

MAJOR FERROALLOY PRODUCER IMPROVES FURNACE FUME CONTROL SYSTEM BY INSTALLING BAGHOUSE WITH MEMBRANE FILTER BAGS

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ABSTRACT

Chelyabinsk Electrometallurgical Kombinant (ChEMK) replaced the existing wet scrubbing system at their Chelyabinsk plant with a dry system using a baghouse filter.

The objectives of the new ventilation system are as follows:

- *Capture the fume and heat evolved in the furnace hooding effectively*
- *Filter the particulate from the gas stream and minimize emissions to the atmosphere*
- *Minimize energy usage and maintenance expenses*

The paper explains the methods used to achieve these objectives.

Previously, Furnaces 45 to 48 were partially enclosed with the central feed area of each furnace venting to a stack, while the outer section of the furnace was enclosed and extracted by a scrubber. New gas cleaning systems were installed at furnaces 45 to 48 to ensure adequate extraction from the furnaces and eliminate atmospheric emissions.

Prior to system design field testing was performed and an off gas model was developed to predict heat generation under future conditions with various combinations of reducing agents. The model predicts the gas temperature rise through the hood based on the gas flow drawn into the furnace hood. The ratio of heat in the furnace off gas to the furnace power input is developed based on the charge mix constituents.

The hood volume was selected as the most appropriate to minimize the baghouse size, but still provide a high enough hood face velocity to keep the fume inside the hood. Various gas cooling methods were evaluated with a radiant/convective (trombone) cooler being selected so the outlet gas temperature does not exceed the limitations of the downstream equipment and filter bags.

The baghouse type and filter media were selected to maximize the filter velocity while assuring long bag life and minimizing operating maintenance expenses. The filter media was selected based on improved cleaning ability of membrane filter media and to minimize system energy consumption and to particulate emissions.

Operating field results are reported.

1 INTRODUCTION

Chelyabinsk Elektrometallurgical Integrated Plant (ChEMK), located in Chelyabinsk, Russia, operates eight submerged arc Ferrosilicon (FeSi) furnaces, numbered 41 to 48, at Melt Shop 7. The furnaces are rated between 23 and 27.6MVA.

Previously furnaces 45 to 48 were partially enclosed, with the central feed area of each furnace venting to a stack, while the outer section of the furnace was enclosed and extracted by a scrubber. New gas cleaning systems are to be installed at furnaces 45 to 48 to ensure adequate extraction from the furnaces and eliminate atmospheric emissions.

2 ORIGINAL LAYOUT & TEST RESULTS

Furnaces 45 to 48 are partially enclosed: the central feed area of the furnace vents to a stack, while the outer section of the furnace is enclosed and extracted by a scrubber.

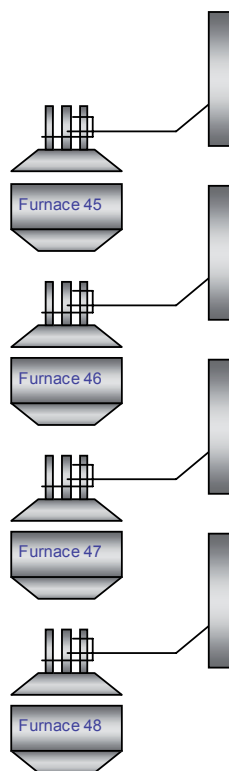


Figure 1: Furnace Gas Handling Layout

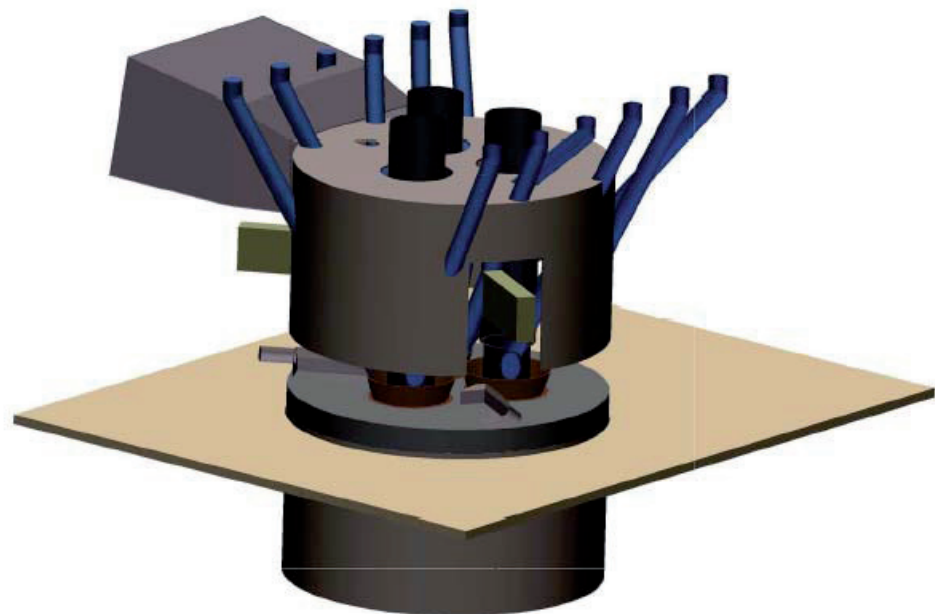


Figure 2: Furnace & Hood Isometric (July 2007)

Test results are summarized in the table below.

Table 1: Summary of test results

Parameter	Unit	Furnace 45	Furnace 46	Furnace 47	Furnace 48
		Stack	Stack	Stack	Stack
Gas Temperature	°C	81	67	71	68
Gas Volumetric flow	Actual m ³ /h	350975	194355	274399	219673
	Normal m ³ /h	260665	150169	207424	168688

3 APC SYSTEM DESIGN METHODOLOGY

3.1 Furnace Reaction Gas Modelling

In the past, off-gas system sizing was done using Specific Extraction (SE) data, which states extraction (Nm³/h) per furnace energy input (kW), i.e. Nm³/h/kW. Specific extraction was benchmarked by visually checking if a furnace is adequately ventilated and then extrapolating the SE value to other plants and industries. Design SE values were for example compared for various Samancor plants by Wall [1]. Rentz [2] did extensive work on reducing emissions from Ferroalloy furnaces and helped establish required SE values for various feed material preparation regimes.

A more sophisticated method of sizing baghouse equipment is based on furnace heat extraction requirements – sometimes referred to as the “X” factor. According to this method, the heat content of

the submerged arc furnace exhaust gas is directly proportional to the furnace load (influenced by the amount and type of raw materials and furnace operation). The ratio of Exhaust Gas Heat to Furnace Power input yields the "X" factor. A typical X factor for 75% is 1.1.

In response to problems with above methods in adequately estimating the effect of various process and operational factors on design of APC systems, a more thoroughly process-based method was developed. This method was also discussed in a previous paper [3].

Furnace reaction gas modeling is done in two steps: furnace reaction gas is estimated by doing a carbon balance over the furnace, where after the reaction gas is combusted and diluted with ambient air. Varying amounts of dilution air are used to calculate off-gas temperatures at the furnace and baghouse inlet. Heat loss at the furnace ducting and trombone cooler is calculated to determine the baghouse inlet gas temperature and volume flow based on off-gas volumes and temperatures calculated with the above carbon mass balance. A standard trombone cooler design procedure was used, as proposed in the EPA's Air Pollution Engineering Manual [4]. The calculation model makes use of correlations by Sieder and Tate [5] for convection heat transfer on the trombone cooler tube inside, McAdams[6] for radiation heat transfer and McAdams [6] for convection heat transfer on the trombone cooler tube outside.

3.2 Furnace Operating Base Data

The four furnaces were to be upgraded to produce 75% ferrosilicon (FeSi) at a maximum energy input of 27.5MW, with an increased diameter of 9.75m. The furnace hoods were to be enclosed and water-cooled. Gas cleaning system design was to cater for use of a very high volatile coal as reductant (~40% volatiles).

4 EQUIPMENT SELECTION CRITERIA

In selecting off-gas equipment for this application, the following factors had to be taken into consideration:

➤ Preferred gas cleaning device.

The furnace hood design dictated that dry filtration (a baghouse) is preferred above gas scrubbing. The type of filter or baghouse had to be determined – reverse pulse or reverse air cleaning.

➤ Requirement for gas cooling equipment.

The amount of cooling required was assessed, whether the baghouse off-gas duct can provide sufficient cooling, or if additional cooling of gas prior to filtration is required.

➤ Selection of gas cooling equipment.

If cooling is required, a number of options exist for ensuring a baghouse inlet temperature within allowable limits for filtration:

- Dilution cooling. Bleeding in ambient air prior to the baghouse results in huge filtration capacity requirement, which is not cost-effective.
- Evaporative cooling. Cooling of gas with water injection to temperatures lower than 500°C is not recommended when gas cleaning is done with a baghouse. Drawbacks of evaporative cooling include high maintenance with frequent spray nozzle blockages, filter bag blockages and rat-holing (build-up of wet material in thimbles).
- Convection cooling. Convection cooling is the method most often used in the ferroalloy industry. Two equipment options exist for convection cooling: a trombone cooler or a forced draft (FD) cooler. A trombone cooler uses 8 to 20 larger tubes with natural convection cooling, while a forced draft cooler uses many more tubes (>100) with fans blowing across the tubes to force cooling.

4.1 Baghouse type selection: Reverse Air vs. Reverse Pulse filters

Fabric filters are generally classified according to the method of cleaning, with the most common types being reverse air and reverse pulse.

Reverse air baghouses have the gentlest cleaning method: a compartment is isolated and cleaned hot gas is sucked through the bags in the direction opposite to normal flow to collapse the bag and dislodge the particulate layer. Reverse pulse baghouses clean by introducing a high pressure pulse of compressed air into the bag, causing a sudden bag expansion and dust is removed primarily by inertial forces when the bag reaches its maximum expansion.

Table 2: A comparison of baghouse design type

Aspect	Reverse air	Reverse pulse
Bag length	Increased length (~10m)	Shorter length (~3-4m, some designs allow longer bags)
Filter velocity	Lower velocity (~0.6m/min)	Higher velocity (~1.0m/min)
Cleaning system	Uncomplicated, dampers & fan	More complicated: many pulse valves
On / off-line cleaning	Off-line cleaning required due to cleaning system mechanism	Off-line cleaning recommended for fume
Bag life	~4 to 8 years	~2 years Longer bags: bag abrasion, cleaning intensity
Cleaning intensity	Can be regulated using "smart cleaning"	Can be regulated using pulse on demand
Maintenance cost	Lower: longer bag life, limited cleaning system maintenance	Higher: shorter bag life, pulse valve maintenance
Installed cost	Lower for larger filters	Higher for large filters if bag length limited to <4m

4.2 Gas Cooling Equipment

A number of options exist for ensuring a baghouse inlet temperature within allowable limits for filtration. As discussed above, convective cooling is preferred above dilution or evaporative cooling. The two options for convection cooling are compared below: trombone vs. forced draft (FD) cooler.

Table 3: Comparison of Trombone and FD coolers

Parameter	Trombone cooler	FD cooler
Temperature control	No temperature control, but temperature fluctuations are equalized out naturally due to increased / decreased mean temperature difference. Baghouse inlet temperature easily kept below maximum bag operating temperature, but low temperatures can result.	Precise temperature control. Generally used on applications where acid dew point and corrosion is a problem. Temperature can be controlled to a set value (e.g. 240°C) by switching on / off additional fans.
Leakage	Fewer tubes, thermal expansion handled by u-tube design and use of floating supports. Consequently less in-leakage	More prone to leakage, as more tubes have to be sealed onto headers. On higher temperature applications (inlet temperature >300°C), thermal expansion can cause a lot of sealing problems of tubes onto headers and consequent leakage
Blockage	Less prone to blockage, as distribution of gas into fewer tubes is easier and tubes are larger (500-1000mm)	More prone to blockage at header (distribution to many tubes, low velocity areas) and smaller tubes (50-250mm)
Size	Large and bulky. Generally preferred where open area is available.	Compact. Generally preferred where space is very limited.
Energy consumption	No additional energy required, natural convection.	Forced draft fans with a capacity of 5 to 10 times the process gas flow are required for effective temperature control at cooler inlet temperatures >300°C. Forced draft fan power consumption can be equal to or more than consumption at the main fans.

4.3 Filter Media Selection

4.3.1 Fiber Selection

When selecting a fiber for gas filtration, attention must be paid to the factors shown in Table 4.

Table 4: Selection of a fiber for gas filtration.

Aspect	Process requirement	Fabric suitability
Temperature	High temperature filtration reduces the size of baghouse / cooler required	Polyester / polypropylene not practical (<120°C) Nomex operating limitation is 180°C Teflon and glass fiber can operate at higher temperatures (~250°C)
Spark resistance	Process sparks generated results in bag loss on existing baghouse	Nomex not resistant; Teflon higher resistance Glass fiber very resistant
Corrosiveness	No corrosive gases present	All suitable
Hydrolysis	Low process gas moisture content; evaporative cooling not included in gas cleaning system	All suitable, no hydrolysis potential
Dimensional stability	Depends on baghouse type / cleaning mechanism	Nomex not suitable for reverse air baghouse (stretching) Glass fiber stability good in reverse air baghouse
Cost	Optimized solution required between baghouse capital investment and bag cost	Teflon very expensive, glass fiber more economical

Fiberglass material is known to have many advantages [7]:

- Non combustible because it is completely inorganic
- Zero moisture absorption; therefore, it is not subject to hydrolysis
- Dimensional stability (low coefficient of linear expansion)
- Very high strength but poor resistance to flex and abrasion; however, there are chemical surface treatments that improve the flex and abrasion characteristics of fiberglass
- Woven fiberglass can operate continuously up to 260°C and depending on the surface treatment withstand up to 288°C for short periods.

Based on the above, glass fiber was selected as the appropriate material.

4.3.2 Conventional vs. Membrane

Person [8] has explained the relatively high filter drag of conventional woven fiberglass material when applied to metallurgical fume. Additionally, one could reasonably expect higher particulate emissions through the conventional fiberglass filter media since the filter cake must be sacrificed to maintain airflow. While aramid material (good to 204°C) in shaker cleaning applications shows lower filter drag than woven fiberglass material, there is limited experience with aramid in ferroalloy baghouses. Furthermore, in the limited cases where aramid had been used in EAF applications, the results have not been encouraging.

Eriksen [9] and Stordahl [10] reported that GORE[®] membrane/fiberglass filter media has substantially lower filter drag than conventional media in metallurgical fume applications. Previous work by Hall, et al¹⁰ demonstrated the improved filtration efficiency of GORE[®] membrane filter bags in a steel EAF application at British Steel when compared to the results with various woven synthetic filter media at the same installation.

Table 5: A comparison of conventional vs. membrane filtration

Aspect	Conventional	Membrane
Efficiency	Penetration of particulate through fabric results in higher average emissions (guarantees <math><25\text{mg}/\text{Nm}^3</math> may be difficult)	Surface filtration can lower emissions to $3\text{mg}/\text{Nm}^3$
Pressure drop	Depth filtration entails high pressure drop, as filtration done by dust cake with lower permeability	Membrane has higher permeability, surface filtration therefore has lower pressure drop for similar flow rate
Baghouse sizing	Typical reverse air filter velocity of $0.40\text{m}/\text{min}$	Typical reverse air filter velocity of $0.65\text{m}/\text{min}$ Filter velocities of 20 to 40% higher can be specified for membrane bags, resulting in a smaller filter at lower capital cost
Ease of cleaning	More difficult to clean, part of dust cake always remains on fabric to achieve filtration	Non-stick PTFE membrane gives good release characteristics, results in less cleaning required and longer bag life
Bag life	Guarantee levels of 2 to 4 years can be achieved, depending on filter cleaning type (reverse air / pulse) and filter velocity.	Bag life can be longer, due to less abrasion by particle penetration into filter fabric.

4.3.3 Evaluation

In selecting off-gas equipment for this application, the following factors have to be taken into consideration:

➤ **Preferred gas cleaning device.**

A large number of reverse air baghouses are installed in the ferroalloy industry. Operating experience has shown that well-designed reverse air baghouses are both rugged and reliable. In terms of costing, reverse pulse baghouses are less costly for smaller units, but reverse air baghouses are more cost-effective for large filters ($>180\ 000\text{m}^3/\text{h}$). Reverse air is therefore preferred above reverse pulse.

➤ **Selection of gas cooling equipment.**

The effect of incorporating a cooler into the design is demonstrated in the chart below.

Off-gas Modelling Results: Furnace 47 - Cooler vs Off-gas duct only Comparison
75% FeSi 27.5MW, X=1.41

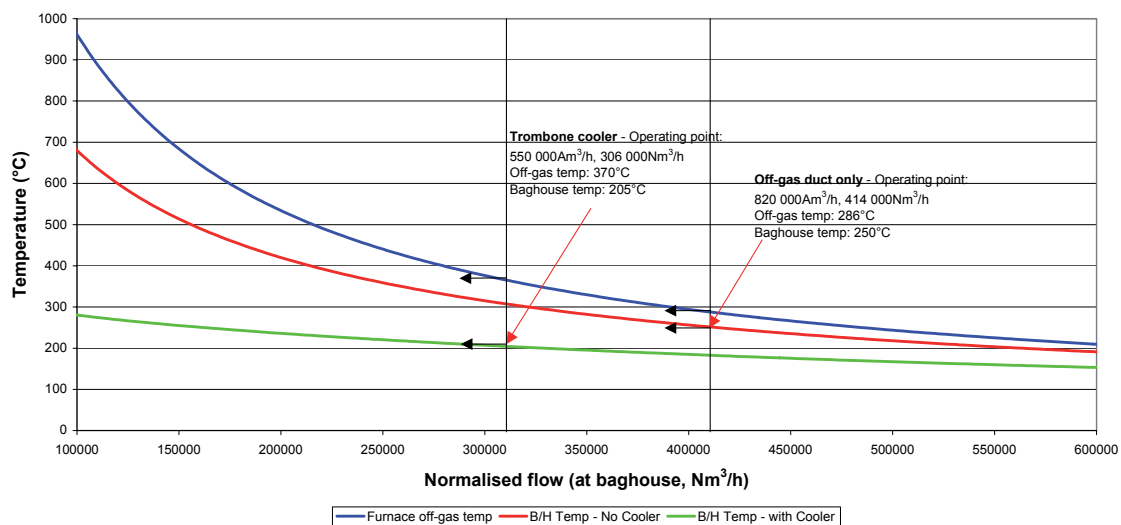


Figure 3: Comparison of Operating points – with / without Cooler

A cooler reduces the required baghouse capacity from 820 000 to 550 000 Am³/h. The baghouse inlet temperature is also reduced from 250 to 205°C. At the new operating point, the furnace off-gas temperature is the limiting factor over baghouse inlet temperature.

A trombone cooler is preferred over an FD cooler, as precise temperature control is not required, leakage over a large FD cooler can be significant, blockage of an FD cooler can be a factor with the generated silica fume, there is sufficient area available for a trombone cooler, FD cooler power consumption would be very high and maintenance of a large trombone cooler is not substantial.

In conclusion, a suction-type reverse air baghouse was preferred, with membrane-type fiber glass bags and a trombone cooler.

5 GAS CLEANING SYSTEM DESIGN

Off-gas modeling was done for furnace 47 operating data, as the energy input, feed rates and reductant composition indicated this to be the worst case of the four furnaces. For simplicity of installation and maintenance and as all four furnaces have similar future operating conditions, the resulting design could be installed at all four furnaces.

5.1 Layout

The gas cleaning system at each of the four furnaces is illustrated below.

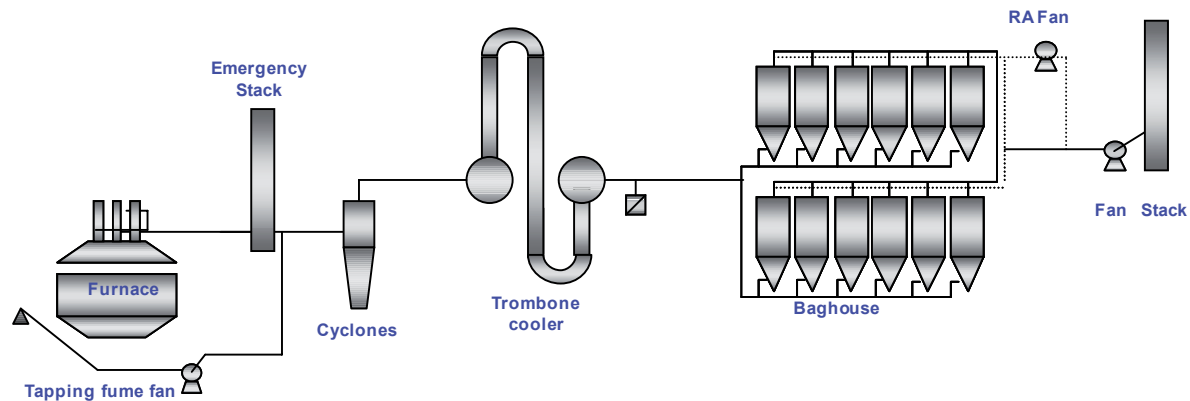


Figure 4: Gas cleaning system layout – Furnaces 45 to 48

A brief description of the gas cleaning system at each furnace is:

- Each furnace hood is extracted via an off-gas duct to a set of cyclones (6-off at each gas cleaning system), where coarse particles and sparks are captured.
- A tapping fume fan serves to extract fumes generated at the furnace taphole. The tie-in point is just after the emergency stack.
- Gas is cooled in a trombone cooler to a temperature suitable for the baghouse.
- The baghouse comprising 12 compartments serves to remove particulate from the gas stream.
- A fan after the baghouse propels gas through the system, followed by a stack to ensure adequate gas dispersion.

The baghouse compartments are cleaned by a reverse air fan, which extracts gas from the main fan inlet and reverses air flow through one compartment.

5.2 Modelling Results

Results of modelling calculations are summarised below. Modelling was done for two conditions: with and without a tapping fume fan in operation. It was assumed that the tapping fume flow is inserted into the off-gas system close to the furnace hood, as this is the most practical position.

5.2.1 Operating Profile with tapping fume

A tapping fume volume of 69 000 Am³/h (56 000 Nm³/h) was used. The results are summarised in the operating profile graph below:

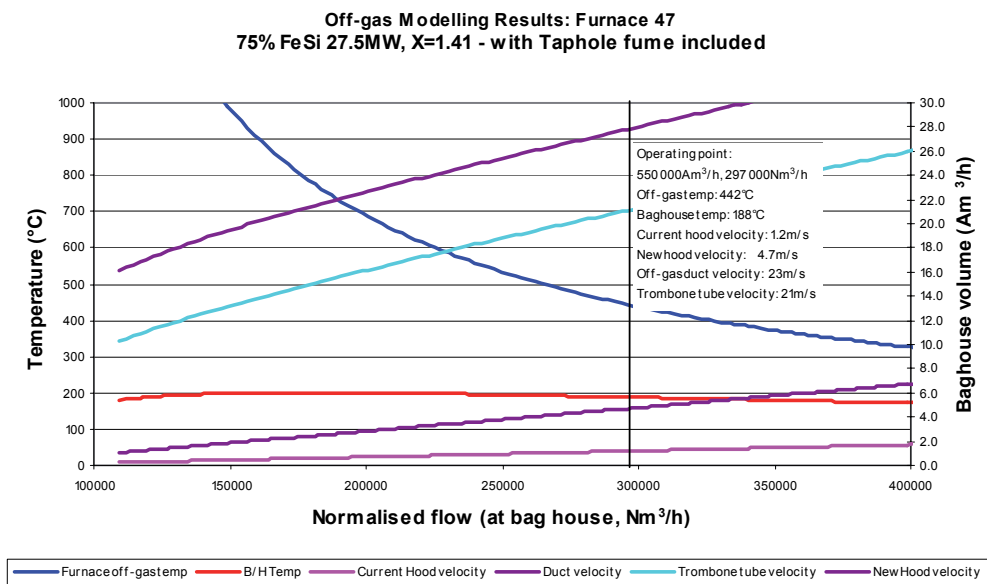


Figure 5: Operating profile with tapping fume

Conclusions from the above figure are:

- The calculated X-factor, or ratio of off-gas energy to electrical energy input, is 1.41.
- The baghouse design volume is 550 000Am³/h.
- The furnace specific extraction is 8.7 Nm³/h/kW, with a predicted furnace hood temperature of 442°C, a trombone cooler outlet temperature of 212°C and a baghouse inlet temperature of 188°C.
- The current hood in-draught velocity is 1.2m/s with tapping fume in operation. This is low, as an average of 2m/s is preferable for a well-balanced hood.
- The new hood in-draught velocity is 4.7m/s, which will result in very good fume extraction.

5.2.2 Operating Profile without tapping fume

The results are summarised in the operating profile graph below:

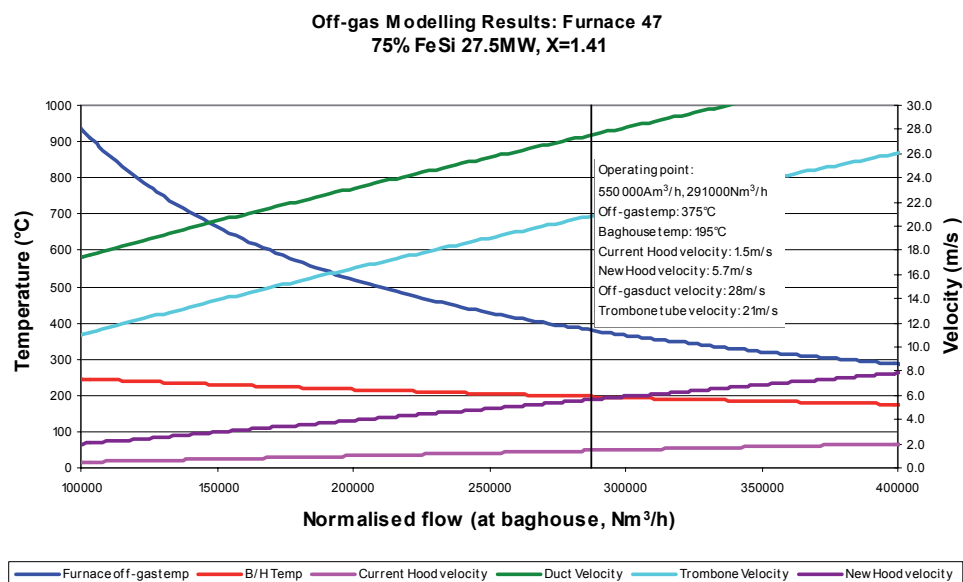


Figure 6: Operating profile without tapping fume

Conclusions from the above figure are:

- The furnace specific extraction is 10.6 Nm³/h/kW, with a predicted furnace hood temperature of 375°C and, as no tapping fume is incorporated, a trombone cooler outlet temperature of 216°C and a baghouse inlet temperature of 195°C.
- The current hood in-draught velocity is 1.5m/s with tapping fume in operation. As before, this is low – an average of 2m/s is preferable for a well-balanced hood.
- The new hood in-draught velocity is 5.7m/s, which will result in very good fume extraction.

5.3 Design Parameters

Table 6: Trombone cooler and baghouse parameters.

Parameter	Unit	Design	Parameter	Unit	Design
Number of Tubes		16	Baghouse volumetric flow	Am ³ /h	550 000
Outside diameter	mm	820	Compartments		12
Length per tube	m	135	Gross filter area	m ²	13,213
Total area	m ²	5 564	Gross air/cloth ratio	m/min	0.69
			Reverse air flow	Am ³ /h	56 156

6 OPERATIONAL EXPERIENCE

The first baghouse was commissioned during July of 2009, with the other three following thereafter. Due to economic factors, the furnace conversion was yet to be completed at the time of commissioning and the furnace was producing silicomanganese and the old open hood and scrubbers were still in operation. In order to optimize fume extraction efficiency from the hood in the interim period, furnace doors were proposed. Computational fluid dynamics (CFD) work was done to illustrate effectiveness of the doors.

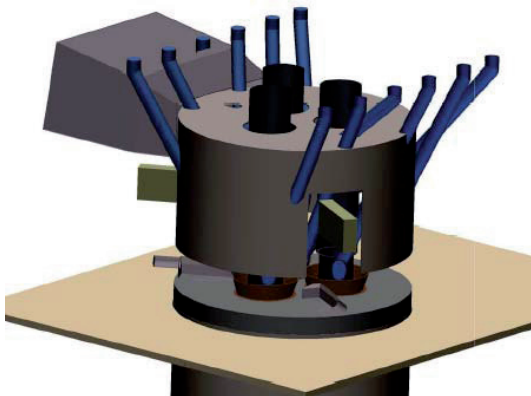


Figure 7: Original hood design

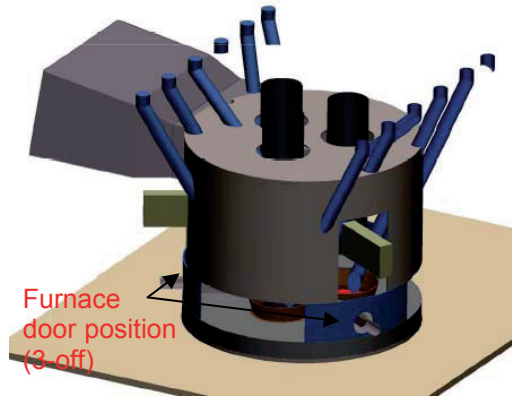


Figure 8: Furnace doors

The results of modeling work are shown below:

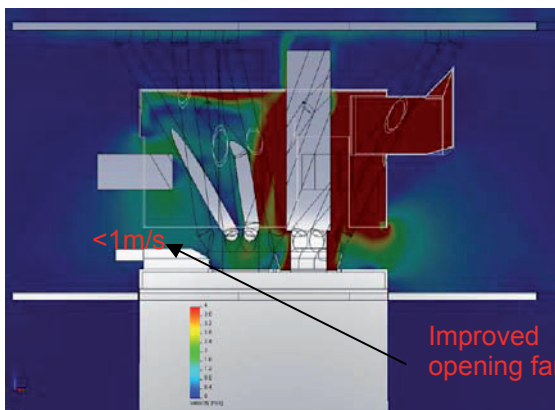


Figure 9: Original hood elevation view velocity

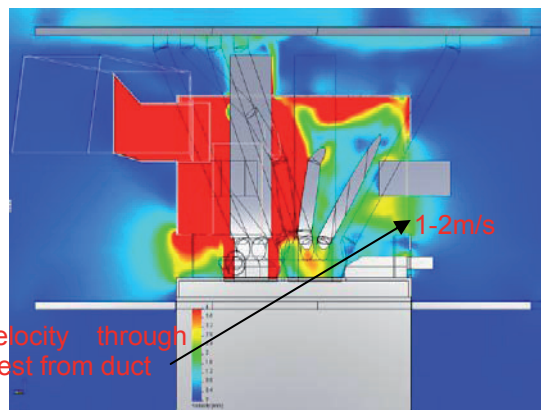


Figure 10: Modified hood elevation velocity

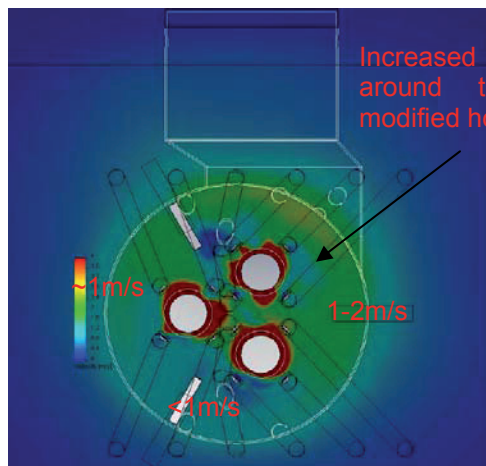


Figure 11: Original hood plan view velocity

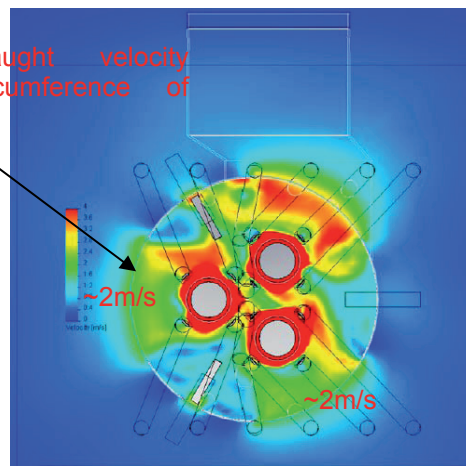


Figure 12: Modified hood plan view velocity

Tests done at furnace 45 gas cleaning system indicated that the baghouse was coping with ease with the furnace generated off-gas.

Table 7: Test results.

Parameter	Unit	Value	Parameter	Unit	Value
Off-gas Temperature	°C	80	Baghouse volumetric flow	Am ³ /h	412 200
Differential pressure	kPa	Max 1.6		Nm ³ /h	367 700

7 CONCLUSIONS

Several techniques were used in the design of the four new gas cleaning systems at ChEMK:

- Off-gas modeling determined that the future maximum energy to the gas cleaning system would be more than 30% higher than what conventional benchmarking parameters indicate. A design using benchmark parameters would therefore ultimately have resulted in overheating of the gas cleaning system and fume spillage at the hood.
- The combination of filtration capacity, fan capacity and cooler capacity could be optimized using off-gas modeling.
- A trombone cooler and high temperature fiber glass bags were used to limit the amount of dilution air required and thereby reduces baghouse size.
- Membrane-type bags were implemented to further reduce the baghouse size. The gross filter velocity could be increased from 0.45 to over 0.65m/min, resulting in a reduction in the equipment capital cost.
- CFD modeling was used to illustrate effective intermediate measures for improvement of hood fume capture.

Overall, environmental conditions were significantly improved by installation of the new gas cleaning equipment.

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