Measurement of Pot Gas Exhaust Flowrate and Heat Loss

Vinko Potocnik[1], **Rawa Ba Raheem**[2] **and Abdalla Alzarooni**[3]
1. Consultant
2. Lead Engineer, Process Control, Reduction
3. Vice President, Technology Development & Transfer
Emirates Global Aluminium ("EGA")
Corresponding author: vinko.potocnik@sympatico.ca

Abstract

Pot duct exhaust flowrate is an important parameter in the control of pot emissions and pot heat balance. The exhaust flowrate must be sufficient to create large enough under-pressure in all areas under the hood to prevent the escape of under-hood gases to the potroom in regular operation as well as during anode changing and tapping. The exhaust gas temperature must also be acceptably low for the scrubbers. Pot exhaust rates and temperature are measured at regular intervals to confirm compliance with these requirements. The exhaust rates are determined from gas velocity measurements in the duct using Pitot tube at a certain number of traverse points across the duct diameter, which should follow international standards, such as ISO 3966:2008. In practice, to save time, the number of traverse points is most often fewer than required by standards, which depend on flow disturbances at the measurement location caused by nearby flow control damper and duct bends. In this paper, the measurements of duct flowrate according to the ISO 3966:2008 standard are compared with abridged ones used for regular flowrate control and the duct heat loss is determined as a function of duct flowrate in DX Technology pots, operating in Potline 8 at DUBAL – an operating subsidiary of Emirates Global Aluminium ("EGA").

Keywords: Aluminium electrolysis pot exhaust; measurement of duct gas velocities; ISO 3966:2008 standard; heat loss through pot gas exhaust duct.

1. Introduction

The main purpose of pot hooding and gas extraction is to capture cell emissions and reduce fugitive emissions into the potroom. The minimum gas flowrate required is that which allows no gas leakage from the pot to the potroom during steady operation with all hoods closed and also during pot operations, such as anode change, tapping and anode dressing, in which pot doors or hoods are open. Pots are usually designed for increased suction during these operations. Pot suction has to provide under-pressure in all under-hood volume, which is the most difficult to achieve at the top of the under-hood space at the exit of anode rods from the hood since buoyancy lifts the air to the top of the volume. This difficulty increases when anode cover is thin as there is more heat lost from the anodes, which provides more buoyancy.

The second role of pot gas flowrate is to take away the heat lost through the anodes and generated inside the hood. It is generally assumed that the heat loss through the duct is proportional to the gas flowrate and that this can be used for pot heat balance control. This is why the duct gas flowrate is measured regularly. In [1] it was shown that in the particular case studied, 74 % of cell heat loss from the anode assembly was taken out through the gas duct. With increased gas flowrate, the calculated heat loss increased at the rate of 21 kW/(1 000 Nm³/h) in the range of 2 000 Nm³/h to 7 500 Nm³/h in [1]. Similarly, in another case, the measured heat loss increased at the same rate of 21 kW/(1 000 Nm³/h) in the measurement range of 2 000 Nm³/h to 6 000 Nm³/h in 170 kA pots [2]. This result is not applicable to the high amperage cells analysed in this paper with a gas flow range from 7 000 Nm³/h to 16 000 Nm³/h, which was substantially outside the range in [1, 2]. In this paper the measurements gave a heat loss increase of 11 kW/(1 000 Nm³/h) in Potline 8 DX Technology pots for the gas flowrate of 7 000 Nm³/h to 16 000 Nm³/h.

The third role of gas flowrate is to lower exhaust gas temperature to a maximum of 140 °C to 145 °C, which is limited by the Gas Treatment Centre (“GTC”). If the duct gas temperature is higher, some means of gas cooling between the pots and GTC has to be installed [3]. In [1], the modeling gave approximately 9 °C/(1 000 Nm³/h) temperature decrease, whereas in [2] the measurement gave 13 °C/(1 000 Nm³/h). In this paper, the measurements gave 4 °C/(1 000 Nm³/h) in Potline 8 DX Technology pots for the gas flowrate in the range of 7 000 Nm³/h to 16 000 Nm³/h.

This paper describes the measurements of the gas exhaust flowrate, duct temperature and duct heat loss in Potline 8 DX Technology pots. The duct flowrate measurements according to the ISO 3966 standard [4] are compared with two simplified methods used in this pot technology.

2. Standards for Gas Flow Measurements in Ducts Using Gas Velocity.

Gas flow in a straight duct is not uniform across the cross-section. The velocity profile is parabolic for laminar flow and rectangular for turbulent flow. The latter is practically flat across most of the cross-section for highly turbulent flows and decreases logarithmically to zero near the wall of the duct. In velocity measurement methods, the flowrate is determined from a certain number of velocity measurements along the diameter of the duct, called duct traverse. The average velocity can be calculated as the algebraic average of these local velocities, if the velocity profile near the wall is taken into account by proper, non-uniform spacing of the traverse points. To this effect, several methods exist and are regulated by international standards in order to guarantee universal applicability of these methods. One of these standards is ISO 3966 [4], which was used in this work.

According to the standards, the minimum number of duct traverse points depends on the distance between the measurement site, and upstream and downstream flow disturbance – as shown in Figure 1.

In pot exhaust ducts, there is an obvious problem – the disturbances upstream and downstream from the measurement site are much closer than required by the standards for a well defined flow profile. In Potline 8 DX Technology pots the damper upstream is about 2 duct diameters away and the duct bend is about 4 diameters away. In DX+ Technology pots, the damper upstream is about 2 duct diameters away and the disturbance downstream about 2 diameters also. This would require 16 traverse points on each diameter and a lot of time for each measurement. A compromise of 8 traverse points was chosen according to ISO 3966 . The relative positions of the traverse points are shown in Figure 2 and the ISO 3966 traverse points are given in Table 1. The measurements were made along two perpendicular diameters, vertical and horizontal. These were compared to the simplified method of 2 traverse points in Potline 8 DX Technology pots; and 5 equally spaced traverse points along vertical diameter only used in another pot technology in DUBAL.

With typical velocities of 14 m/s and duct diameter of 600 mm, which gives Reynolds number of about 350 000, the gas flow in the duct is turbulent and has a flat velocity profile across the diameter if there are no obstructions in the duct. In the wall boundary layer, the velocity decreases from bulk value in a logarithmic way to 0 as per Equation (1).

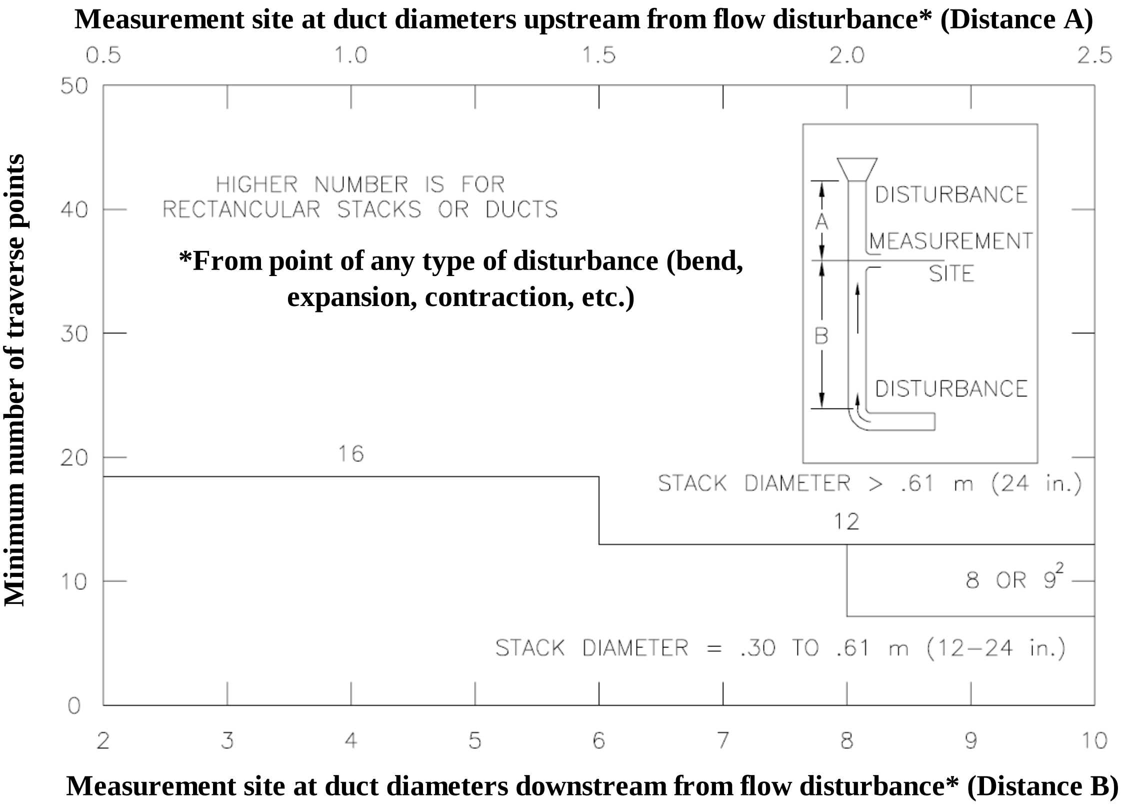

Figure 1. Minimum number of traverse points for velocity (non-particulate) traverses. The number of points is 8 to 16 minimum, depending on distance from measurement site to flow disturbance [5].

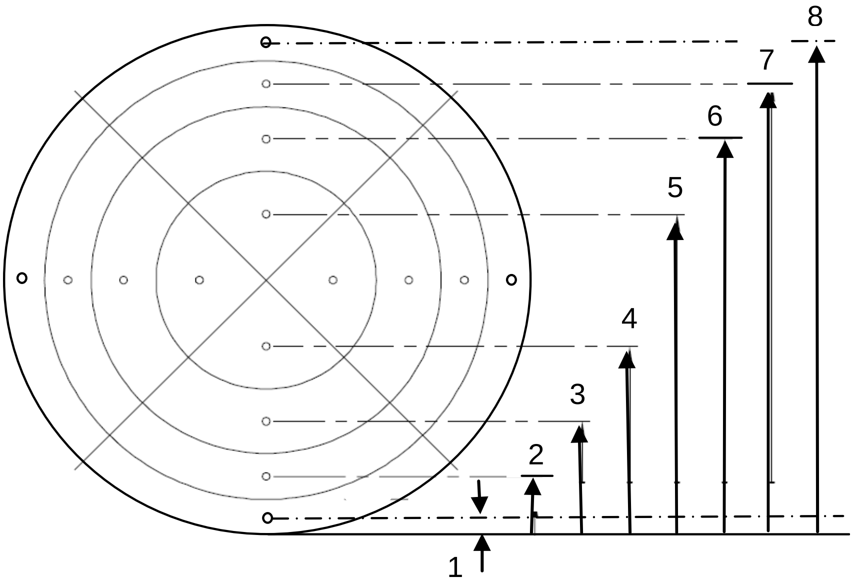

Figure 2. Log-Linear and Log-Tschebyshev positions of 8 velocity points per duct diameter traverse. The distances for each position from inner wall of the duct are given in Table 1 for Log-Linear and in Table 2 for Log-Tschebyshev method.

Table 1. Positions of the velocity traverse points in Log-Linear and Log-Tchebysheff method for 8 traverses on each diameter.

Position	**Log-Linear method: Fraction of the duct diameter from inner wall [5]**	**Log-Tchebysheff method:Fraction of the duct diameter from inner wall [4]**	**Difference between Log-Tschebyshev and Log-Linear (fraction)**
1	0.0210	0.0238	0.0028
2	0.1170	0.1000	-0.0170
3	0.1840	0.1938	0.0098
4	0.3450	0.3343	-0.0107
5	0.6550	0.6657	0.0107
6	0.8160	0.8062	-0.0098
7	0.8830	0.9000	0.0170
8	0.9790	0.9762	-0.0028

$$v = A \log y + C \tag{1}$$

where: v Gas velocity, m/s
y Distance to the duct wall, m
A, C Constants.

This velocity profile is taken into account in two measurement methods, used in ISO 3966:

1) Log-linear method in which by hypothesis, the mathematical form of the velocity distribution law for each element as a function of the distance from the wall is logarithmic in the outermost elements of the section near the wall and linear in the other elements.
2) Log-Tschebyshev method in which by hypothesis the mathematical form of the velocity distribution law as a function of the distance from the wall is logarithmic in the outermost elements of the section near the wall and polynomial in the other elements.

In this work, Log-linear method was used at the beginning and Log-Tschebyshev method later on. The recommendation for the future measurements is to use the latter. As seen in Table 1, the differences between the two are small: for a 600 mm diameter, the maximum difference in position is ± 10.2 mm at positions 2 and 7.

3. Duct Velocity Measurement with Pitot tube

The principle of Pitot tube velocity measurement is explained in Figure 3. The Pitot tube measures local differential pressure and static pressure. The differential pressure is the difference between the total pressure at stagnation point (A+ B) at the orifice of the tube and the static pressure on the side of the tube (A), where velocity pressure is not felt in the holes because velocities are parallel to the hole’s entrance. The velocity pressure or dynamic pressure (B in Figure 3) is

$$\Delta p = \frac{1}{2}\rho v^2 \tag{2}$$

from where Equation (3) is derived:

$$v = \sqrt{\frac{2\Delta p}{\rho}} \tag{3}$$

In Equations (2) and (10):
v = Gas velocity, m/s

Δp = Differential pressure, measured with Pitot tube, Pa
ρ = gas density at duct temperature and pressure, kg/m³

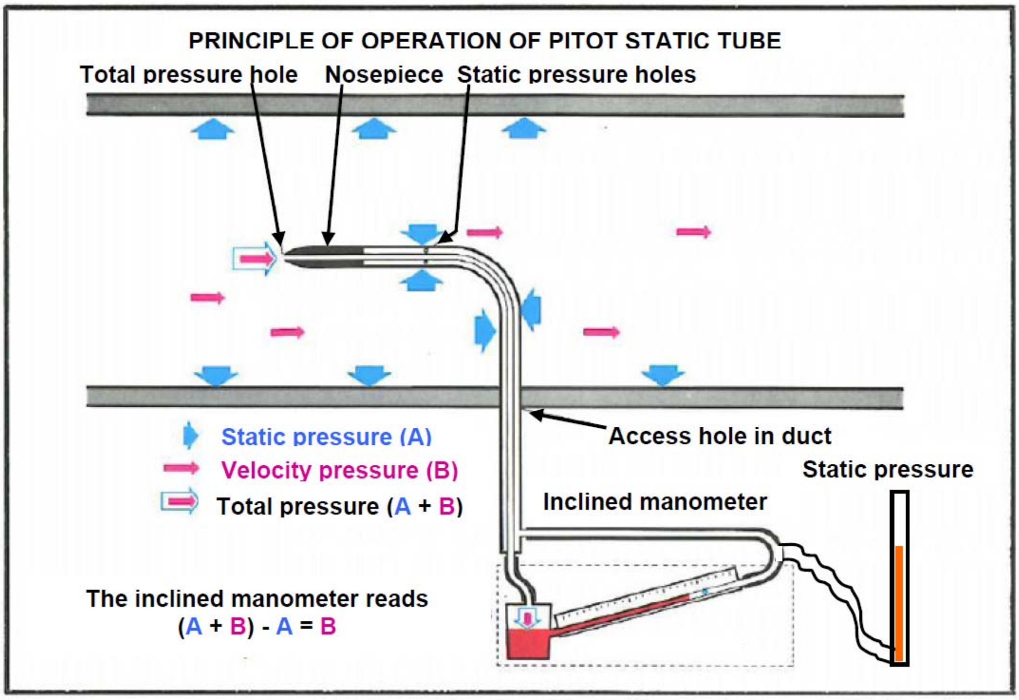

Figure 3. Principle of velocity measurement with Pitot tube (modified from Internet).

The differential pressure is read on the inclined manometer as shown in Figure 3, or on a digital manometer. Both were used in our measurements. The velocity traverse measurements along the duct diameter, discussed in the previous paragraph, are taken by pushing the Pitot tube along the vertical or horizontal diameter to the specified position; then reading the static and differential pressure at each position. The bent portion of the tube must be strictly parallel to the flow and free of dust in the stagnation point orifice. If an unusual reading is seen, the probe must be taken out of the duct and shaken to get rid of any dust particles in the orifice.

For accurate positioning of the Pitot tube in the duct, the positions were marked with respect to outer duct diameter for each position, specified in Table 1.

During the measurements, pot hoods and doors must be closed in the measured pot and in the neighbouring pots. Opening of these would change the flow conditions in the measured duct.

3. Calculation of Duct Flowrate

The duct gas volumetric flowrate is calculated from gas velocity and duct cross-section, with Equation (4):

$$\phi_V = vA \qquad (4)$$

where: ϕ_V Volumetric flowrate, m³/s
A Area of duct cross-section, m²
v Gas velocity, m/s

At EGA, gas flowrate is standardized to normal temperature and pressure, which is 0 °C and 101.325 kPa, according to the ISO 10780:1994 standard. Gas density in the duct, assumed to be air density, can be derived from the density of 1.293 kg/m³ at standard pressure and temperature, Equation (5).

$$\rho = 1.293 \frac{101325 - p_D}{101325} \frac{273}{T_D + 273} \tag{5}$$

where: p_D Static pressure in the duct, Pa
T_D Temperature of the gas in the duct, °C

The normalized gas flowrate is given by Equation (6):

$$\phi_{VN} = \phi_V \frac{p_{\text{actual}}}{p_{\text{standard}}} \frac{T_{\text{standard}}}{T_{\text{actual}}} = \phi_V \frac{101325 - p_D}{101325} \frac{273}{T_D + 273} = \phi_V \frac{\rho}{1.293} \tag{6}$$

Exhaust gasses also carry out a lot of heat coming from the anode cover surface, yokes and anode rods as well as from combustion of carbon and carbon monoxide under the hood. The heat loss through the duct is:

$$Q_D = \phi_m c_p (T_D - T_a) \tag{7}$$

where: Q_D Duct heat loss, kW,
ϕ_m Gas mass flowrate, (kg/s),
c_p Specific heat, J/kgK
T_D Duct gas temperature, °C
T_a Ambient air temperature, °C

Gas mass flowrate is obtained from volume flowrate, which is:

$$\phi_m = \rho \phi_V \tag{8}$$

The same mass flowrate is obtained if standard values or actual duct values of gas density and volumetric flow rates are used.

Ambient air temperature is the temperature of the air entering through the gaps in the pot hoods and doors. It was measured at about 30 cm from the hood at mid-height of the hood at three positions on the upstream and downstream side (centre and quarter points) and at each end of the pot. Then, the length-weighted average of these ambient temperatures was calculated as per Equations (9) and (10),

$$T_a = \frac{L T_{as} + \frac{w}{2} T_{ae}}{L + \frac{w}{2}} \tag{9}$$

where:

$$T_{as} = \frac{T_{1US} + T_{2US} + T_{3US} + T_{1DS} + T_{2DS} + T_{3DS}}{6} \quad \text{and} \quad T_{ae} = \frac{T_{DE} + T_{TE}}{2} \tag{10}$$

where: L Pot length, m
w Pot width,
T Temperature,

Indices: a = ambient, as = ambient on sides, ae = ambient on ends, US = upstream, DS = downstream, 1, 2, 3 are positions on the sides.

For the end ambient temperatures, only half of the pot width was taken because the gaps are essentially only around the pot doors.

4. Measurements and Results

4.1. Duct velocity profiles at normal and increased flowrate

On 19 and 20 June 2013, the measurements were taken at normal flowrate of 9 825 ± 505 Nm³/h (average over 4 pots and 2 successive days ± standard deviation). The minimum and maximum flowrates were 8 841 and 10 385 Nm³/h. The damper position was at 30° in Pot 23 and 45° in pots 30, 32 and 38 with respect to vertical plane. The same measurements were taken on two successive days to observe the day-to-day variation.

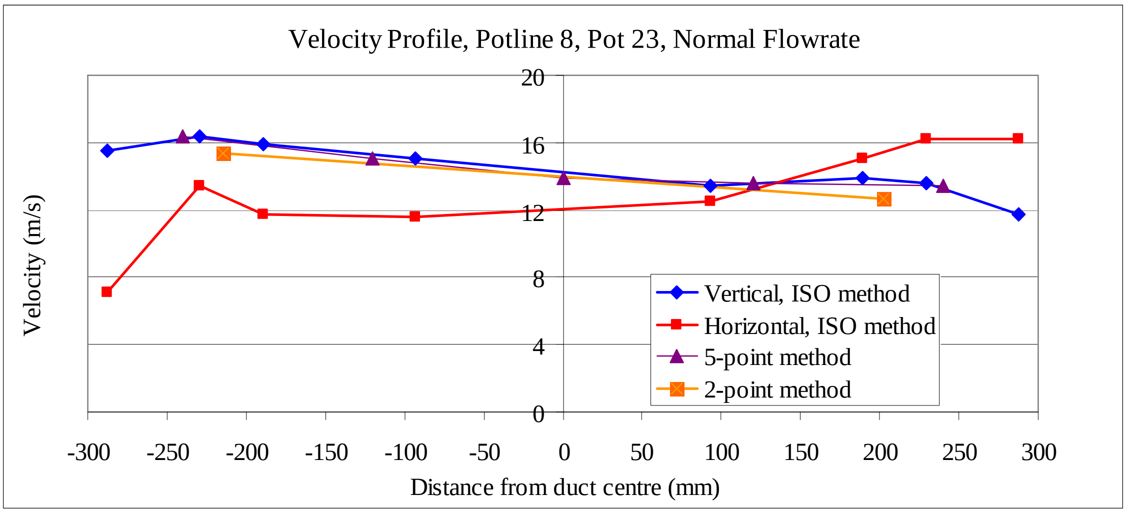

Figure 4. Velocity profile in the duct in DX Potline 8, Pot 23 at normal flowrate on 19 June 2013. Pot 38 had similar velocity profile.

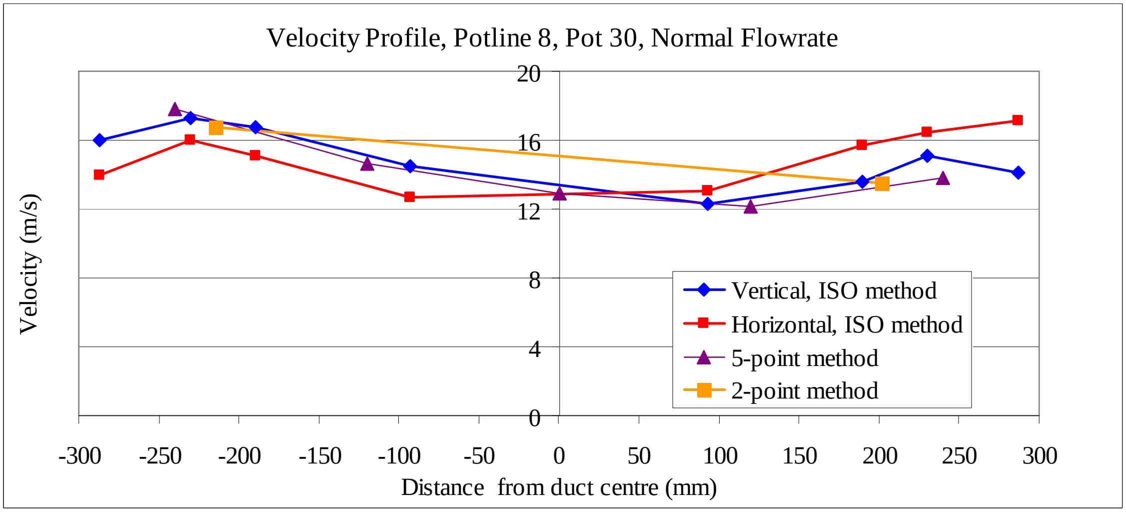

Figure 5. Velocity profile in the duct in DX Potline 8, Pot 30 on 19 June 2013. Pot 32 had similar velocity profile.

On 30 June and 1 July 2013, the measurements were taken at increased flowrate. The average flowrate at increased flowrate, with all dampers fully open, was 13 770 ± 2 160 Nm³/h with minimum and maximum flowrates of 11 115 and 16 418 Nm³/h. The scatter is so large that it is not very meaningful to speak about the average.

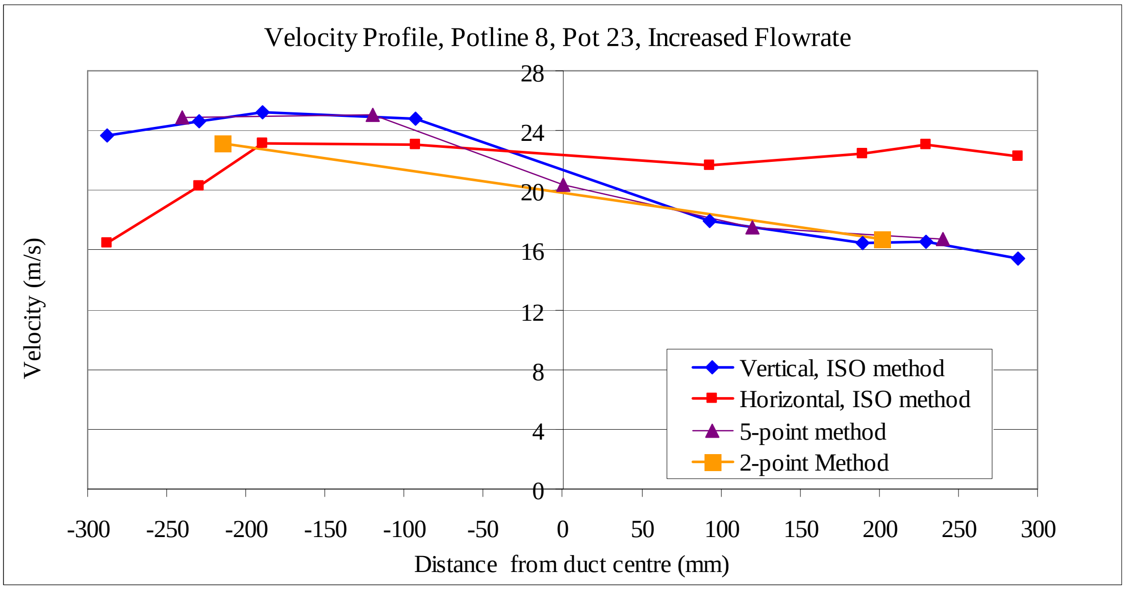

Figure 6. Velocity profile in the duct in DX Potline 8, Pot 23 at increased flowrate of 15974 Nm³/h on 1 July 2013.

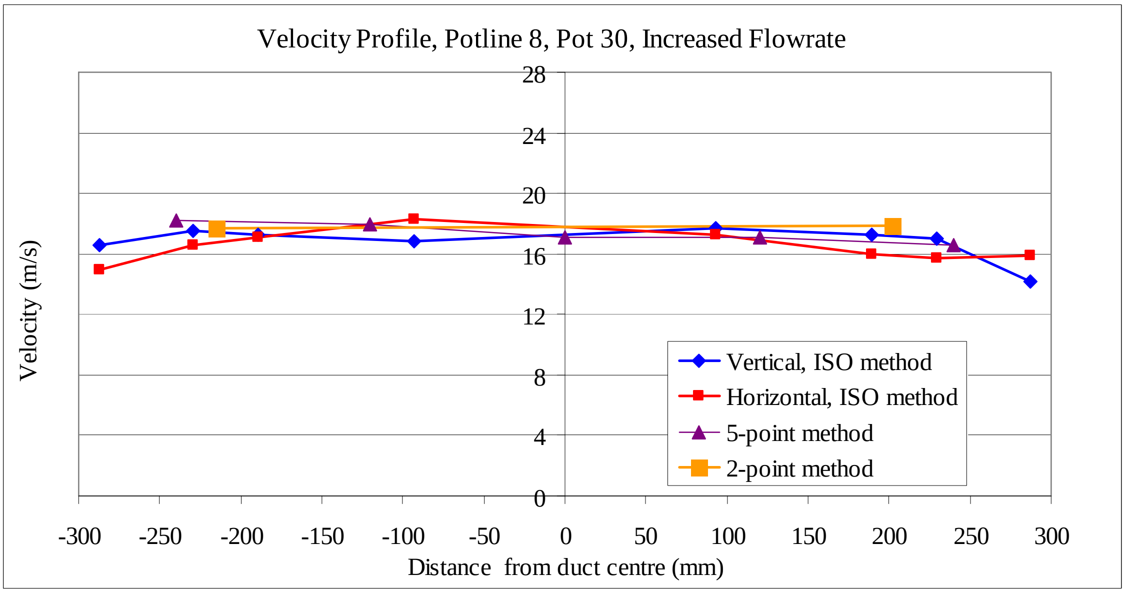

Figure 7. Velocity profile in the duct in DX Potline 8, Pot 23 at increased flowrate of 11277 Nm³/h on 1 July 2013.

It is evident that the presence of flow obstructions has a major effect on the duct flow distribution. The damper leaves a clear mark downstream and at the measurement site causes a velocity decrease in the central area of the duct. With the damper fully open, the normal turbulent profile is nearly recovered (Figure 7) at lower flowrate, but at high flowrate, the velocity profile is still very asymmetric.

4.2. Duct flowrate – comparison of measurement methods

The 16-point ISO 3966 method gave the flowrate within + 6 %, -10 % of the 5-point method. In a relatively undisturbed flow, when baffles are fully open for high flowrate, the 5-point method, clearly overestimates the flowrate by 6 %. This is in agreement with published literature.

The 16-point ISO 3966 method gave the flowrate within + 6 %, -7 % of the 2-point method.

The simplified 5-point and 2-point methods can be used for process control, but for accurate measurements, the ISO 3966 method is recommended, using at least 8 traverse points on two diameters.

4.3. Duct heat loss

All measurements were made at the amperage of 385 kA.

At normal flowrates, the duct heat loss was 294 ± 18 kW/pot. The minimum was 274 kW and the maximum 318 kW, a difference of 44 kW. The internal heat within the anode cover-yoke-anode-rod boundary at the average pot voltage of 4.260 V was 716 kW. Average heat loss difference between two successive days was 10 kW/pot.

At increased flowrates, the duct heat loss was 337 ± 26 kW/pot. The minimum was 307 kW and the maximum 377 kW, a difference of 70 kW. The average heat loss difference between two successive days was 20 kW/pot.

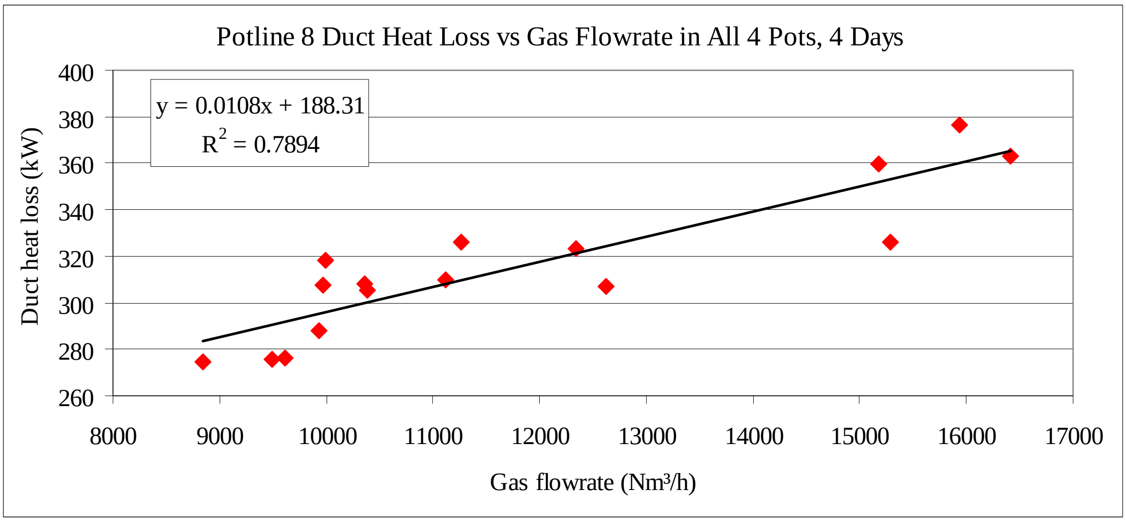

Figure 8. Duct heat loss at normal and increased flowrate in DX Potline 8 pots.

Overall, for all pots and all flowrates, the heat loss increased by 10.7 kW per 1 000 Nm³/h and the duct temperature decreased by 3.6 °C per 1 000 Nm³/h as shown in Figures 1 and 2.

4.4. Duct temperature

Duct gas temperature was measured with a sheathed thermocouple, which was pushed through the same hole vertically to the duct centre. Tests showed that the gas has uniform temperature in the whole cross-section; therefore the temperature in the middle was representative.

The results are shown in Figure 9. The duct gas temperature decreased by 3.6 °C per 1000 Nm³/h.

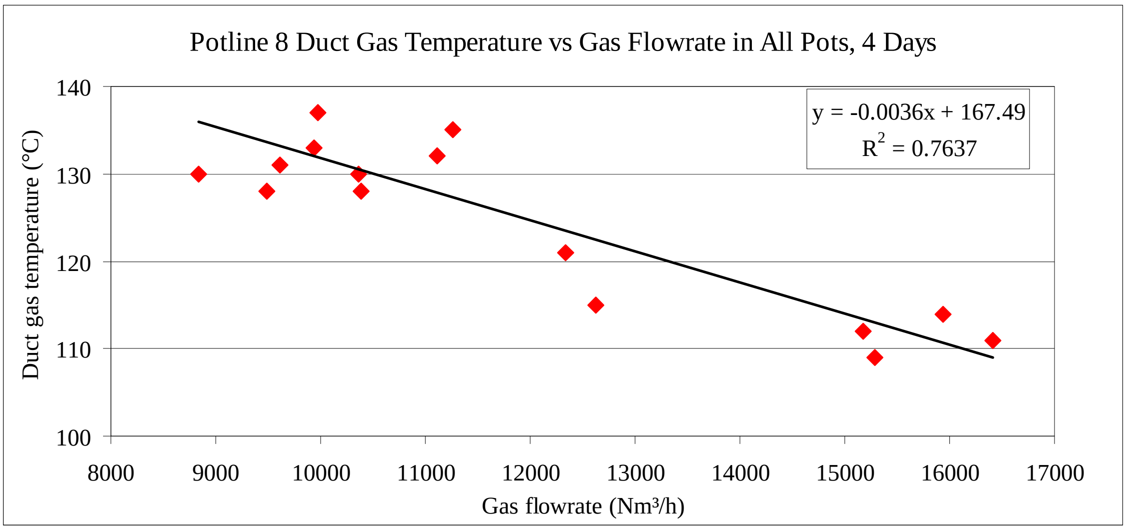

Figure 9. Duct gas temperature at normal and increased flowrate in DX Potline 8 pots.

4.5. Bath temperature

Bath temperature was monitored on a daily basis. The results are shown in Figure 10. Statistically, there is no correlation between the gas flowrate and bath temperature. This means that bath temperature is controlled more by other parameters than by gas exhaust flowrate.

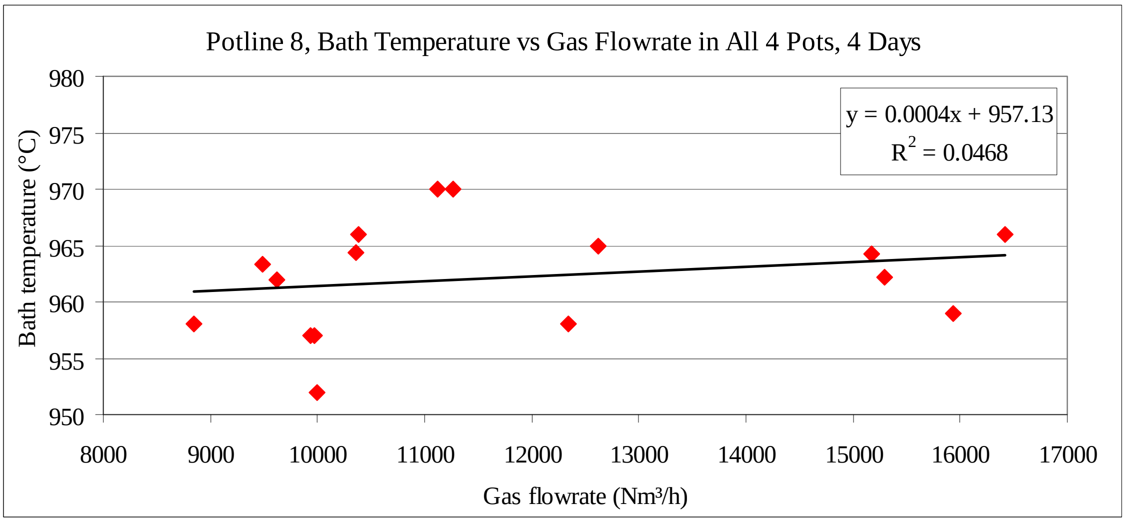

Figure 10. Bath temperature at normal and increased flowrate in DX Potline 8 pots.

5. Conclusions

The ISO 3966 method of duct flow measurement with 8 traverse points along two diameters (16 points) is more accurate than the simplified 5-point method and 2-point method; the latter can be used for process control if an error of 5 % to 10 % is accepted.

The ISO 3966 standard (or any other similar standard) for flow measurement cannot be fully satisfied because upstream and downstream flow disturbances are too close to the measurement location. However, the accuracy of the measurements is reasonable if the number of traverse points is a minimum of 8 along 2 diameters.

In these measurements, the duct heat loss increased with the flowrate increase, but the bath temperature did not decrease. Therefore, using gas flowrate to control thermal balance of the pot appears to be ineffective especially at high gas flowrate ranges (7 000 Nm^3/h to 16 000 Nm^3/h) . Also, pot-to-pot and day-to-day variability is too great to hope for uniformity in the potline if the flowrate is changed for thermal balance control.

Exhaust duct gas temperature decreases with gas flowrate increase, but in these measurements much less rapidly than reported in the quoted references.

The numerical results obtained in these measurements are specific to this technology and to the state of this technology at the time of measurements and should not be used as universal.

6. References

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