the air quality varies due to the smoke and dust.

2.1 Measuring techniques

As the main focus was to identity- and understand the SO_2 formation it was measured at 4 different locations (Figure 1) and with 3 different measuring techniques. A Bohmem FTIR (Fourier Transformed Infrared Spectroscopy) gas analyzer (marked as 6) was used to measure SO_2, SO_3, CS_2, COS and H_2S, a Horiba PG-250 (infrared) gas analyzer (marked as 3) measured SO_2 and two Testo 350 (electrochemical) gas analyzers (marked as 4 and 5) measured SO_2, H_2S, NO, CO, CO_2. In addition SO_2 was measured with a portable gas monitor, carried by one of the operators.

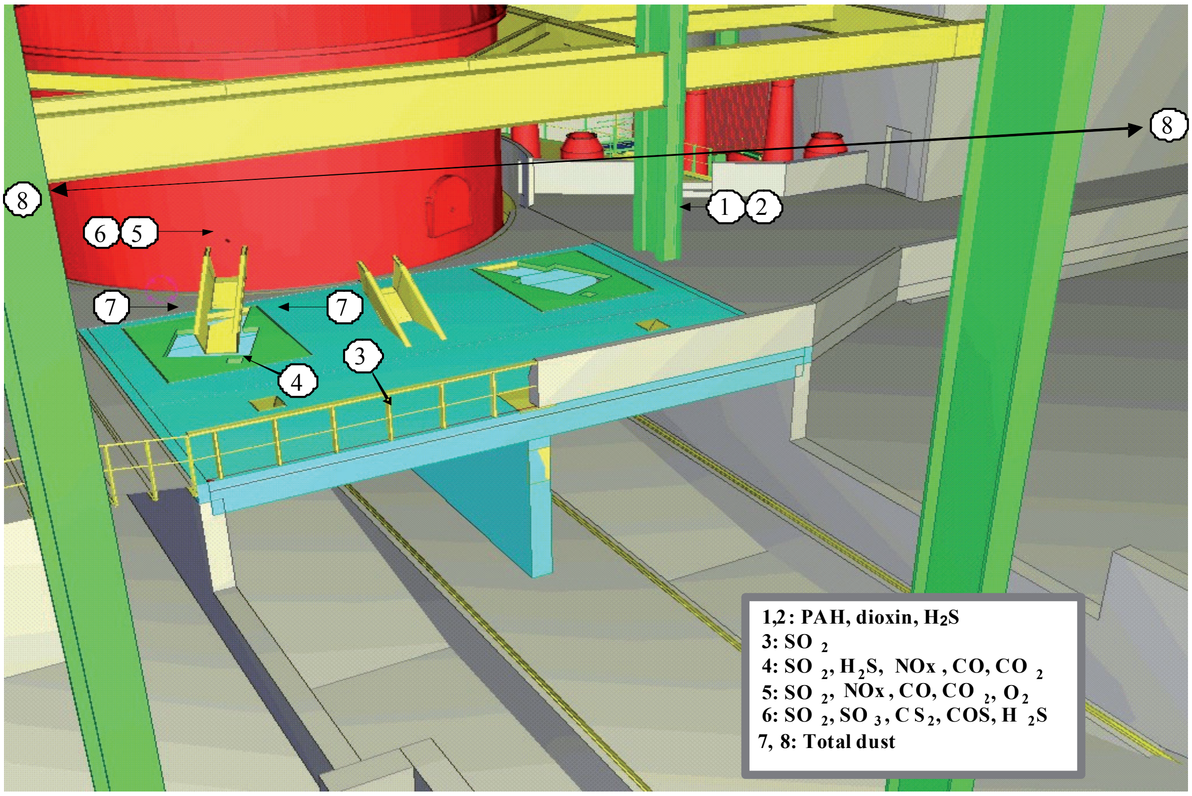

Figure 1: An overview of the measuring points in the tapping area

PAH, dioxin and H_2S (marked as 1 and 2) was measured as a one week average to record if any phase of work may form some of these toxic chemicals. PAH may be formed by heating of carbon-containing materials and dioxin mainly forms by burning of materials containing chlorine.

The dust amount in the tapping area was measured optically both close to the metal tapping and in the area outside the tapping area (marked as 7 and 8). Dust was also registered by personal inhalable particulate samplers carried by the operators.

2.2 Results from the measuring campaign

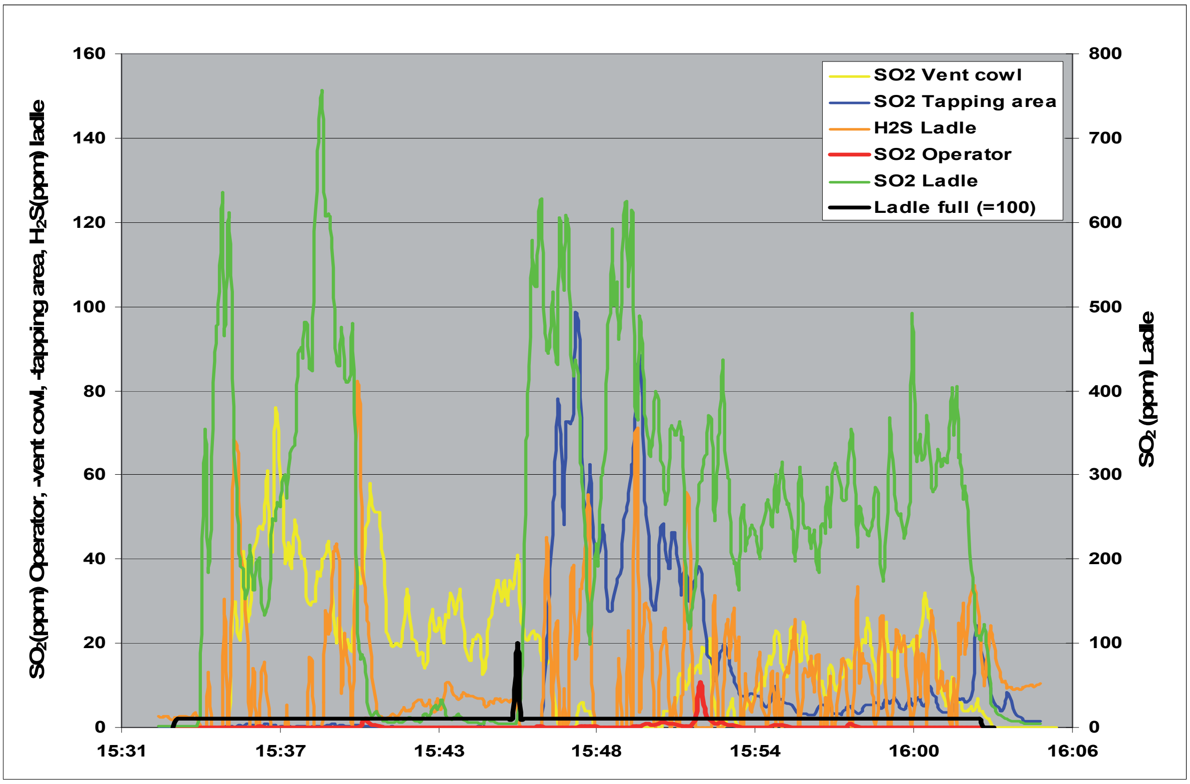

Figure 2: SO_2 from the tapping area, the vent cowl, the ladle and the operator, H_2S from the ladle

Figure 2 shows typical measuring results of the gases containing sulphur done in the tapping area. The black curve shows when the tapping starts and stops and the peak shows when the first ladle is full. Most of the SO_2 flows from the ladle (the green curve), in addition H_2S is measured (the orange curve) with a good correlation to SO_2. Sulphurous gases forms when the molten metal gets in touch with oxygen and water vapor, and SO_2 and H_2S decreases as the ladle fills due to a very viscous layer of slag that forms at the top of the ladle. When the second ladle fills (the slag ladle) SO_2 flows out in the tapping area (the blue curve) due to the existing design of the tapping area (as described in section 3). When the slag ladle fills, the molten slag increases its contact area to the air due to a longer tapping jet and turbulence in the ladle. Therefore, SO_2 and H_2S increase. The red curve shows that only a small amount of SO_2 registered by the operator because he is away of the most exposed area, but it has to be noticed that the daily recommend average of SO_2 in the working environment, formed by The Norwegian Labor Inspection Authority, is only 0.8 ppm (or 2 mg/m^3). The corresponding limit for H_2S is 15 mg/m^3 (or 10 ppm) and the measured average in the working area was only 0.004 mg/m^3 as a one week average.

During tapping the dust amount just above the runner is higher than recommended but this is not an area where personnel stays long under normal operation. Norwegian rule to respirable manganese dust has become (from 2008-07-01) more stringent and must be within a limit of 0.1 mg/m^3 as an 8 hour average. The PAH values in the tapping area also have to be followed up, but they were within the recommended limit. The measured SO_3, CS_2, COS and dioxin values were all well below the recommended values.

Obviously, ERAMET operates within the rules of the Norwegian Labor Inspection Authority. It is compulsory for personnel to wear an adapted mask in the tapping area in order to prevent possible risks.

2.3 Temperatures and air circulation in the tapping area

Systematic airflow and temperature measurements were collected, and an infrared camera allowed measuring wall temperatures that were decisive for the natural convection. The aim with these measurements was to build understanding of the transport and spreading phenomena. Another objective was to gather data for building a CFD model. This data was used to set up boundary conditions and to validate the model.

3 MODELING OF EXISTING DESIGN

Firstly a model of the airflow under tapping with the existing design was built and partly validated using measurements. In a second step, possible design improvements are tested and ranked in terms of fume collection efficiency. These results, together with rough techno-economical considerations, allowed deciding which industrial trials to be first performed.

3.1 Model set up

The model was built using the Computational Fluid Dynamic (CFD) code Fluent. The k-ω turbulence model was used and the gas density was temperature dependent in order to include natural convection. One tapping side is modeled (Figure 3). Some simplifications of the ladle design have been performed to facilitate meshing. It is thought that the simplifications have a limited impact on the features of the flow. All the ladles are assumed to be full. The primary hood is assumed to draw 100 000 Nm^3/h.

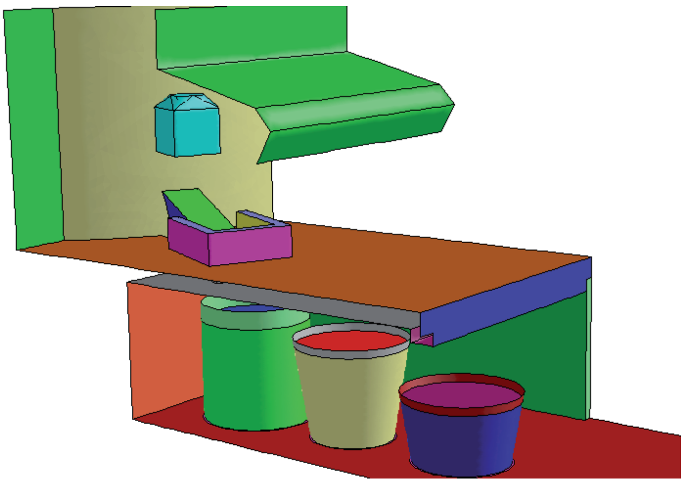

Figure 3: Modelled geometry

Based on infrared pictures, the temperatures of the different surfaces have been assessed (Table 1).

Table 1: Temperatures at the main boundaries of the model

Boundary	Temperature (°C)
Liquid surface in the metal ladle	1450
Liquid surface in the slag ladle after metal ladle	1400
Liquid surface in the last slag ladle	1350
Steel shell of the metal ladle	370
Shell of the slag ladles	490
Side walls and ceiling of the ladle pit	180
Side walls of the runner	200
Tapping floor	90
Secondary hood walls outside / inside	90 / 200
Primary hood walls	250

3.2 Dispersion of fumes from melts

Some weightless particles were slipped in the gas from the melt surfaces to visualized the distribution of fumes and gasses emitted by the liquids in the ladles. The model gives a similar spreading of the fumes over the tapping floor to the one observed in reality (Figure 4). Computed temperatures and velocities agree well with measurements from [1]. Consequently, we concluded that the model was validated for the purpose of studying effect on fume collection of different actions. Large amounts of smoke coming between the tapping floor and the runner are not collected by the primary hood. They spread under the secondary hood.

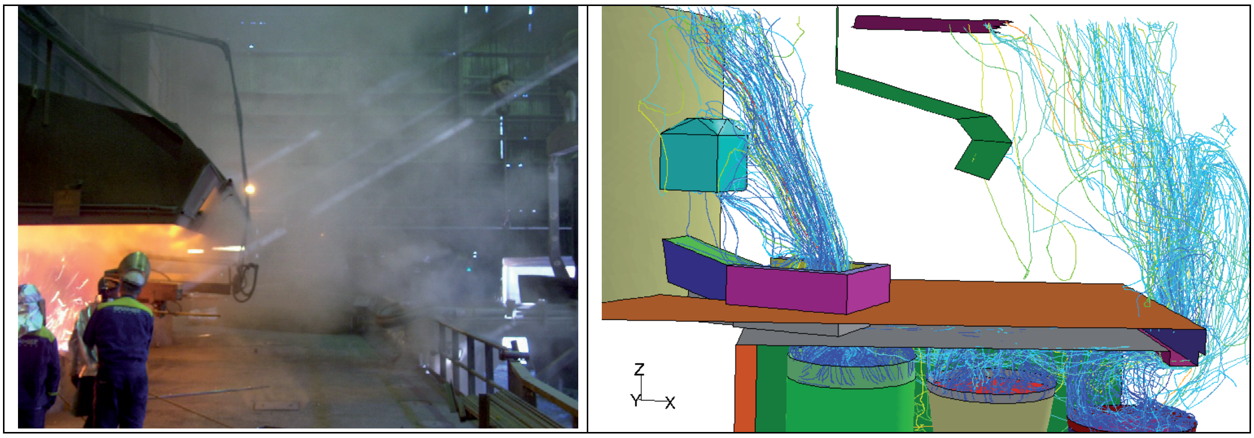

Figure 4: Fume spreading over the tapping floor. Left: picture. Right: simulation.

3.3 Plots of various quantities

Hereafter, we present the velocity vectors, temperature and pressure distribution in the symmetry plan of the ladles. As expected, the heating up of the gases as illustrated in Figure 5, results in a flow field mostly generated at the ladle walls and liquid surfaces (Figure 6). The warming up creates an overpressure under the tapping floor while near the primary hood, there is an expected significant under pressure.

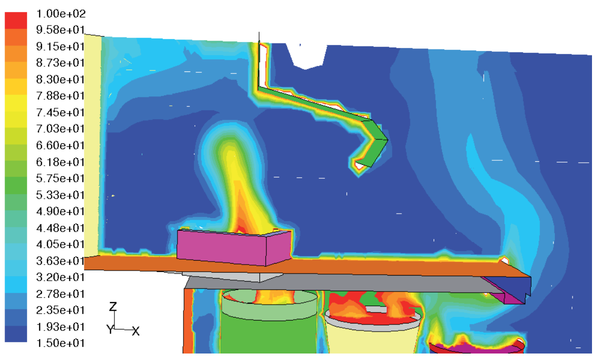

Figure 5: Temperature contour (°C). Transparent zones surrounded by red: over 100°C

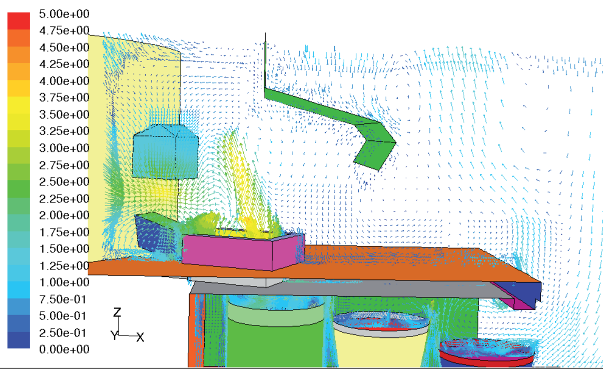

Figure 6: Velocity vectors (m/s)

The model gave satisfactory results when compared to measurements. It was then used to test different design changes.

4 NUMERICAL TESTS

Here is the list of the numerically tested changes using the CFD model described previously.

4.1 Test 1: Central plates

The idea of this test is to reduce the active volume of air under the tapping floor. With a smaller volume, the air sucked by the ventilation points will be more concentrated in fumes and other pollutants. Therefore, the same fan capacity will be able to collect more pollutants. The wall goes all the way to the roof of the tapping pit (Figure 7).

4.2 Test 2: Down ports

Hanging plates from the edge are placed in order to increase the resistance for fumes to leak outwards around the floor, but leaving in opening to drive the ladles in and out (Figure 8).

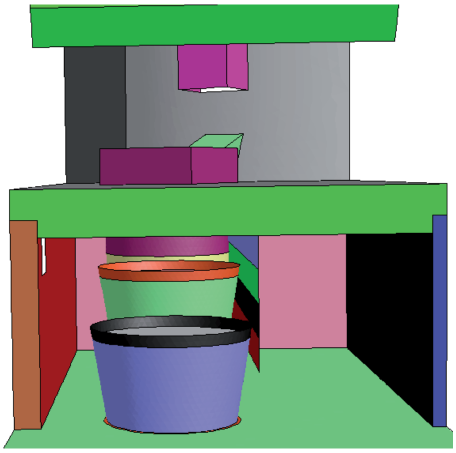

Figure 7: Central wall test

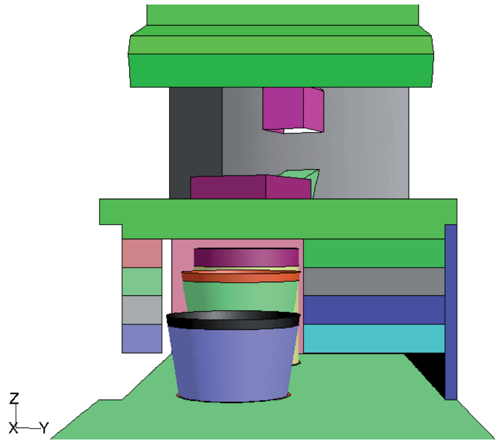

Figure 8: Down port

4.3 Test 3: Leading walls

In this test, it was tried to lead the fumes and gasses outside the region where operators work by placing upwards wall from the edge of the tapping floor. In the meantime, the secondary hood was extended downwards in order to limit the amount of air from the floor to be drawn in the ventilation (Figure 9).

4.4 Test 4: Side ventilation

A 60 x 60 cm^2 ventilation point was tested on the side under the tapping floor, drawing 30 000 Nm^3/h (Figure 10).

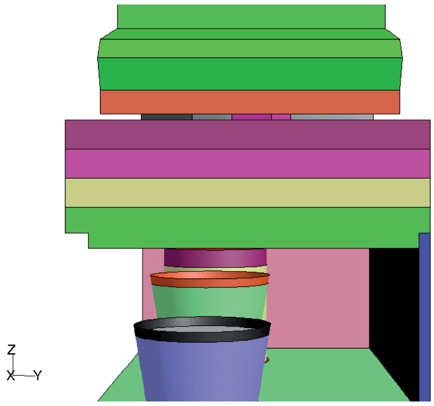

Figure 9: Leading plate test

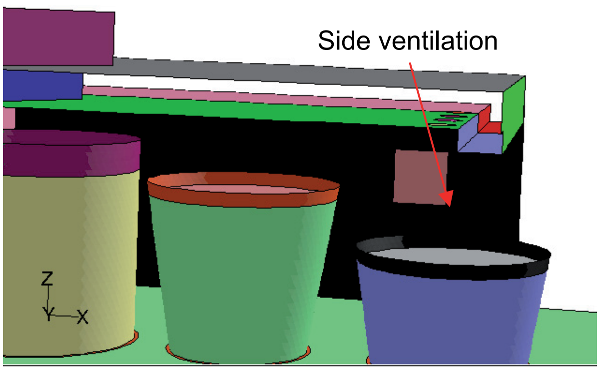

Figure 10: Side ventilation test

4.5 Test 5: Hole ventilation

Four 350 mm diameter holes with a total capacity of 30 000 Nm^3/h were tested (Figure 11).

4.6 Test 6: Increased primary

Currently, one fan's capacity is divided for the central chimney and the ventilation points, 50% each. It should be possible to install a regulation (possibly with a dust detector) that would allow increasing the ratio of the fan dedicated to ventilation of the tapping area when tapping, for example to 70%.

4.7 Test 7: All walls under

This is the combination of central plates (test 1) and down ports (test 2) combined with an additional 1-m wall in the pathway of the ladles (Figure 12).

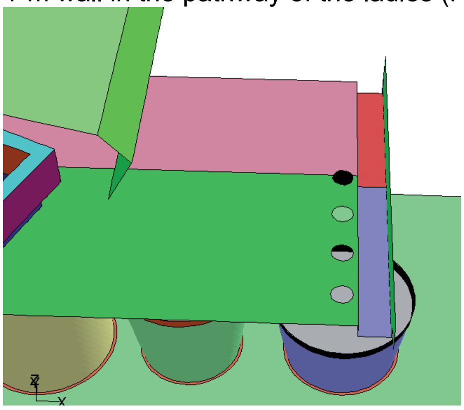

Figure 11: Hole ventilation test

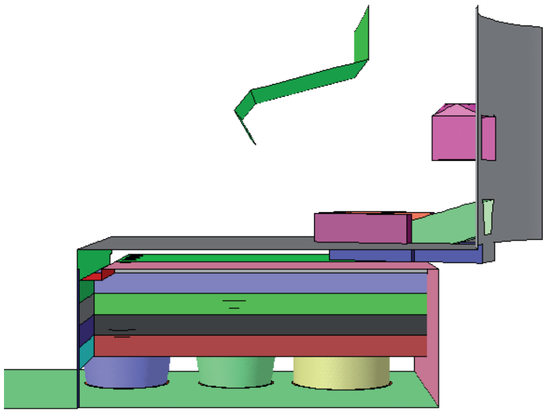

Figure 12: All walls under the tapping floor

4.8 Test 8: Holes and walls

This is the combination of the down ports (test 2) and the holes (test 5).

4.9 Test 9: All fixed walls

All walls under the tapping floor that are not in the way of the path of the ladles are used.

4.10 Test 10: 1m-high wall down

This test corresponds to a 1m-high vertical wall going down at the end of the tapping floor

4.11 Test 11: 0.5m-high down wall design

Similar to the previous test but the wall is 0.5m high instead of 1 m.

5 NUMERICAL RESULTS

In order to assess the impact of the changes on the collection of fumes, dispersion of fumes from the melts was tracked and the proportion of the fumes collected by ventilation points (on total fume emitted) was calculated. The results are presented in Table 2. Good results are obtained by adding ventilation points under the tapping floor either as a side ventilation (test 4) or by using holes in the floor (test 5). Using a 1m-high wall in front on the outside gives similar good results (test 10) however 0.5m is too short (test 11). This solution should be less costly. Best results are obtained by combining down walls and ventilation (test 8).

Table 2: Proportion (% of total) of fumes collected by the various ventilation points. Note: uniform production of fumes by all melts

Test #	Test case	Collected fumes (%)
	Reference case	43
1	Central wall	62
2	Down ports	69
3	Leading walls	40
4	Side ventilation	91
5	Hole ventilation	95
6	Increased primary	47
7	All walls under	89
8	Holes and walls	97
9	All fixed walls	61
10	1m-high wall down	93
11	0.5-m high wall down	56

6 INDUSTRIAL TESTS

The model gave a classification on the potential of the possible solutions. The least costly and most practical to test solutions were first tested: use of additional walls (or in the form of curtains). In addition, the idea to direct the smoke coming between the runner and the tapping floor was also tested. The motivation is to limit the amount of smoke escaping the primary and polluting the tapping area (though part of it is taken by the secondary hood).

A heat resistant curtain was installed on the outside of the tapping floor that confirmed the good effect observed for previous similar tests. Tests were first performed with a 1 m long curtain and showed good results (Figure 13). Further tests using a 0.5 m long curtain showed large leakages. This is in agreement with the results from the modeling and validates further the model. This curtain was combined with a plate covering most of the area over the runner (Figure 14).

Figure 13: Curtain outside tapping floor

Figure 14: Plate used over the runner

This system makes it possible to collect and direct the large amounts of fumes that flow between the runner and the floor towards the primary hood (Figure 15). This contributes to both a significant improvement of work environment for the tapping operators and reduces the fugitive emissions.

Figure 15: Usual tapping (left) and tapping using a leading plate (right)

The full implementation of the solutions is on going and is facing practical challenges connected to the exposure to heat and slag projection of the materials used to build the permanent solutions.

7 CONCLUSION

An approach combining measurements on site, numerical modeling and industrial tests was used to improve the environment in the tapping area of a ferromanganese furnace. Many possible improvements have been tested numerically with a Computational Fluid Dynamics and their potentials have been characterized. Based on these results, first industrial tests were performed. A 1m-high curtain or wall hanging at the outside of the tapping floor reduces significantly the amount of smoke and SO_2 coming in the working environment of the tapping workers. This has been confirmed through industrial tests. A plate leading the smoke flowing between the runner and the floor towards the primary hood further improves the work environment and limits the fugitive emissions.

To improve the working environment, ventilated booths from where the operators can carry out most of the work tasks have been implemented. The next step is a full automation of the tapping process which is currently being assessed.

8 AKNOWLEDGEMENTS

The authors are thankful to the Research Council of Norway and the Norwegian Ferroalloy Producers Research Association for their financial support of the measuring campaign.

9 REFERENCES

[1] Grådahl, S. and Wittgens, B., "Measurement campaign Eramet Porsgrunn with focus on emission in the tapping area", SINTEF report STF80MK F07142, 2007 (In Norwegian).

[2] Saridikmen, H., Kucukkaragoz C.S., Eric R.H., "Sulphur behaviour in ferromanganese smelting", Proceedings Infacon XI, 2007, pp.311-320