ASSESSMENT OF ERROR DUE TO ORIFICE DIAMETER MIS-MEASUREMENT

A Report for

National Grid
Brick Kiln Street
HINCKLEY
Leicestershire
LE10 0NA

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1 INTRODUCTION

Owing to a mis-measurement of orifice diameters flows have been mis-measured at affected offtakes connected to the National Transmission System. This project has been undertaken to resolve these errors.

2 ORIFICE DIAMETERS

The calibrations of the orifice plates in question gave the measured diameters shown in Table 1. The diameters at 20 °C have been calculated. The effective bores include the effect of a drain hole to BS ISO/TR 15377:1998.

TABLE 1

ORIFICE DIAMETERS

			Measured values			Values at 20 °C	
Calibration Reference	Plate serial no	Declared certificate date	Orifice bore (mm)	Effective bore (mm)	Temperature	Orifice bore (mm)	Effective bore (mm)
3112	226	27/07/03	366.5015		21	366.4956	
3113	225	27/07/03	366.843		21	366.8371	
4124	225	08/05/04	366.8525	367.0033	21	366.8466	366.9975
4125	226	08/05/04	364.5075	364.6598	21	364.5017	364.654
4185	225-1	04/01/05	366.4775		21	366.4716	
50164	225-1	27/07/05	366.4845		21	366.4786	
50165	226-1	27/07/05	366.578		21	366.5721	
50199	226	29/06/06	366.499	366.6505	21	366.4931	366.6447
50200	225	07/10/06	366.846	366.9971	21	366.8401	366.9913
60147	226-1	12/07/06	366.25		21	366.2441	
60148	225-1	07/09/07	366.156		21	366.1501	
70077	225	16/07/07	366.524	366.6744	20.7	366.5199	366.6703
70096	226	27/09/07	366.1955	366.3466	20	366.1955	366.3466
80017	225-2	14/05/08	366.488	366.6384	19.9	366.4886	366.639
80075	225	31/10/08	366.8515	367.0034	20.2	366.8503	367.0023
80076	225-1	07/11/07	366.4895		20.3	366.4877	

Figure 1 shows the data from Table 1 for the orifice bores at 20°C (omitting 4125, which is outside the period under consideration and is an error for which a correction has previously been made). This figure shows that there is a reduction in measured diameter followed by a recovery, although perhaps it is surprising that after 226-1 suffered a reduction, a correct measurement of 225 was taken; this may be due to a difference between the declared certificate date and the actual date. The deduction from this graph is that for a period of time around 2007 the plates were mis-measured: erroneous measurements were obtained from calibrations with calibration references from 60146 to 70099 inclusive.

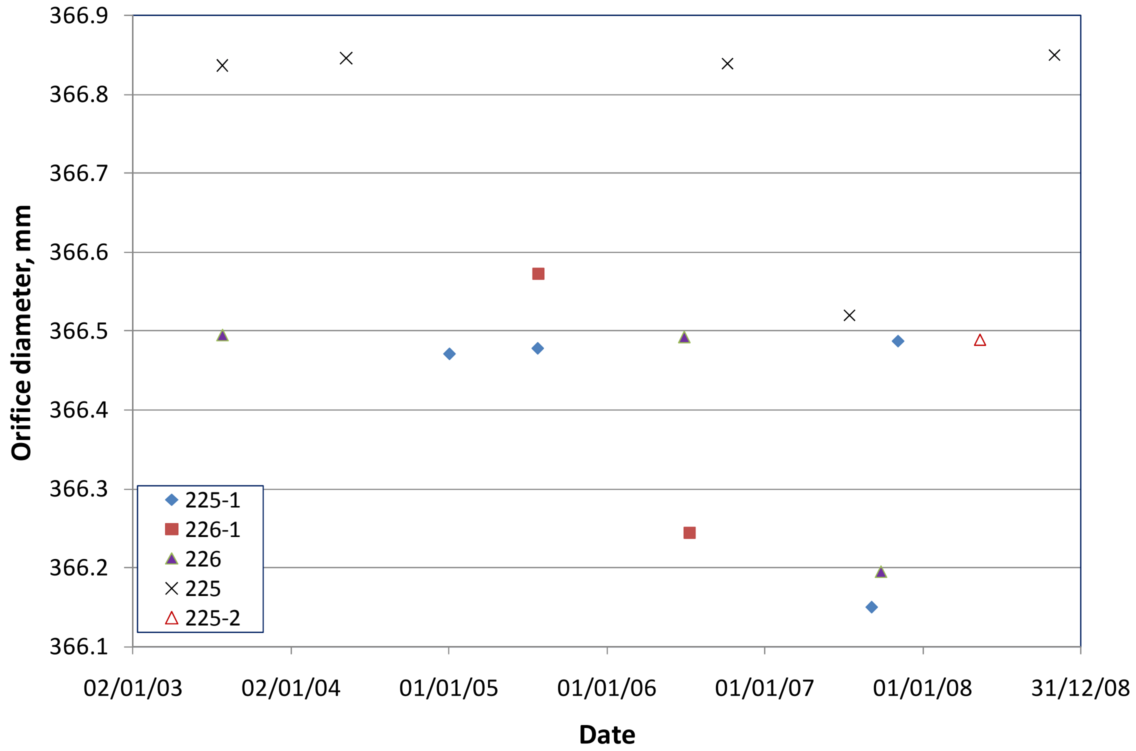

Figure 1 Orifice bore diameters at 20 °C

The plates actually used in each of the two meter tubes MTA and MTB tube can be determined from Table 2 in conjunction with Table 1.

TABLE 2

PLATES USED IN EACH LINE AS CONFIGURED BY FLOW COMPUTER

MTA	Before 16/07/2007	16/07/2007	18/07/2007	15/07/2008	02/07/2009
Orifice plate bore diameter (mm)	366.846	366.156	366.156	366.3466	367.0034
Expansion coefficient of the plate (/°C)	0.000016	0.000016	0.000016	0.000016	0.000016
Orifice plate calibration temperature	21	21	21	20	20.2
Meter tube diameter (mm)	730.1738	730.1738	730.1738	730.1738	730.1738
Expansion coefficient of the meter tube (/°C)	0.000011	0.000011	0.000011	0.000011	0.000011
Meter tube calibration temperature	20	20	20	20	20
Isentropic Exponent	1.3256	1.3256	1.3257	1.328646	1.328646
Dynamic Viscosity (Pa.s)	0.0000118	0.0000118	0.0000119	0.0000117	0.0000117
Orifice plate certificate number	OP50200	OP60148	OP60148	OP70096	OP80075
MTB					
Orifice plate bore diameter (mm)	366.499	366.499	366.6744	366.6384	366.4895
Expansion coefficient of the plate (/°C)	0.000016	0.000016	0.000016	0.000016	0.000016
Orifice plate calibration temperature	21	21	21	19	20.3
Meter tube diameter (mm)	730.2849	730.2849	730.2849	730.2849	730.2849
Expansion coefficient of the meter tube (/°C)	0.000011	0.000011	0.000011	0.000011	0.000011
Meter tube calibration temperature	20	20	20	20	20
Isentropic Exponent	1.3256	1.3256	1.3257	1.328646	1.328646
Dynamic Viscosity (Pa.s)	0.0000118	0.0000118	0.0000119	0.0000117	0.0000117
Orifice plate certificate number	OP50199	OP50199	OP70077	OP80017	OP80076

3 CORRECTING THE FLOWRATE

To correct the measured flowrate by replacing an incorrect diameter with the correct diameter might appear to be fairly straightforward. However, the data supplied only give time to the nearest minute and at four-minute intervals. This is inadequate for very accurate calculation. It is possible to calculate the flow over each time interval and to add the values over several days; this method can be used to check that the calculations are being done correctly, but the differences between the summed figures and the ones already given in the spreadsheet are too large to enable the correction to be calculated in this way. Moreover, the size of the files (one as large as 69 MB) makes them difficult to analyse especially once an attempt is made to calculate the flow, since this is an iterative procedure that greatly increases the number of columns. An alternative method has therefore been considered.

The mass flowrate q_m is given by

$$q_m = \frac{\pi d^2 C \varepsilon \sqrt{2\rho \Delta p}}{4\sqrt{1-\beta^4}}$$

where d is the orifice diameter, C is the discharge coefficient, ε is the expansibility, ρ is the density, Δp is the differential pressure, and β is the diameter ratio.

If the corrected and original data are described with subscripts *c* and *o*, then the following correction factor is obtained:

$$\frac{q_{m,c}}{q_{m,o}} = \left(\frac{d_c}{d_o}\right)^2 \frac{C_c \varepsilon_c}{C_o \varepsilon_o} \sqrt{\frac{1-\beta_o^4}{1-\beta_c^4}}$$

The correct effective diameter is taken as the average of the measurements shown in Table 1 for that plate excluding the erroneous measurement. 3112, 3113 and 4125 are excluded because in the case of 3112 and 3113 the effective bore is different from later values since no drain hole is included and 4125, as stated earlier, is in error. It is then necessary to calculate C and ε in each case, and they were determined from the equations in ISO 5167-1:1991. A change of 0.2% in Reynolds number causes such a small change in C that iteration is not required. Neglecting iteration causes a change of less than 0.000001% in C. C is a function of β and Re_D; so there is a change in C due to β, but the change varies with Reynolds number. A differential pressure of 10 mbar gives a pipe Reynolds number of around 3×10^6 in each tube; a differential pressure of 500 mbar gives a pipe Reynolds number of around 2×10^7. Throughout the calculations the upstream pressure p_1 is taken as 53 bar a; the change in $q_{m,c}/q_{m,o}$ due to changing the static pressure by 10 bar is around 0.00001% at maximum.

Over the period from 16/07/2007 to 15/07/2008 the correction on MTA can be calculated as in Table 3. Throughout this calculation the meter tube diameter D is 730.1738 mm and the isentropic exponent κ is 1.3257.

TABLE 3

THE CORRECTION ON MTA FROM 16/07/2007 TO 15/07/2008

	d mm	β	ε	$\left(\frac{d_c}{d_o}\right)^2 \frac{\varepsilon_c}{\varepsilon_o} \sqrt{\frac{1-\beta_o^4}{1-\beta_c^4}}$	Re_D	C	$\frac{q_{m,c}}{q_{m,o}}$
Original: Δp=10 mbar	366.1501	0.501456	0.999938		3.000×10^6	0.602777	
Corrected Δp=10 mbar	366.4793	0.501907	0.999938	1.00192075	3.006×10^6	0.602786	1.00193591
Original Δp=500 mbar	366.1501	0.501456	0.996925		2.000×10^7	0.602605	
Corrected Δp=500 mbar	366.4793	0.501907	0.996924	1.00192019	2.004×10^7	0.602614	1.00193512

So $q_{m,c}/q_{m,o}$ is 1.001936.

Over the period from 18/07/2007 to 15/07/2008 the correction on MTB can be calculated as in Table 4; throughout this calculation D = 730.2849 mm and κ = 1.3257.

TABLE 4

THE CORRECTION ON MTB FROM 18/07/2007 TO 15/07/2008

	d mm	β	ε	$\left(\frac{d_c}{d_o}\right)^2 \frac{\varepsilon_c}{\varepsilon_o} \sqrt{\frac{1-\beta_o^4}{1-\beta_c^4}}$	Re_D	C	$\frac{q_{m,c}}{q_{m,o}}$
Original: Δp=10 mbar	366.6703	0.502092	0.999938		3.000×10^6	0.602790	
Corrected Δp=10 mbar	366.997	0.502539	0.999938	1.0019041	3.006×10^6	0.602799	1.00191910
Original Δp=500 mbar	366.6703	0.502092	0.996924		2.000×10^7	0.602617	
Corrected Δp=500 mbar	366.997	0.502539	0.996923	1.00190354	2.004×10^7	0.602626	1.00191832

So $q_{m,c}/q_{m,o}$ is 1.001919.

Over the period from 15/07/2008 to 02/07/2009 the correction on MTA can be calculated as in Table 5; throughout this calculation D = 730.1738 mm and κ = 1.328646.

TABLE 5

THE CORRECTION ON MTA FROM 15/07/2008 TO 02/07/2009

	d mm	β	ε	$\left(\frac{d_c}{d_o}\right)^2 \frac{\varepsilon_c}{\varepsilon_o} \sqrt{\frac{1-\beta_o^4}{1-\beta_c^4}}$	Re_D	C	$\frac{q_{m,c}}{q_{m,o}}$
Original: Δp=10 mbar	366.3466	0.501725	0.999939		3.000×10^6	0.602782	
Corrected Δp=10 mbar	366.6447	0.502133	0.999939	1.00173851	3.005×10^6	0.602790	1.0017522
Original Δp=500 mbar	366.3466	0.501725	0.996931		2.000×10^7	0.602610	
Corrected Δp=500 mbar	366.6447	0.502133	0.996931	1.001738	2.003×10^7	0.602618	1.0017515

So $q_{m,c}/q_{m,o}$ is 1.001752.

4 CONCLUSIONS

Correction factors should be applied as shown in Table 6.

TABLE 6

CORRECTION FACTORS

Meter tube	Date	Correction factor $q_{m,c}/q_{m,o}$
MTA	16/07/2007 to 15/07/2008	1.001936
MTB	18/07/2007 to 15/07/2008	1.001919
MTA	15/07/2008 to 02/07/2009	1.001752

These correction factors apply to both measured volume and measured energy.