



Calculation of mismeasurement due to incorrect installation of orifice plate

Report Produced for Cadent Gas Limited

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National Engineering
Laboratory

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Executive Summary

TÜV SÜD National Engineering Laboratory (hereinafter NEL) were contracted by Cadent Gas Limited (hereinafter Cadent) to calculate the mismeasurement of natural gas flow due to an incorrectly installed (reversed) orifice plate at the Alrewas facility operated by Cadent.

The results from the Computational Fluid Dynamics (CFD) work in Report 2021_423 were used to calculate correction factors for each day during the mismeasurement and are tabulated here.

Over the whole period from 23rd May 2019 to 23rd February 2021 inclusive, in which the total measured flow was 14,426 GWh and 1,321.4 million sm^3 , there was an undermeasurement of 867.09 GWh and 79.441 million sm^3 , in each case 6.01 % of the measured values.

The results are also compared with an equation based on experimental data from different orifice plates, and good agreement was achieved.



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1. INTRODUCTION

The meter error at Alrewas started on 23rd May 2019 during the annual meter validation when a replacement orifice plate (295/5) was installed reversed. On 20th May 2020 the orifice plate was exchanged, and the replacement plate (ALRE5036) was also installed reversed. On 23rd February 2021 the incorrectly oriented plate was removed and the replacement plate installed correctly, and so the meter error ended.

NEL was contracted by Cadent to calculate the mismeasurement of natural gas due to this meter error.

After consideration of the project brief it was decided that Computational Fluid Dynamics (CFD) was the most suitable approach. The resulting shifts in discharge coefficient for a range of Reynolds numbers were presented for both plates in NEL Report 2021_423.

In this report recommended correction factors for each day during the mismeasurement are calculated.

2. CALCULATIONS

From NEL Report 2021_423 the computed discharge coefficient shifts for each plate have been transposed into Table 1.

TABLE 1 COMPUTED DISCHARGE-COEFFICIENT SHIFTS FOR PLATES 295/5 AND ALRE5036

Case	Reynolds Number	Shift In Discharge Coefficient (%) Plate 295/5	Shift In Discharge Coefficient (%) Plate ALRE5036
Low Flow	7,095,190	6.45	5.32
Medium Flow	14,190,381	6.88	5.34
Maximum Flow	26,606,964	7.37	5.64

For the plate 295/5 the data in Table 1 were fitted by

$$P = 5.1331 + 1.514 \left(\frac{Re_D}{10^7} \right)^{0.4} \quad (1)$$

where P is the percentage increase in discharge coefficient and Re_D is the pipe Reynolds number.

For the plate ALRE5036 the data in Table 1 were fitted by

$$P = 5.3162 + 0.006458 \left(\frac{Re_D}{10^7} \right)^4 \quad (2)$$

The 8-minute flowrate data (2017-2021V) were recalculated. First the apparent flowrate was calculated using the equations in ISO 5167-2:2003; the calculation included the evaluation of the Reynolds number.

Then the actual flowrate (given a reversed plate) was calculated using Equation (1) or (2) as appropriate; this involves iteration since Equations (1) and (2) are based on the true Reynolds number.

Then for each 24-hour period both the total apparent mass passing through the orifice plate and the total corrected mass were calculated and the correction factor, the ratio of the total corrected mass to the total apparent mass, obtained. The figures are in Table A.1 and can be used to correct the measured values of both volume and energy for each day by multiplying the measured values by the correction factor.

These figures assume that orifice plates were changed at 12 noon. Where the differential pressure is low Equations (1) and (2) are being extrapolated: however, less than 5 % of the total flow occurs at Reynolds numbers where extrapolation occurs (less than 1 % of the total flow occurs at a Reynolds number below 6,000,000); so there is no significant increase in uncertainty.

Over the whole period from 23rd May 2019 to 23rd February 2021 inclusive, in which the total measured flow was 14,426 GWh and 1,321.4 million sm³, there was an undermeasurement of 867.09 GWh and 79.441 million sm³, in each case 6.01 % of the measured values.

Values from an equation based on experimental data from different orifice plates are given in Appendix B as a check.

3 CONCLUSIONS

The results from the Computational Fluid Dynamics (CFD) work in Report 2021_423 have been used to calculate correction factors for each day during the mismeasurement: they have been tabulated.

The results have also been compared with an equation based on experimental data from different orifice plates, and good agreement has been achieved.

(End of Report)

REFERENCES

1. Calculation of mismeasurement due to incorrect installation of orifice plate using computational fluid dynamics. NEL Report produced for Cadent Gas Limited. August 2021. Report No: 2021_423.
2. Reader-Harris, M.J. Orifice plates and Venturi tubes. Springer, 2015.

APPENDIX A: CORRECTION FACTOR FOR EACH DAY

TABLE A.1 CORRECTION FACTOR FOR EACH DAY

GEMINI BILLED DATA				
ALREOF				
ALREWAS EM				
	Energy (KWh)	Volume (scm)	CV (MJ/m ³)	Correction factor
23/05/2019	2,674,583	0.245	39.3	1.03431
24/05/2019	1,110,667	0.102	39.2	1.06445
25/05/2019	0	0	39.2	
26/05/2019	0	0	39.2	
27/05/2019	0	0	39.2	
28/05/2019	2,390,750	0.219	39.3	1.06441
29/05/2019	0	0	39.3	
30/05/2019	2,663,667	0.244	39.3	1.06491
31/05/2019	0	0	39.2	
01/06/2019	0	0	39.3	
02/06/2019	0	0	39.2	
03/06/2019	0	0	39.1	
04/06/2019	0	0	39.2	
05/06/2019	0	0	39.2	
06/06/2019	0	0	39.1	
07/06/2019	0	0	39.1	
08/06/2019	0	0	39.2	
09/06/2019	0	0	39.4	
10/06/2019	0	0	39.3	
11/06/2019	0	0	39.3	
12/06/2019	0	0	39.4	
13/06/2019	0	0	39.3	
14/06/2019	0	0	39.2	
15/06/2019	0	0	39.1	
16/06/2019	29,029,778	2.666	39.2	1.06543
17/06/2019	41,149,111	3.779	39.2	1.06569
18/06/2019	39,610,472	3.647	39.1	1.06548
19/06/2019	43,130,889	3.961	39.2	1.06598
20/06/2019	20,438,444	1.877	39.2	1.06610
21/06/2019	0	0	39.3	
22/06/2019	0	0	39.3	
23/06/2019	0	0	39.3	
24/06/2019	0	0	39.4	
25/06/2019	0	0	39.3	
26/06/2019	0	0	39.2	

27/06/2019	0	0	39.2	
28/06/2019	0	0	39	
29/06/2019	0	0	39.2	
30/06/2019	0	0	39.2	
01/07/2019	0	0	39.1	
02/07/2019	0	0	39.3	
03/07/2019	0	0	39.4	
04/07/2019	0	0	39.6	
05/07/2019	0	0	39.3	
06/07/2019	0	0	39.1	
07/07/2019	0	0	39.3	
08/07/2019	0	0	39.6	
09/07/2019	0	0	39.4	
10/07/2019	0	0	39.1	
11/07/2019	0	0	39.2	
12/07/2019	0	0	39.2	
13/07/2019	0	0	39.2	
14/07/2019	0	0	39.2	
15/07/2019	0	0	39.4	
16/07/2019	0	0	39.2	
17/07/2019	0	0	39.1	
18/07/2019	0	0	39.1	
19/07/2019	0	0	39.2	
20/07/2019	0	0	39.1	
21/07/2019	0	0	39.2	
22/07/2019	0	0	39.2	
23/07/2019	0	0	39.3	
24/07/2019	0	0	39.2	
25/07/2019	0	0	39.2	
26/07/2019	0	0	39.3	
27/07/2019	0	0	39.4	
28/07/2019	0	0	39.3	
29/07/2019	0	0	39.2	
30/07/2019	0	0	39.2	
31/07/2019	0	0	39.2	
01/08/2019	0	0	39.1	
02/08/2019	0	0	39.2	
03/08/2019	0	0	39	
04/08/2019	0	0	39.2	
05/08/2019	0	0	39.1	
06/08/2019	0	0	39.1	
07/08/2019	0	0	39	
08/08/2019	0	0	39.1	

09/08/2019	0	0	39.2	
10/08/2019	0	0	39.3	
11/08/2019	0	0	39.3	
12/08/2019	0	0	39.2	
13/08/2019	250,444	0.023	39.2	1.05965
14/08/2019	0	0	39.4	
15/08/2019	0	0	39.3	
16/08/2019	0	0	39.4	
17/08/2019	0	0	39.4	
18/08/2019	0	0	39.5	
19/08/2019	0	0	39.7	
20/08/2019	0	0	39.8	
21/08/2019	0	0	39.7	
22/08/2019	0	0	39.6	
23/08/2019	0	0	39.6	
24/08/2019	0	0	39.5	
25/08/2019	0	0	39.6	
26/08/2019	0	0	39.6	
27/08/2019	0	0	39.8	
28/08/2019	0	0	39.7	
29/08/2019	0	0	39.8	
30/08/2019	0	0	39.8	
31/08/2019	0	0	39.8	
01/09/2019	0	0	39.7	
02/09/2019	0	0	39.7	
03/09/2019	0	0	39.8	
04/09/2019	0	0	39.7	
05/09/2019	0	0	39.8	
06/09/2019	0	0	39.9	
07/09/2019	0	0	39.9	
08/09/2019	0	0	40	
09/09/2019	0	0	39.9	
10/09/2019	0	0	39.7	
11/09/2019	0	0	39.8	
12/09/2019	0	0	39.9	
13/09/2019	0	0	39.7	
14/09/2019	0	0	39.7	
15/09/2019	0	0	39.8	
16/09/2019	0	0	39.7	
17/09/2019	0	0	39.7	
18/09/2019	0	0	40	
19/09/2019	0	0	39.8	
20/09/2019	0	0	39.8	

21/09/2019	0	0	39.7	
22/09/2019	0	0	39.8	
23/09/2019	0	0	39.8	
24/09/2019	0	0	39.7	
25/09/2019	0	0	39.8	
26/09/2019	0	0	39.9	
27/09/2019	0	0	39.9	
28/09/2019	0	0	39.8	
29/09/2019	0	0	39.6	
30/09/2019	0	0	39.4	
01/10/2019	0	0	39.1	
02/10/2019	0	0	39.3	
03/10/2019	0	0	39.2	
04/10/2019	0	0	39.4	
05/10/2019	0	0	39.4	
06/10/2019	0	0	39.5	
07/10/2019	0	0	39.3	
08/10/2019	0	0	39.4	
09/10/2019	0	0	39.4	
10/10/2019	0	0	39.4	
11/10/2019	0	0	39.4	
12/10/2019	0	0	39.3	
13/10/2019	0	0	39.3	
14/10/2019	0	0	39.4	
15/10/2019	0	0	39.5	
16/10/2019	0	0	39.4	
17/10/2019	0	0	39.3	
18/10/2019	0	0	39.3	
19/10/2019	0	0	39.4	
20/10/2019	0	0	39.4	
21/10/2019	0	0	39.3	
22/10/2019	0	0	39.4	
23/10/2019	0	0	39.5	
24/10/2019	0	0	39.4	
25/10/2019	0	0	39.4	
26/10/2019	0	0	39.4	
27/10/2019	0	0	39.4	
28/10/2019	0	0	39.5	
29/10/2019	0	0	39.5	
30/10/2019	0	0	39.4	
31/10/2019	21,822,417	1.999	39.3	1.06489
01/11/2019	37,356,833	3.422	39.3	1.06564
02/11/2019	37,773,556	3.469	39.2	1.06494

03/11/2019	39,400,000	3.6	39.4	1.06522
04/11/2019	37,957,250	3.477	39.3	1.06493
05/11/2019	42,070,444	3.844	39.4	1.06575
06/11/2019	50,038,000	4.572	39.4	1.06669
07/11/2019	46,601,444	4.258	39.4	1.06621
08/11/2019	42,738,056	3.905	39.4	1.06575
09/11/2019	48,254,056	4.409	39.4	1.06659
10/11/2019	41,742,111	3.814	39.4	1.06583
11/11/2019	44,430,833	4.07	39.3	1.06616
12/11/2019	49,659,917	4.549	39.3	1.06675
13/11/2019	48,775,667	4.468	39.3	1.06665
14/11/2019	57,498,083	5.267	39.3	1.06763
15/11/2019	52,410,917	4.801	39.3	1.06715
16/11/2019	45,710,278	4.166	39.5	1.06633
17/11/2019	43,623,000	3.996	39.3	1.06593
18/11/2019	51,438,889	4.7	39.4	1.06717
19/11/2019	59,844,222	5.468	39.4	1.06806
20/11/2019	54,356,389	4.954	39.5	1.06741
21/11/2019	56,889,222	5.198	39.4	1.06777
22/11/2019	46,502,944	4.249	39.4	1.06644
23/11/2019	42,661,444	3.898	39.4	1.06584
24/11/2019	41,085,000	3.735	39.6	1.06573
25/11/2019	45,348,194	4.133	39.5	1.06620
26/11/2019	41,402,833	3.783	39.4	1.06568
27/11/2019	40,768,056	3.725	39.4	1.06558
28/11/2019	45,025,444	4.114	39.4	1.06602
29/11/2019	51,745,000	4.74	39.3	1.06692
30/11/2019	53,277,556	4.868	39.4	1.06709
01/12/2019	51,723,444	4.726	39.4	1.06686
02/12/2019	55,216,500	5.058	39.3	1.06721
03/12/2019	50,530,500	4.617	39.4	1.06662
04/12/2019	54,834,417	5.023	39.3	1.06710
05/12/2019	51,033,944	4.663	39.4	1.06666
06/12/2019	41,625,250	3.813	39.3	1.06552
07/12/2019	41,310,417	3.765	39.5	1.06558
08/12/2019	44,215,556	4.04	39.4	1.06609
09/12/2019	58,602,639	5.341	39.5	1.06801
10/12/2019	57,200,000	5.2	39.6	1.06778
11/12/2019	54,323,472	4.951	39.5	1.06743
12/12/2019	55,036,667	5.016	39.5	1.06770
13/12/2019	54,229,722	4.955	39.4	1.06739
14/12/2019	54,738,444	5.027	39.2	1.06725
15/12/2019	53,649,667	4.902	39.4	1.06728

16/12/2019	59,559,667	5.442	39.4	1.06806
17/12/2019	58,033,000	5.316	39.3	1.06763
18/12/2019	57,972,444	5.324	39.2	1.06739
19/12/2019	48,549,167	4.47	39.1	1.06634
20/12/2019	48,077,000	4.404	39.3	1.06633
21/12/2019	45,817,250	4.197	39.3	1.06606
22/12/2019	41,660,889	3.826	39.2	1.06548
23/12/2019	45,055,833	4.159	39	1.06583
24/12/2019	40,001,472	3.683	39.1	1.06528
25/12/2019	39,690,000	3.645	39.2	1.06527
26/12/2019	44,780,167	4.102	39.3	1.06615
27/12/2019	43,230,556	3.95	39.4	1.06589
28/12/2019	36,745,972	3.349	39.5	1.06485
29/12/2019	43,593,000	3.963	39.6	1.06590
30/12/2019	45,529,000	4.139	39.6	1.06613
31/12/2019	47,685,000	4.335	39.6	1.06655
01/01/2020	43,558,889	3.98	39.4	1.06585
02/01/2020	44,736,917	4.119	39.1	1.06585
03/01/2020	44,063,528	4.057	39.1	1.06573
04/01/2020	41,647,083	3.815	39.3	1.06548
05/01/2020	38,382,167	3.507	39.4	1.06533
06/01/2020	44,547,222	4.06	39.5	1.06609
07/01/2020	47,312,833	4.323	39.4	1.06625
08/01/2020	41,603,417	3.811	39.3	1.06540
09/01/2020	44,037,833	4.034	39.3	1.06583
10/01/2020	51,395,111	4.696	39.4	1.06678
11/01/2020	43,570,694	3.971	39.5	1.06591
12/01/2020	39,952,000	3.632	39.6	1.06556
13/01/2020	52,305,000	4.755	39.6	1.06710
14/01/2020	51,088,667	4.668	39.4	1.06689
15/01/2020	49,271,889	4.502	39.4	1.06675
16/01/2020	51,251,250	4.671	39.5	1.06703
17/01/2020	50,860,750	4.659	39.3	1.06677
18/01/2020	53,252,028	4.903	39.1	1.06692
19/01/2020	54,240,389	4.994	39.1	1.06704
20/01/2020	57,787,333	5.307	39.2	1.06741
21/01/2020	56,785,556	5.215	39.2	1.06732
22/01/2020	52,323,583	4.793	39.3	1.06683
23/01/2020	47,836,833	4.382	39.3	1.06623
24/01/2020	48,640,667	4.467	39.2	1.06632
25/01/2020	43,773,333	4.02	39.2	1.06572
26/01/2020	45,216,833	4.142	39.3	1.06589
27/01/2020	55,444,556	5.066	39.4	1.06736

28/01/2020	56,549,944	5.167	39.4	1.06767
29/01/2020	55,061,500	5.031	39.4	1.06740
30/01/2020	44,412,556	4.058	39.4	1.06614
31/01/2020	40,081,528	3.653	39.5	1.06556
01/02/2020	37,225,833	3.41	39.3	1.06498
02/02/2020	37,947,778	3.485	39.2	1.06504
03/02/2020	48,571,444	4.438	39.4	1.06661
04/02/2020	53,731,833	4.922	39.3	1.06718
05/02/2020	50,740,667	4.648	39.3	1.06672
06/02/2020	53,737,222	4.91	39.4	1.06735
07/02/2020	52,872,611	4.831	39.4	1.06708
08/02/2020	42,487,667	3.892	39.3	1.06555
09/02/2020	41,963,667	3.844	39.3	1.06550
10/02/2020	57,414,556	5.246	39.4	1.06763
11/02/2020	64,211,833	5.882	39.3	1.06841
12/02/2020	60,685,750	5.559	39.3	1.06775
13/02/2020	54,616,083	5.003	39.3	1.06708
14/02/2020	50,664,250	4.641	39.3	1.06662
15/02/2020	38,863,333	3.56	39.3	1.06513
16/02/2020	43,679,278	3.991	39.4	1.06602
17/02/2020	56,057,083	5.109	39.5	1.06764
18/02/2020	58,135,000	5.285	39.6	1.06786
19/02/2020	59,807,000	5.437	39.6	1.06805
20/02/2020	54,809,778	5.008	39.4	1.06749
21/02/2020	55,039,611	5.029	39.4	1.06753
22/02/2020	45,080,167	4.119	39.4	1.06622
23/02/2020	47,465,833	4.326	39.5	1.06653
24/02/2020	50,880,722	4.649	39.4	1.06700
25/02/2020	55,258,500	5.049	39.4	1.06753
26/02/2020	57,983,667	5.298	39.4	1.06781
27/02/2020	57,206,611	5.227	39.4	1.06775
28/02/2020	55,152,222	5.065	39.2	1.06719
29/02/2020	43,794,917	4.053	38.9	1.06565
01/03/2020	44,021,833	4.074	38.9	1.06568
02/03/2020	48,430,500	4.482	38.9	1.06628
03/03/2020	54,501,056	5.018	39.1	1.06718
04/03/2020	51,515,333	4.731	39.2	1.06672
05/03/2020	57,086,000	5.256	39.1	1.06740
06/03/2020	49,874,222	4.592	39.1	1.06648
07/03/2020	41,682,667	3.828	39.2	1.06550
08/03/2020	40,555,389	3.734	39.1	1.06549
09/03/2020	44,666,222	4.102	39.2	1.06598
10/03/2020	40,253,667	3.678	39.4	1.06553

11/03/2020	38,809,000	3.546	39.4	1.06529
12/03/2020	46,068,333	4.22	39.3	1.06628
13/03/2020	42,562,944	3.889	39.4	1.06588
14/03/2020	35,799,278	3.271	39.4	1.06487
15/03/2020	37,572,278	3.433	39.4	1.06511
16/03/2020	38,380,833	3.498	39.5	1.06526
17/03/2020	36,105,722	3.299	39.4	1.06469
18/03/2020	38,841,833	3.549	39.4	1.06518
19/03/2020	45,955,722	4.199	39.4	1.06627
20/03/2020	42,561,250	3.879	39.5	1.06583
21/03/2020	41,275,917	3.781	39.3	1.06548
22/03/2020	39,181,806	3.571	39.5	1.06535
23/03/2020	39,903,444	3.646	39.4	1.06534
24/03/2020	36,094,778	3.298	39.4	1.06479
25/03/2020	36,105,722	3.299	39.4	1.06480
26/03/2020	37,356,000	3.396	39.6	1.06512
27/03/2020	39,006,000	3.546	39.6	1.06537
28/03/2020	39,653,611	3.614	39.5	1.06562
29/03/2020	43,877,917	3.999	39.5	1.06601
30/03/2020	45,787,083	4.173	39.5	1.06638
31/03/2020	42,286,944	3.854	39.5	1.06584
01/04/2020	42,922,000	3.902	39.6	1.06586
02/04/2020	38,424,722	3.502	39.5	1.06520
03/04/2020	36,735,000	3.348	39.5	1.06481
04/04/2020	36,357,444	3.322	39.4	1.06475
05/04/2020	65,667	0.006	39.4	1.05798
06/04/2020	0	0	39.5	
07/04/2020	0	0	39.4	
08/04/2020	0	0	39.4	
09/04/2020	0	0	39.5	
10/04/2020	0	0	39.4	
11/04/2020	0	0	39.5	
12/04/2020	11,000	0.001	39.6	1.06450 ¹
13/04/2020	0	0	39.6	
14/04/2020	0	0	39.6	
15/04/2020	0	0	39.5	
16/04/2020	0	0	39.4	
17/04/2020	0	0	39.5	
18/04/2020	21,286,111	1.94	39.5	1.06525
19/04/2020	0	0	39.5	
20/04/2020	10,944	0.001	39.4	1.05522
21/04/2020	0	0	39.4	
22/04/2020	0	0	39.4	

23/04/2020	0	0	39.4	
24/04/2020	0	0	39.4	
25/04/2020	0	0	39.5	
26/04/2020	0	0	39.6	
27/04/2020	0	0	39.5	
28/04/2020	0	0	39.5	
29/04/2020	0	0	39.5	
30/04/2020	0	0	39.4	
01/05/2020	0	0	39.5	
02/05/2020	0	0	39.3	
03/05/2020	0	0	39.6	
04/05/2020	0	0	39.6	
05/05/2020	0	0	39.3	
06/05/2020	0	0	39.3	
07/05/2020	0	0	39.4	
08/05/2020	0	0	39.4	
09/05/2020	0	0	39.5	
10/05/2020	0	0	39.4	
11/05/2020	0	0	39.4	
12/05/2020	0	0	39.4	
13/05/2020	0	0	39.4	
14/05/2020	0	0	39.4	
15/05/2020	0	0	39.4	
16/05/2020	0	0	39.4	
17/05/2020	0	0	39.5	
18/05/2020	2,816,000	0.256	39.6	1.06450
19/05/2020	1,658,333	0.15	39.8	1.06441
20/05/2020	836,000	0.076	39.6	1.05930
21/05/2020	2,640,000	0.24	39.6	1.05318
22/05/2020	1,327,639	0.121	39.5	1.05317
23/05/2020	0	0	39.6	
24/05/2020	0	0	39.6	
25/05/2020	0	0	39.5	
26/05/2020	0	0	39.5	
27/05/2020	0	0	39.5	
28/05/2020	0	0	39.5	
29/05/2020	0	0	39.5	
30/05/2020	0	0	39.5	
31/05/2020	0	0	39.6	
01/06/2020	0	0	39.3	
02/06/2020	0	0	39.3	
03/06/2020	0	0	39.5	
04/06/2020	0	0	39.6	

05/06/2020	0	0	39.4	
06/06/2020	0	0	39.5	
07/06/2020	0	0	39.5	
08/06/2020	0	0	39.5	
09/06/2020	0	0	39.4	
10/06/2020	0	0	39.4	
11/06/2020	0	0	39.5	
12/06/2020	0	0	39.4	
13/06/2020	0	0	39.3	
14/06/2020	0	0	39.3	
15/06/2020	0	0	39.3	
16/06/2020	0	0	39.4	
17/06/2020	0	0	39.4	
18/06/2020	0	0	39.4	
19/06/2020	0	0	39.4	
20/06/2020	0	0	39.3	
21/06/2020	0	0	39.4	
22/06/2020	0	0	39.4	
23/06/2020	0	0	39.5	
24/06/2020	0	0	39.5	
25/06/2020	0	0	39.4	
26/06/2020	0	0	39.4	
27/06/2020	0	0	39.4	
28/06/2020	0	0	39.5	
29/06/2020	0	0	39.5	
30/06/2020	0	0	39.5	
01/07/2020	0	0	39.6	
02/07/2020	0	0	39.6	
03/07/2020	0	0	39.5	
04/07/2020	0	0	39.4	
05/07/2020	0	0	39.4	
06/07/2020	0	0	39.5	
07/07/2020	0	0	39.4	
08/07/2020	0	0	39.4	
09/07/2020	0	0	39.3	
10/07/2020	0	0	39.4	
11/07/2020	0	0	39.3	
12/07/2020	0	0	39.4	
13/07/2020	0	0	39.5	
14/07/2020	0	0	39.4	
15/07/2020	0	0	39.4	
16/07/2020	0	0	39.3	
17/07/2020	0	0	39.4	

18/07/2020	0	0	39.3	
19/07/2020	0	0	39.3	
20/07/2020	0	0	39.4	
21/07/2020	37,200,167	3.399	39.4	1.05319
22/07/2020	32,752,083	2.985	39.5	1.05318
23/07/2020	0	0	39.2	
24/07/2020	0	0	39.5	
25/07/2020	0	0	39.5	
26/07/2020	0	0	39.4	
27/07/2020	0	0	39.3	
28/07/2020	0	0	39.3	
29/07/2020	0	0	39.1	
30/07/2020	0	0	39.3	
31/07/2020	0	0	39.4	
01/08/2020	0	0	39.6	
02/08/2020	0	0	39.4	
03/08/2020	0	0	39.5	
04/08/2020	0	0	39.5	
05/08/2020	0	0	39.6	
06/08/2020	0	0	39.7	
07/08/2020	0	0	39.7	
08/08/2020	0	0	39.6	
09/08/2020	0	0	39.7	
10/08/2020	0	0	39.5	
11/08/2020	0	0	39.7	
12/08/2020	0	0	39.5	
13/08/2020	0	0	39.7	
14/08/2020	0	0	39.6	
15/08/2020	0	0	39.4	
16/08/2020	0	0	39.4	
17/08/2020	0	0	39.3	
18/08/2020	0	0	39.4	
19/08/2020	0	0	39.4	
20/08/2020	0	0	39.3	
21/08/2020	0	0	39.2	
22/08/2020	0	0	39.2	
23/08/2020	0	0	39.3	
24/08/2020	0	0	39.4	
25/08/2020	0	0	39.5	
26/08/2020	0	0	39.4	
27/08/2020	0	0	39.3	
28/08/2020	0	0	39.4	
29/08/2020	0	0	39.4	

30/08/2020	0	0	39.4	
31/08/2020	0	0	39.5	
01/09/2020	0	0	39.4	
02/09/2020	0	0	39.5	
03/09/2020	0	0	39.4	
04/09/2020	0	0	39.5	
05/09/2020	0	0	39.5	
06/09/2020	0	0	39.4	
07/09/2020	0	0	39.4	
08/09/2020	0	0	39.5	
09/09/2020	0	0	39.3	
10/09/2020	0	0	39.4	
11/09/2020	0	0	39.6	
12/09/2020	0	0	39.3	
13/09/2020	0	0	39.5	
14/09/2020	0	0	39.4	
15/09/2020	0	0	39.5	
16/09/2020	0	0	39.5	
17/09/2020	0	0	39.4	
18/09/2020	0	0	39.6	
19/09/2020	0	0	39.6	
20/09/2020	0	0	39.6	
21/09/2020	0	0	39.6	
22/09/2020	11,000	0.001	39.6	1.05320 ¹
23/09/2020	39,314,000	3.574	39.6	1.05319
24/09/2020	0	0	39.5	
25/09/2020	0	0	39.6	
26/09/2020	0	0	39.5	
27/09/2020	0	0	39.6	
28/09/2020	0	0	39.6	
29/09/2020	0	0	39.5	
30/09/2020	0	0	39.5	
01/10/2020	0	0	39.5	
02/10/2020	0	0	39.3	
03/10/2020	0	0	39.2	
04/10/2020	0	0	39.1	
05/10/2020	0	0	39.2	
06/10/2020	0	0	39.2	
07/10/2020	32,928,000	3.024	39.2	1.05323
08/10/2020	15,941,333	1.464	39.2	1.05317
09/10/2020	31,370,889	2.881	39.2	1.05317
10/10/2020	22,830,056	2.102	39.1	1.05318
11/10/2020	22,148,000	2.034	39.2	1.05317

12/10/2020	29,464,083	2.699	39.3	1.05317
13/10/2020	33,267,778	3.032	39.5	1.05318
14/10/2020	32,664,306	2.977	39.5	1.05318
15/10/2020	32,756,722	2.993	39.4	1.05318
16/10/2020	33,511,889	3.062	39.4	1.05318
17/10/2020	30,348,944	2.773	39.4	1.05317
18/10/2020	30,524,722	2.782	39.5	1.05317
19/10/2020	31,158,833	2.847	39.4	1.05317
20/10/2020	0	0	39.4	
21/10/2020	0	0	39.4	
22/10/2020	18,667,500	1.71	39.3	1.05317
23/10/2020	33,358,667	3.048	39.4	1.05318
24/10/2020	35,031,583	3.209	39.3	1.05318
25/10/2020	31,647,417	2.899	39.3	1.05317
26/10/2020	38,415,000	3.51	39.4	1.05319
27/10/2020	41,796,833	3.819	39.4	1.05320
28/10/2020	41,030,722	3.749	39.4	1.05320
29/10/2020	43,065,972	3.925	39.5	1.05321
30/10/2020	31,040,417	2.829	39.5	1.05317
31/10/2020	25,380,167	2.319	39.4	1.05317
01/11/2020	22,914,083	2.099	39.3	1.05317
02/11/2020	19,650,000	1.8	39.3	1.05318
03/11/2020	38,513,500	3.519	39.4	1.05319
04/11/2020	41,846,083	3.8235	39.4	1.05320
05/11/2020	41,567,000	3.798	39.4	1.05320
06/11/2020	39,826,833	3.639	39.4	1.05319
07/11/2020	37,294,583	3.399	39.5	1.05319
08/11/2020	34,089,000	3.099	39.6	1.05318
09/11/2020	37,294,583	3.399	39.5	1.05319
10/11/2020	35,000,333	3.198	39.4	1.05318
11/11/2020	46,305,639	4.199	39.7	1.05322
12/11/2020	40,425,000	3.675	39.6	1.05320
13/11/2020	42,790,000	3.89	39.6	1.05321
14/11/2020	37,305,556	3.4	39.5	1.05319
15/11/2020	37,011,333	3.399	39.2	1.05318
16/11/2020	36,003,167	3.298	39.3	1.05318
17/11/2020	30,664,917	2.809	39.3	1.05317
18/11/2020	33,265,556	3.055	39.2	1.05318
19/11/2020	47,247,333	4.328	39.3	1.05323
20/11/2020	49,856,417	4.567	39.3	1.05325
21/11/2020	34,082,222	3.13	39.2	1.05318
22/11/2020	38,108,556	3.482	39.4	1.05319
23/11/2020	51,264,889	4.708	39.2	1.05325

24/11/2020	38,459,417	3.523	39.3	1.05319
25/11/2020	41,472,417	3.799	39.3	1.05320
26/11/2020	47,804,083	4.379	39.3	1.05323
27/11/2020	44,234,333	4.052	39.3	1.05323
28/11/2020	44,834,750	4.107	39.3	1.05321
29/11/2020	37,116,667	3.4	39.3	1.05319
30/11/2020	43,893,111	4.031	39.2	1.05321
01/12/2020	53,976,222	4.957	39.2	1.05327
02/12/2020	56,220,833	5.15	39.3	1.05328
03/12/2020	53,557,167	4.906	39.3	1.05326
04/12/2020	54,572,417	4.999	39.3	1.05328
05/12/2020	51,439,333	4.712	39.3	1.05325
06/12/2020	55,685,917	5.101	39.3	1.05329
07/12/2020	57,918,000	5.319	39.2	1.05330
08/12/2020	56,262,889	5.167	39.2	1.05331
09/12/2020	54,749,333	5.028	39.2	1.05327
10/12/2020	53,094,222	4.876	39.2	1.05326
11/12/2020	45,515,556	4.18	39.2	1.05321
12/12/2020	43,961,417	4.027	39.3	1.05321
13/12/2020	49,299,667	4.516	39.3	1.05325
14/12/2020	48,066,083	4.403	39.3	1.05323
15/12/2020	51,690,417	4.735	39.3	1.05325
16/12/2020	53,797,333	4.928	39.3	1.05327
17/12/2020	52,410,917	4.801	39.3	1.05325
18/12/2020	41,567,000	3.798	39.4	1.05320
19/12/2020	39,278,167	3.598	39.3	1.05319
20/12/2020	49,059,500	4.494	39.3	1.05323
21/12/2020	46,473,778	4.268	39.2	1.05322
22/12/2020	48,251,667	4.42	39.3	1.05323
23/12/2020	48,412,000	4.446	39.2	1.05323
24/12/2020	52,367,250	4.797	39.3	1.05326
25/12/2020	50,694,667	4.632	39.4	1.05325
26/12/2020	45,598,917	4.177	39.3	1.05323
27/12/2020	46,098,000	4.212	39.4	1.05323
28/12/2020	58,924,889	5.384	39.4	1.05332
29/12/2020	62,383,333	5.7	39.4	1.05337
30/12/2020	61,978,389	5.663	39.4	1.05340
31/12/2020	61,365,500	5.607	39.4	1.05336
01/01/2021	59,179,250	5.421	39.3	1.05332
02/01/2021	58,778,222	5.398	39.2	1.05332
03/01/2021	57,857,139	5.327	39.1	1.05330
04/01/2021	61,028,583	5.619	39.1	1.05334
05/01/2021	63,309,417	5.829	39.1	1.05337

06/01/2021	64,004,528	5.893	39.1	1.05339
07/01/2021	64,525,861	5.941	39.1	1.05342
08/01/2021	64,515,000	5.94	39.1	1.05350
09/01/2021	62,440,528	5.749	39.1	1.05336
10/01/2021	64,069,694	5.899	39.1	1.05338
11/01/2021	63,158,333	5.83	39	1.05336
12/01/2021	62,562,500	5.775	39	1.05335
13/01/2021	64,141,778	5.936	38.9	1.05341
14/01/2021	64,458,333	5.95	39	1.05337
15/01/2021	64,623,611	5.95	39.1	1.05339
16/01/2021	60,385,000	5.574	39	1.05332
17/01/2021	54,935,833	5.071	39	1.05327
18/01/2021	60,796,667	5.612	39	1.05334
19/01/2021	49,057,222	4.54	38.9	1.05323
20/01/2021	45,608,333	4.21	39	1.05322
21/01/2021	57,269,444	5.3	38.9	1.05329
22/01/2021	62,169,000	5.724	39.1	1.05335
23/01/2021	67,089,083	6.177	39.1	1.05343
24/01/2021	74,279,139	6.839	39.1	1.05358
25/01/2021	70,151,917	6.459	39.1	1.05353
26/01/2021	71,954,861	6.625	39.1	1.05350
27/01/2021	56,864,167	5.249	39	1.05330
28/01/2021	54,023,167	4.974	39.1	1.05326
29/01/2021	48,760,444	4.478	39.2	1.05323
30/01/2021	59,095,306	5.441	39.1	1.05331
31/01/2021	63,678,694	5.863	39.1	1.05337
01/02/2021	63,144,667	5.799	39.2	1.05336
02/02/2021	56,358,306	5.189	39.1	1.05329
03/02/2021	53,425,806	4.919	39.1	1.05326
04/02/2021	55,380,806	5.099	39.1	1.05327
05/02/2021	48,150,667	4.422	39.2	1.05323
06/02/2021	52,484,444	4.82	39.2	1.05325
07/02/2021	64,233,556	5.899	39.2	1.05338
08/02/2021	72,389,333	6.648	39.2	1.05350
09/02/2021	72,758,583	6.699	39.1	1.05350
10/02/2021	76,538,000	7.029	39.2	1.05358
11/02/2021	77,528,889	7.12	39.2	1.05356
12/02/2021	80,226,583	7.349	39.3	1.05365
13/02/2021	78,152,417	7.159	39.3	1.05363
14/02/2021	71,384,083	6.539	39.3	1.05351
15/02/2021	54,201,250	4.965	39.3	1.05328
16/02/2021	46,375,778	4.259	39.2	1.05322
17/02/2021	45,025,556	4.135	39.2	1.05321

18/02/2021	49,114,083	4.499	39.3	1.05323
19/02/2021	51,143,389	4.673	39.4	1.05325
20/02/2021	41,584,667	3.819	39.2	1.05320
21/02/2021	41,366,889	3.799	39.2	1.05320
22/02/2021	47,793,167	4.378	39.3	1.05322
23/02/2021	26,699,556	2.452	39.2	1.00206

NOTE ¹ There is no point in the 8-minute data with a positive value for used differential pressure; so the Reynolds number could not be evaluated. Therefore, the correction factor given is that for low flow in Table 1. The total flow for this point is very low.

APPENDIX B: A COMPARISON

To determine the flowrate error due to reversing an orifice plate it is possible to use Equation (2.18) in [2], which is

$$f = (-17.2 - 10.4\beta^{2.5}) \left(1 - \exp\left(\frac{-1270\frac{b}{d}}{17.2 - 10.4\beta^{2.5}}\right) \right) \quad (\text{B.1})$$

where f is the % flowrate error due to reversing the plate, d is the orifice diameter, β is the diameter ratio, which is equal to d/D , where D is the pipe diameter, and b is the bevel width, which is equal to $E - e$, where E is the plate thickness and e the orifice (bore) thickness.

This equation is a fit to experimental data, all of which have higher values of b/d than the plates used at Alrewas. However, it is physically reasonable, treating a bevel as similar to a rounded edge so that the error goes to 0 as b/d goes to 0. Equation (2.17) of [2] does not tend to 0 as b/d goes to 0 and so is not considered here.

P , the percentage increase in discharge coefficient, is related to f by

$$P = 100 \left(\frac{1}{1 + \frac{f}{100}} - 1 \right) \quad (\text{B.2})$$

For the two orifice plates the dimensions as measured by DNVGL are given in Table B.1.

TABLE B.1 DIMENSIONS FOR PLATES 295-5 AND ALRE5036

Orifice plate	295/5	ALRE5036
D	432.2096	432.2096
d	309.9971	310.0018
β	0.717238	0.717249
E	9.237	9.2873
e	7.015	7.45
b	2.222	1.8373
b/d	0.007168	0.005927
f (Equation (B.1))	-6.4933	-5.6751
P (Eqns (B.1) and (B.2))	6.9442	6.0166

When the undermeasurement is computed as in Section 2 for the periods when each of the orifice plates was installed reversed, both computed values are within 0.7 % of the values calculated from Table B.1: for the experimental data to which Equation (B.1) is fitted twice the r.m.s. deviation of the data from Equation (B.1) is 0.7 %.

NOTE It is also worth noting that, as reported in NEL Report 2021_423, when CFD was used to compute the measured shift in discharge coefficient from a reversed orifice plate (4° , $\beta = 0.67$, $E/D = 0.03125$, $e/E = 0.5$) in an SwRI experiment the computed value was within 0.25 % of the measured shift.

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