A SPREADSHEET TOOL TO CALCULATE LANDFILL GAS FLOW RATE FROM PRESSURE OBSERVATIONS ACROSS WELLHEAD CONTROL VALVES


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ABSTRACT

Trials were undertaken as part of larger investigations (ZWS, 2012) examining management of low calorific gas from historical landfills in Scotland. Landfill gas well yields from historical sites are lower than operational landfills such that it may not be appropriate to use conventional valves to control landfill gas extraction on these sites.

Landfill gas extraction from any pipe system requires balancing of extraction flow rates from point sources at well heads or manifolds. Modern gas analysers, in addition to monitoring gas quality, also have the ability to monitor differential pressure either side of a valve. These trials were designed to assess whether pressure observations across a valve could be used to define flow through a valve. If so gas quality data captured during normal balancing exercises could be supplemented with extraction flow rates at individual well heads saving time and negating the need to use additional instruments (pitot or anemometer).

This paper presents the findings of site trials which developed a set of characteristic head-loss curves and operator design tools for commonly used well head flow control valves used to manage landfill gas extraction from municipal solid waste landfills in Scotland.

The findings from the site trials were then used to develop nomographs and spreadsheet algorithms to calculate flow from head-loss observations across respective valves. The spreadsheet algorithms can be easily applied to support commonly used balancing software e.g. Rungas™ or similar.

A basic design tool was also developed to size valves for a given design flow and desired control range of valve opening settings to support the design of landfill gas collection control systems.

This research showed that commonly used valves in the landfill industry are oversized and maybe unsuited for managing landfill gas extraction from historical sites with lower gas yields. The spreadsheet algorithms also provide a simple tool that allows operators to define flow rates at respective well heads from pressure observations taken during gas quality balancing exercises.
INTRODUCTION

These trials were part of larger investigations (ZWS, 2012) examining management of low calorific gas from historical landfills, the objectives of which were to:

- assess auditing and balancing protocols for landfill gas extraction;
- identify key operational parameters affecting gas flares in the context of issues associated with mitigation of greenhouse gas emissions;
- review remote monitoring protocols to monitor flares and boreholes in inaccessible locations;
- review the biological methane oxidation potential of readily available materials such as woodchip and materials containing compost;
- review the characteristic curves of well head flow control valves.

The auditing and balancing trials reviewed: a balancing protocol which balanced extraction on the basis of gas quality only, on an existing site; and a proposed system for balancing landfill gas extraction which used both quality and flow based extraction criteria. Flow based extraction (Cronin et. al., 2008) maybe used where off site migration is an issue which is often a concern on old unlined landfill sites.

The flare trials (AFS, 2012) focused on maximising the oxidation of GHG emissions for low calorific landfill gas. This element of the research examined the behaviour of:

- low calorific value open flares;
- high temperature, high calorific value (HT HC) flares and high temperature, low calorific value (HT LC) flares operating under in accordance with best practice; and
- stack emissions and olfactory impacts.

The remote monitoring trials investigated the deployment of:

- a remote Global System for Mobile Communications (AFS, 2012) to monitor and control flare operations (gas quality, flow and flare operating parameters) with a view to assessing the suitability of such systems for historic landfills;
- a remote GSM well monitoring system (DCU, 2012) to continuously monitor gas in boreholes and gas collection infrastructure.

The biological methane oxidation trials assessed fugitive greenhouse gas emissions using flux boxes and a flame ionisation detector (FID) meter from a variety of readily available woodchip and compost materials.

A common denominator in the above investigations was a need to be able to manage more effectively the extraction flow rates from wellheads or similar. Accordingly these valve trials were initiated to review the characteristic curves from commonly used wellhead control valves in the landfill industry.

Gas yields from wellheads on historical landfills maybe less than 20 m$^3$/hour whereas an operational landfill may have wellhead flow rates in excess of 50 m$^3$/hour. Typically in Scotland 63mm diameter ball or angle seat valves are used to control extraction flow rates from wellheads and anecdotal evidence suggests that, even when used to throttle the higher yielding wells on operational sites, it is common for 63mm valves, when being closed from a fully open position, to have little or no effect on throttling flows within the first 75% of the valve position range.

Typically headloss characteristic curves produced by valve manufacturers are developed using water and as such cannot be used for landfill gas related works. Therefore these trials set out to:

- review commonly available valves to determine the landfill gas characteristic curves;
- develop tools to select and size appropriate valves;
- develop tools to define flow rates for respective valves using findings from empirical pressure observations upstream and downstream of a valve.
METHODOLOGY

The nine valves selected for the trials were:

- angle seat (Plasston\textsuperscript{TM}) valve 25mm;
- angle seat (Plasston\textsuperscript{TM}) valve 45mm;
- angle seat (Plasston\textsuperscript{TM}) valve 63mm (typically used on landfill sites in Scotland);
- dosing (Profidos\textsuperscript{TM}) valve 25 mm;
- dosing (Profidos\textsuperscript{TM}) valve 45 mm;
- dosing (Profidos\textsuperscript{TM}) valve 63 mm;
- globe (Safi\textsuperscript{TM}) valve 25 mm;
- globe (Safi\textsuperscript{TM}) valve 45 mm;
- globe (Safi\textsuperscript{TM}) valve 63 mm (typically used on landfill sites in Scotland).

63mm Safi\textsuperscript{TM} valves and Plasston\textsuperscript{TM} valves are commonly used on landfills sites within Scotland. The Profidos\textsuperscript{TM} valve was included in the trial because the vee slot in the ball valve allows a greater degree of control for very low extraction flow rates. The Profidos\textsuperscript{TM} valve is not typically used on landfill sites in Scotland. Figure 1 shows the layout of valves used in the trials. Landfill gas extraction was carried out using a variable speed drive blower on a 100 m\textsuperscript{3}/hour high temperature low calorific flare. Representative valve cross-sections from manufacturers catalogues are presented below in Figure 2.

Figure 1 Trial Layout
The valve openings were divided into 10 subdivisions. This allowed for readings of percentage opening of the valve to be taken. Two manometers were used to take pressure readings both upstream and downstream of each valve in the main 180 mm pipework. Velocity was monitored using a hot wire anemometer in the 63mm pipework at dedicated flow monitoring ports. Each valve was fully open at the start of each test and the (flare) blower was operated over a range of defined flow rates in order to change head loss conditions across the valve for respective openings.

The valve was then closed for respective blower flow rates slowly; once a pressure differential was observed, the corresponding flow readings were recorded at valve position intervals not exceeding 10% of the available range. The process was then repeated commencing with each valve starting from a closed position, to assess the impacts, if any, of hysteresis. The impacts of temperature and density were not assessed.

Characteristic curves from the trials were initially presented graphically in nomograph formats to illustrate relationships developed between headloss, flow and % valve opening.

Following a review of the nomograph findings, spreadsheet algorithms using MS Excel were then developed to produce:

- a flow calculator which uses pressure observations upstream and downstream of the valve to define flow through the valve;
- a valve sizing tool that allows an operator to input an expected well head design flow and assess the % valve opening settings.

**RESULTS**

Observations for the 63 mm Safi valve are presented in Figure 3 to illustrate a typical relationship between differential pressure and valve opening for respective flow rates. Curves for other valves are available from the web (FTC, 2013).
Figure 3 Characteristic Curves for 63 mm SafiT™ Ball Valve

The nomograph presented in Figure 3 illustrates how flow is determined from pressure observations:

- the “X” axis defines differential pressure;
- the “negative” range of the “Y” axis shows pressure upstream and downstream of a well head control valve;
- the “positive” range of the “Y” axis of the graph defines flow.

Figure 3, Quadrant 1 (Q1) shows the relationships between flow through the valve and respective pressures across the valve as a consequence of different blower settings.

The key observations in Q1 are:

- there is a straight line \( y = mx + c \) relationship between flow and headloss across the valve for respective pressures upstream and downstream of the valve; and
- each pair of straight lines has a unique upstream and downstream intercept with the “Y” axis.

Figure 3, Q2 shows that for a family of straight lines (respective blower settings), a polynomial relationship \( y = ax^6 + bx^5 + cx^4 + dx^3 + ex^2 + fx + g \) is evident.

Figure 3 Q3 shows a similar polynomial relationship between flow and valve opening for headloss scenarios.

Figure 3, Q4 shows the valve used in the trial.

Nomographs facilitate a definition of flow through the valve based on pressure observations upstream and downstream of the valve. The nomograph procedure to determine flow from pressure observations with reference to Figure 3 numbered text boxes, is as follows:

1. Define downstream pressure in Q1 by drawing a horizontal line.
2. Define upstream pressure in Q1 by drawing a horizontal line.
3. Define the differential pressure in Q1 by drawing a vertical line and extend it into Q2.
4. The intersect in Q1 between vertical and horizontal lines defines the pair of curves to which the headloss observations apply (red curve). Draw a horizontal line where the vertical line intersects with the Q2 red curve. The vertical line intersect between curve and “Y” axis defines the flow through the valve.
5. Extend the Q2 horizontal line into Q3. The intersect between horizontal line and red curve defines the valve opening on the “X” axis.

SPREADSHEET ALGORITHMS

The nomograph results from each valve were used to develop spreadsheet algorithms to calculate flow from head-loss observations across the valve. Typically pressure derived flow rates were within 95% of the anemometer derived flow rates.

Figure 4 illustrates the steps taken in the calculation of the flow across a valve based on head-loss observations.

![Figure 4 Calculation Steps to Determine Flow Across a Valve](image)

Figure 4 Calculation Steps to Determine Flow Across a Valve
The following section describes the spreadsheet structure by showing key formulae in respective cells. The Excel™ screen illustrations show selected rows and columns of the spreadsheet tool. Text shown in CAPITAL LETTERS refers to specific spreadsheet functions.

![Figure 5 Excel™ Screenshot Showing Step 1](image)

Figure 5 Excel™ Screenshot Showing Step 1
With reference to Figures 4 and 5, Step 1 is the User Input of Upstream Head in C6 (defined as "KnownY_US") and known Downstream Head in C7 (defined as “KnownY_DS”). The model calculates the differential pressure in C8 across the valve, this is defined as “Known_X”. The User selects the valve type and size from a dropdown menu shown above (Safi Globe valve 63mm). C13 contains a nested IF that selects the correct result to output to the User, based on the valve selection.

![Image of Excel spreadsheet](image1)

**Figure 6 Excel ™ Screenshot Showing Step 2**

With reference to Figure 6, Step 2 uses predefined Excel functions, SLOPE and INTERCEPT, to define the equation of the line (i.e. y = mx+c) for upstream head vs. differential pressure, and downstream head vs. differential pressure for each valve type and blower setting combination. Ranges have been defined elsewhere within the model for measured upstream and downstream head, flow and differential pressure for each valve and blower setting combination arising from the onsite trials (e.g. USHead_63Safi_20 is the upstream head for a 63 mm Safi™ valve at a 20% blower speed setting).

Known X and Y inputs, as defined in Step 1, are inputs into the line equations, and a ‘c’ value is calculated. The calculated ‘c’ value is compared to the theoretical value, and the best match is selected. This defines the blower setting to be used in Step 3.

![Image of Excel spreadsheet](image2)

**Figure 7 Excel ™ screenshot showing Step 3**

With reference to Figure 7, Step 3 uses predefined Excel functions, INDEX and LINEST, to calculate the coefficients (first order through to sixth order, fifth through second are hidden above) and the constant that define the polynomial equation (i.e. \( y = ax^6 + bx^5 + cx^4 + dx^3 + ex^2 + fx + g \)) of the curve of flow vs. differential pressure for each blower setting examined. The known differential pressure (Known_X) is input to the polynomial curve for the correct blower setting and the flow is calculated. The flow calculated for the blower setting selected in Step 2 above is output as CalcFlow_ValveXXX (e.g. CalcFlow_63Safi for a 63 mm Safi valve). The nested IF in Step 1 selects the required calculated flow and returns this to the user.

**VALVE FLOW CALCULATOR**

The algorithms developed for this paper have been presented in a dedicated spreadsheet the interface of which is presented in Figure 8. This allows an operator to enter upstream and downstream pressure observations and to select the valve type. The algorithms then define flow through the valve.

These algorithms can equally be adapted to calculate flow from gas analyser data logger pressure outputs at respective well heads in a tabular format.
The spreadsheet algorithms and trial results are freely available from the web (FTC, 2013).

Figure 8 Valve Flow Calculator for Respective Valves

**VALVE SIZING TOOL**

Figure 9 shows the valve sizing design tool which presents valve opening characteristics for respective valves to illustrate the range of valve openings for respective flow rates. The tool is basic and needs to be treated with caution. It takes a design flow, increases and decreases this design flow by 50% and then assesses whether it is possible to control flows over the specified range of valve openings.

Two cases are presented in Figures 9 and 10 to illustrate the impact of valve size and % valve opening.

Figure 9 assumes that the input design flow is 50 m³/hour and that there is a control requirement for the valve to be effective over 50% of its range. The histogram in Figures 9.1 shows the maximum flow possible through respective valves. The design flow is represented by the horizontal dotted line. Blower settings of 100 % and 50 % are reviewed to assess the impact of available head across the valve. When the blower setting is 100 % the valve will be required to dissipate more energy than when the valve is set at a blower capacity of 50%.

The valves recommended for this application (defined in italics under heading of Suitable Valves) are the Plasson™ valves 25mm, 45mm and 63mm and the Safi™ valve 63mm.
Figure 10 assumes that the design flow is 25 m³/hour and that there is a requirement for the valve to be effective over 50% of its range. The only valve suited to this application (defined in italics under heading of Suitable Valves) is the Plasson™ valve 25mm.
This simple valve sizing tool example shows that it may not be appropriate to use 63mm valves to control extraction flow rates when well head flows are less than 25 m³/hour. Furthermore, when flows are less than 15 m³/hour it may be appropriate to use only 25 mm valves Plasson™ or the Profidos™ dosing valves, none of which are commonly used on landfill sites in Scotland at present. Use of smaller valves in pipework may, subject to pipe alignments, also cause condensate problems.

CONCLUSIONS

The trials showed that it is possible to develop a correlation between headloss across, and flow through, valves over a range of upstream and downstream conditions using either nomographs or spreadsheet algorithms. These algorithms can utilise ASCII data logger outputs from modern gas analysers to supplement gas quality data with flow observations from well heads or similar with minimal additional works and without using pitot tubes or other anemometers.

The valve trials showed that the commonly used 63mm valves may be oversized and unable to facilitate easy control of low extraction rates as may be expected from future historical landfill sites where wellhead flows maybe less than 25 m³/hour. For very low flows (less than 10 m³/hour) it may be necessary to explore the use of very small valves (25 mm diameter) or dosing valves, none of which are currently used on operational landfills in Scotland.

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