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# Measurement of Air Leakage through Rotary Valves

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# Measurement of Air Leakage Through Rotary Valves

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**Summary** This paper explains the procedure used to determine the amount of air leakage expelled from two different sized drop-through rotary valves.
When designing a pneumatic conveying system, rotary valve air leakage may be overlooked, believed to be only a minor factor. This is somewhat true when conveying in dilute-phase where low pressures are generated, however in dense-phase pneumatic conveying where higher pressures can be produced, rotary valve air leakage can be a high proportion of the supplied air. Knowing the air leakage present for any given situation, the total supplied air mass flowrate can be adjusted to represent the actual air mass flowrate travelling through the conveying line, thus giving a more accurate representation of the actual conveying conditions.
A series of tests have been performed from which a series of graphs have been produced. Comparisons have been made for the air leakage through the different sized rotary valves and also these results have been compared to two existing models used in the prediction of rotary valve air leakage.

## 1 NOMENCLATURE

| | |
|---|---|
| $A_c$ | leakage area through sides and ends, $m^2$ |
| b | "blockage factor" |
| c | valve rotor clearance, mm |
| D | rotor diameter, m |
| $D_A$ | annubar diameter, m |
| F | correction factor allowing for gas expansion |
| $h_w$ | differential pressure, mm $H_2O$ |
| K | annubar coefficient |
| L | rotor length, m |
| $m_f$ | air mass flowrate, kg $s^{-1}$ |
| N | rotor speed, RPM |
| $P_A$ | annubar pressure, kPa abs |
| $P_f$ | absolute air pressure, Pa abs |
| $Q_c$ | clearance leakage, $m^3\ s^{-1}$ |
| $Q_p$ | carry-over leakage, $m^3\ s^{-1}$ |
| $Q_T$ | total leakage, $m^3\ s^{-1}$ |
| T | air temperature, K |
| $v_1$ | "leakage velocity", m $s^{-1}$ |
| $\Delta p_v$ | pressure drop across the rotary valve, Pa |
| $\rho_f$ | air density, kg $m^{-3}$ |

**subscripts**

| | |
|---|---|
| 1 | below rotary valve |
| 2 | above rotary valve |

## 2 INTRODUCTION

There are a number of issues dependent on the degree of rotary valve air leakage present in a pneumatic conveying system, including system pressure, rotor clearances, material being handled, head of product above the valve and whether there is venting present. By disregarding this leakage at the design phase of a pneumatic conveying system, incorrect sizing of fans, blowers or compressors can result. Oversized prime movers may result in higher velocities, reduced solids throughput, increased abrasion and/or erosion of the plant, an increase in product degradation or even unnecessary over-expenditure. Whereas undersized prime movers may result in insufficient transport velocities causing unnecessarily high pressure or pipe blockages [1].

This paper presents results from investigations into measuring and modelling rotary valve air leakage. The experimental work provided has been carried out under air-only conditions, which is the worst case scenario for rotary valve air leakage. This is due to there being no head of product in or above the rotary valve, thus no restriction to the flow of air through the rotary valve and as a result the air leakage is at a maximum. This situation can also be likened to the end of a pneumatic conveying batch process where the feeding bin has just run out of product, but product still needs to be conveyed through the pipeline.

## 3 TYPES OF AIR LEAKAGE

Labyrinth leakage occurs if there is poor sealing between the rotor shaft and the side plates of the casing. This leakage can be minimised by using suitable seals [3].

Carry-over leakage is where compressed gas is fed up into the feeding hopper through the returning pockets of the rotary valve. As product is being discharged into the system, compressed gas fills the empty pockets and returns to the feeding bin. Depending on the degree of air leakage present, it is possible that the flow of air leaking through the valve could hinder feeding of the product. Carry-over leakage can be reduced by venting air from the pockets before coming in contact with feed material [3].

Clearance leakage is that in which air leaks between the gaps between the moving rotors and the housing. To minimise this form of air leakage, small tolerances are used between the rotors and the valve housing and also manufacturers have experimented with such things as spring loaded, flexible and adjustable rotor tips [3].

## 4 MEASUREMENT OF AIR LEAKAGE

### 4.1 The Air Leakage Rig

The air leakage tests were performed on two different sized Waeschle high pressure rotary valves, a ZGR 250 having 10 pockets and a ZGH 320 having 12 pockets. A bank of 6 adjustable sonic nozzles was used to supply air to the rig over a wide range of air flows. An inverted silo was positioned above the rotary valve and used as an air reservoir to dampen the effects of the pulsating air travelling through the valve as it is rotating. A 25mm NB Dieterich Standard Diamond II annubar was attached to the top of the silo and used to measure the flowrate of air travelling through the rotary valve and out through the silo. Pressure meters were used to measure the pressure above and below the rotary valve and one also used to measure the pressure at the annubar. Differential pressure meters were attached to the annubar to record the differential pressure caused by the various air flows. Figure 1shows the arrangement for the Waeschle ZGR 250 rotary valve.

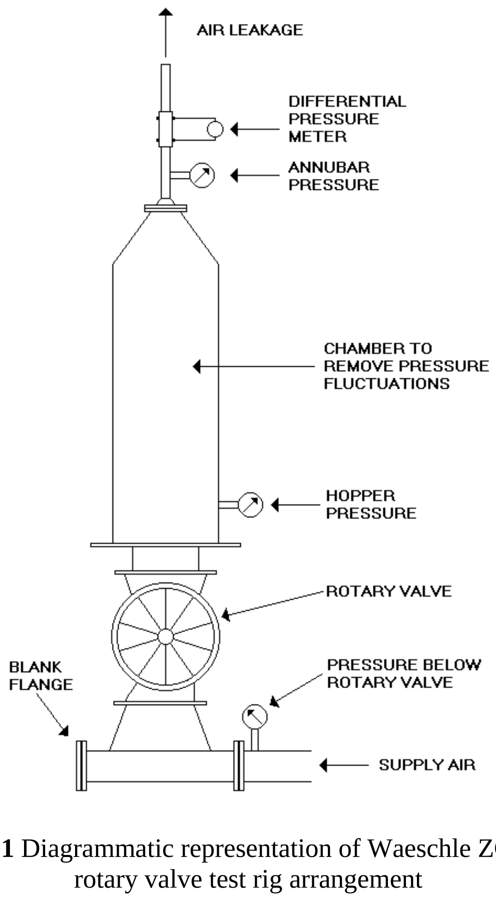


**Figure 1** Diagrammatic representation of Waeschle ZGR 250 rotary valve test rig arrangement

### 4.2 Experimental Procedure and Results

Five sets of tests were performed for each rotary valve, they being; 0 RPM (maximum and minimum), 5 RPM, 15 RPM and 30 RPM. There were two situations for 0 RPM (maximum or minimum), depending on the positioning of the blades. On the vent port side of the rotary valve there can be either 3 or 4 blades in contact with the surface for the ZGR 250 rotary valve and 4 or 5 blades in contact with the surface for the ZGH 320 rotary valve. Minimum air leakage at 0 RPM is recorded when more blades are in contact, hence maximum air leakage at 0 RPM is recorded when the least blades are in contact.

The procedure involves creating a steady-state back pressure under the rotary valve, then recording the pressures above and below the rotary valve and also the readings from the annubar. Using the annubar equation, shown as Equation 1, where K = 0.5547 and $D_A$ = 26.6446mm, the air mass flowrate can be calculated. This procedure is repeated for the necessary range of back pressures and each required rotary valve speed.

$$m_f = 6.4876 \times 10^{-6} K D_A^2 \sqrt{\frac{h_w P_A}{T}} \tag{1}$$

Once all testing has been completed, the air mass flowrate of the air leakage is converted to volumetric flowrate at ambient conditions and plotted against back pressure (pressure below the rotary valve). The resultant graphs for both rotary valves are displayed on the following page in Figure 2 and Figure 3.

A noticeable result for the Waeschle ZGR 250 rotary valve is that the maximum air leakage for 0 RPM shows the highest result, whereas the results for the Waeschle ZGH 320 rotary valve show the maximum air leakage for 0 RPM still being lower than the results for when the valve is rotating at the various tested rotary valve speeds. This could be put down to the fact that in the larger valve, carry-over leakage effects have more influence on the amount of leakage present.

## 5 AIR LEAKAGE MODELS

There are several methods available which can be used to estimate rotary valve air leakage. Previously, work has been carried out into the theoretical determination of rotary valve air leakage and two approaches are explained below.

### 5.1 Marcus Method

In determining rotary valve air leakage, Marcus [3] includes both carry-over leakage, $Q_p$, which is the transfer of air from the pipeline to the hopper through the empty pockets of the rotary valve, and clearance leakage, $Q_c$, which is present between the rotor and valve housing. Marcus does not include Labyrinth leakage in his model as he assumes it will be negligible.

Marcus [3], uses the following method for estimating the total air leakage,

$$Q_T = \left(\frac{P_{f1}}{P_{f2}}\right)\left(Q_c + Q_p\right) \tag{2}$$

The clearance leakage is given by,

$$Q_c = 36 F A_c \sqrt{\frac{2\Delta p_v}{\rho_{f1}}} \tag{3}$$

where,

$$F = \frac{1}{3.5}\left[4.35 - \frac{P_{f1}}{P_{f2}}\right] - 0.2 \tag{4}$$

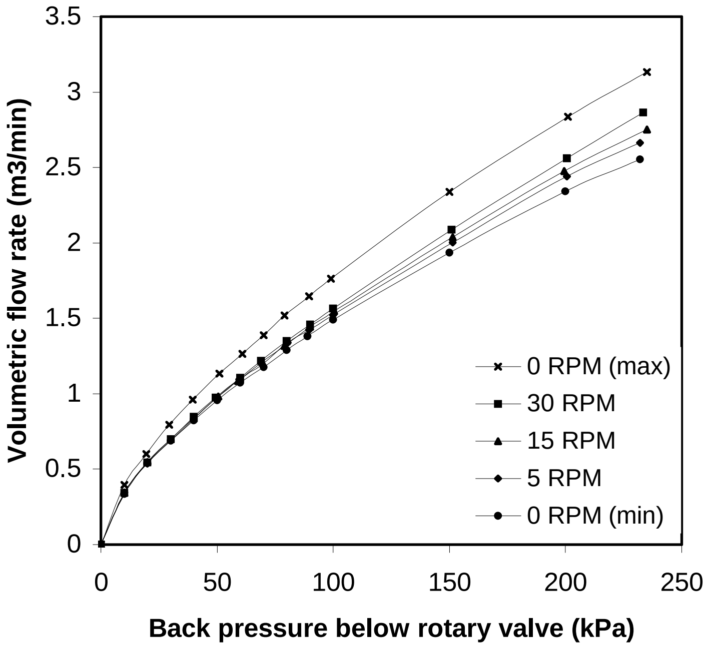


**Figure 2** Experimental air leakage from Waeschle ZGR 250 rotary valve

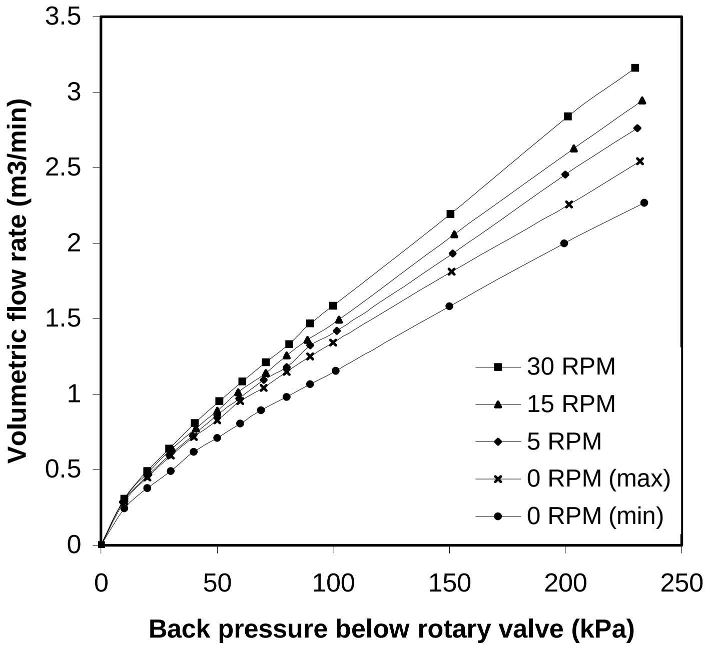


**Figure 3** Experimental air leakage from Waeschle ZGH 320 rotary valve

and the carry-over leakage is given by,

$$Q_p = \frac{\pi}{4} D^2 L N \qquad (5)$$

Marcus' method results in a curve being produced for each distinct rotary valve speed used, as can be seen in Figure 4 and Figure 5. Figure 4 and Figure 5 show the comparison of the predicted air leakage by Marcus against the experimental results for both the ZGR 250 and the ZGH 320 rotary valves respectively.

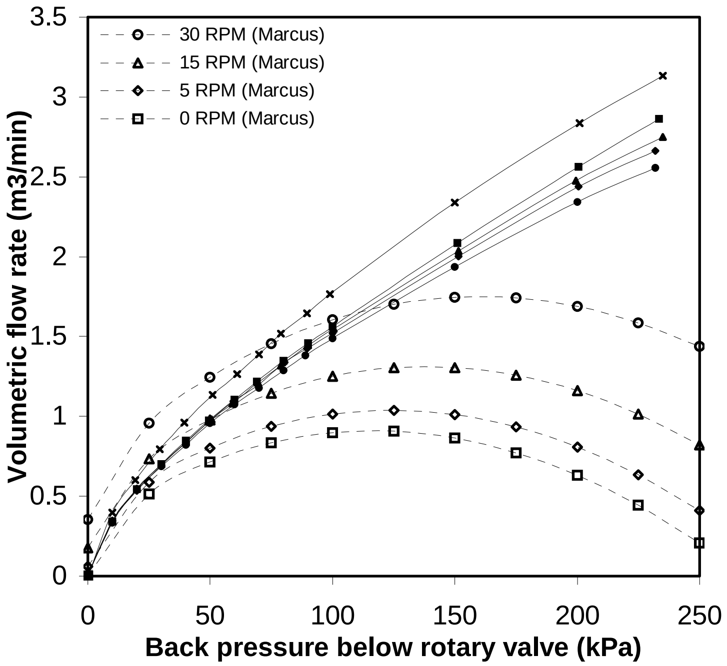


**Figure 4** Comparison of Marcus model with ZGR 250 experimental results

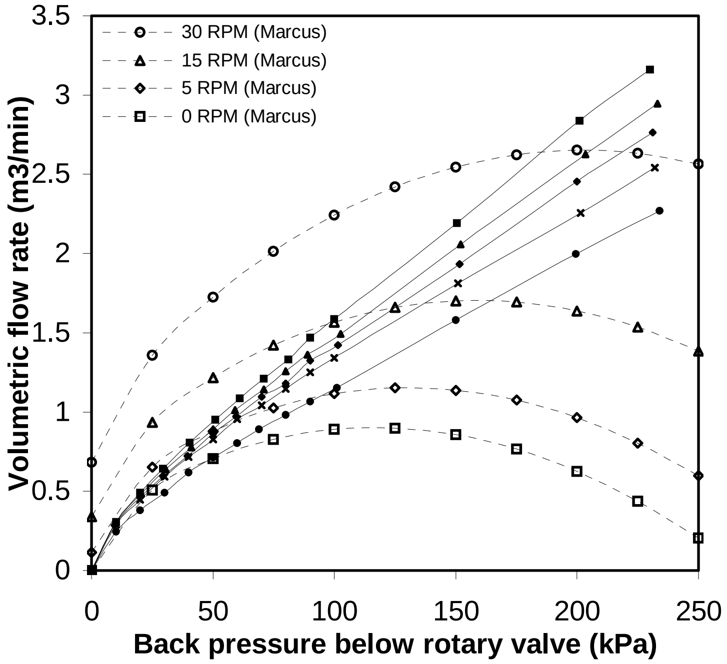


**Figure 5** Comparison of Marcus model with ZGH 320 experimental results

## 5.2 Reed Method

Reed et al. [4] uses an empirical method to estimate rotary valve air leakage. During his experiments, Reed found that carry over leakage was negligible and so not included in his calculations to determine rotary valve air leakage.

Reed represents the total rotary valve air leakage as follows,

$$Q_T = 0.0001 b v_1 L c \qquad (6)$$

where b is taken from either Figure 6 or Figure 7 depending on whether static or actual conditions are required and $v_1$ is taken from Figure 9. Originally a maximum pressure ratio of 1.7 was tested as shown in Figure 8, hence extrapolation and the use of curve fitting functions was required to both produce a curve for 10 pockets and also to increase the curves to a higher pressure ratio.

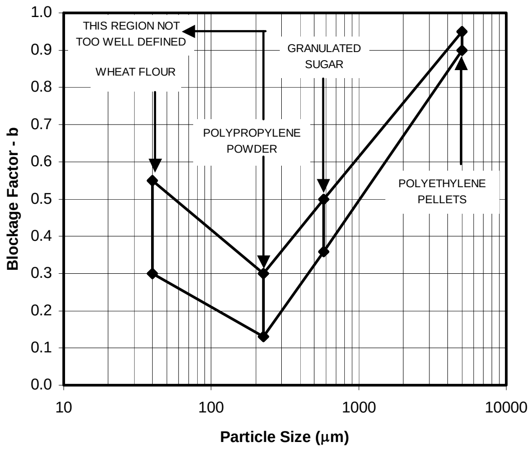


**Figure 6** Static blockage factor [4]

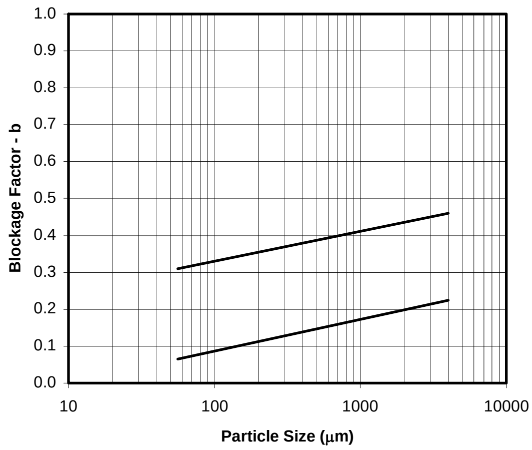


**Figure 7** Actual blockage factor [2]

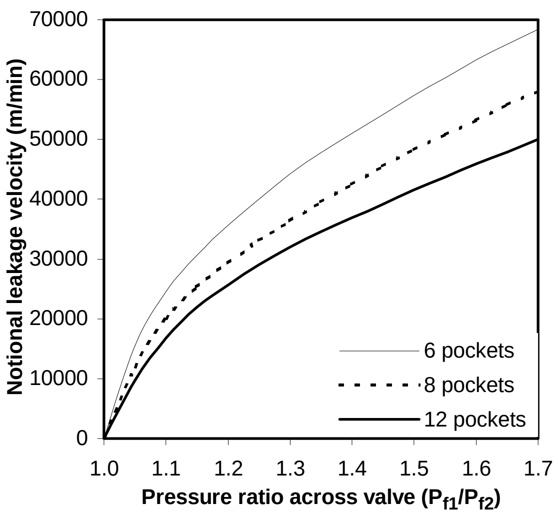


**Figure 8** Leakage velocity versus pressure ratio for 6, 8 and 12 pocket rotary valves

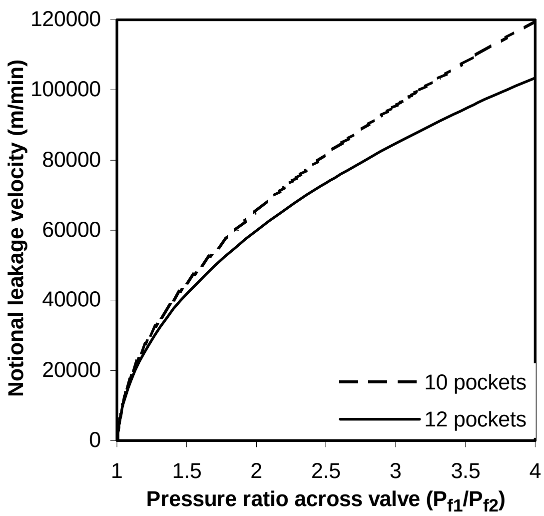


**Figure 9** Extrapolated leakage velocity versus pressure ratio for 10 and 12 pocket rotary valves

Reed's method [4] produces one curve to represent rotary valve air leakage as is shown in Figure 10 and Figure 11, however it cannot be used on high pressure rotary valves which use end-plate seals to remove the clearances. Figure 10 and Figure 11 have a second Reed curve plotted, for 50% of the original Reed curve. In later work Reed et al. [5] states that having a valve with a length equal to it's diameter and end-plate seals to minimise the clearances, it in effect reduces the area in which air can leak by approximately 50%.

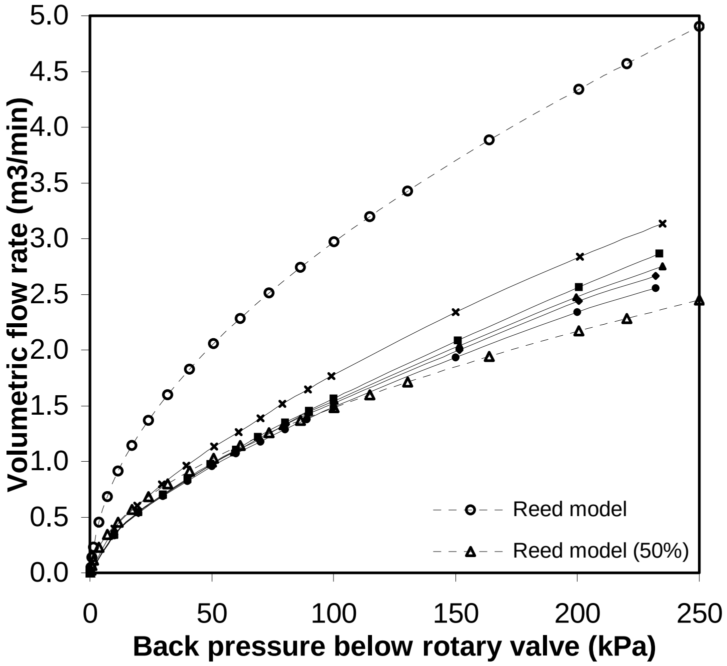


**Figure 10** Comparison of Reed model with ZGR 250 experimental results

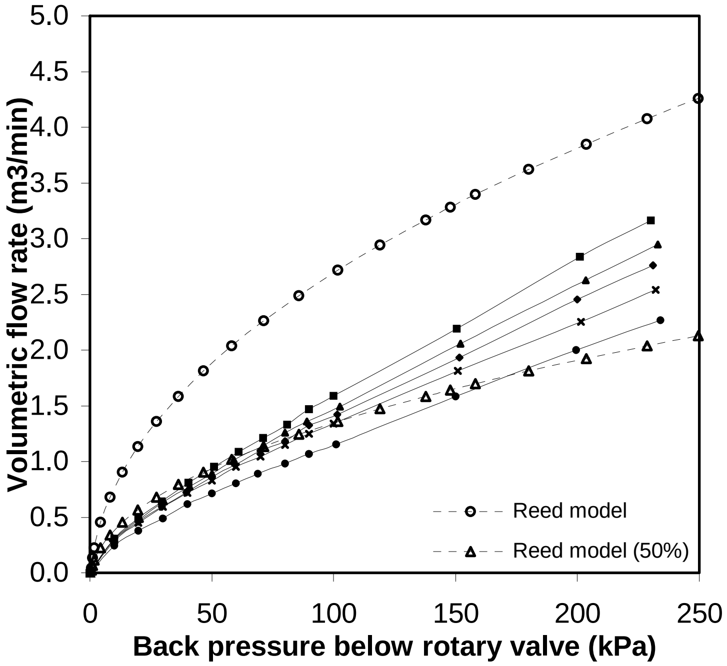


**Figure 11** Comparison of Reed model with ZGH 320 experimental results

# 6 DISCUSSION OF MODELS

## 6.1 Marcus Model

There are a number of limitations with the Marcus model, including;

- not considering the effect product will have in and above the valve in reducing the leakage by impeding air flow and decreasing clearances;

- not considering the effect of the number of blades in contact with valve housing, ie. more blades in close contact with housing will reduce air leakage;
- using total volume within the valve housing for carry-over leakage rather than the swept volume, ie. volume within the valve housing less the volume of the rotor;
- as the back pressure below the rotary valve, a maximum value of air leakage is reached for each speed and then the air leakage apparently begins to drop again, which from the experimental tests performed has shown not to be the case;
- the Marcus curves in Figure 4 and Figure 5 show an initial offset at 0 kPa back pressure below the rotary valve when it is rotating. This is due to the calculation of carry-over leakage, see Equation 5. In actual fact if there is no back pressure below the rotary valve then there shouldn't be any carry-over leakage and all curves should start from the origin.

### 6.2 Reed Model

A positive point of the Reed model is that it takes into account product in and above the valve, whereas Marcus doesn't, by using blockage factors as explained in Section 5.2. However in this test program where air-only tests were performed a blockage factor of 1 has been used.

There are a number of limitations with the Reed model, including;

- Reed's experimental work found that carry-over leakage was insignificant. This may be true for relatively small conventional style rotary valves but for larger high pressure rotary valves as those used in the test program carry-over leakage did seem to have an effect on the amount of rotary valve air leakage;
- rotary valve speed not being considered. The experimental results shown in Section 4.2 clearly show distinctly different air leakage curves for each rotary valve speed tested and also for both the maximum and minimum cases for the stationary rotary valve;
- it is only able to be used for conventional rotary valves with no end seals. However in later work Reed concluded that for high pressure rotary valves with end-plate seals the air leakage generated will be approximately 50% of that for conventional valves. With this modification, the Reed (50%) model represents the experimental data reasonably well.

## 7 CONCLUSION

Rotary valve air leakage is an important issue that needs to be addressed in pneumatic conveying systems. With any pneumatic conveying system, as soon as a back pressure is generated below the rotary valve, a degree of air leakage will be present. In dilute-phase pneumatic conveying this air leakage will be relatively low due to the low back pressures generated but in dense-phase conveying where back pressure rises substantially, so will rotary valve air leakage.

Comparisons between the experimental results and the existing methods used to determine rotary valve air leakage showed marked differences. The main difference with the Marcus [3] method is that at a certain point, for a given back pressure, rotary valve air leakage reaches a maximum and then begins to drop, from the experimental work this has shown not to be the case. The original Reed et al. [4] method is unable to be used on high pressure rotary valves, thus feeding in the valve parameters a curve is produced which is substantially higher than those found experimentally. Also with the Reed method, only one curve is produced as rotary valve speed is not considered. In later work Reed et al. [5] has accounted for high pressure rotary valves and a comparison of this against the experimental work shows closer results.

It must be noted that the air leakage curves produced from this testing are only accurate for these particular rotary valves, as clearances and any possible wear will be unique for each individual valve.

Further work is needed in the modelling of rotary valve air leakage to more accurately predict what is occurring. This will better help in the design of pneumatic conveying systems where air leakage is then able to be accounted for.

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