Estimating diverter valve corrections

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A new method has been developed for estimating the corrections to be made to the measured time interval for diverter valves used in primary liquid flow measurement facilities. The model relates the mass flowrate, $\dot{m}$, to the measured mass of liquid collected and the effective collection time. The effective collection time is the sum of the measured time interval and the diverter valve correction, τ, to be estimated. The diverter valve correction is the adjustment made to the collection time to account for the non-instantaneous diversion of the flow between the collection vessel and the reservoir of the flow loop. An auxiliary flow measurement device in the flow pipeline is used to estimate $\dot{m}$ and an iterative process is used in the estimation of τ. This method gives statistical information on the variability of the performance of the system as indicated by the individual estimates of τ. Experimental data for two diverters used in the US National Bureau of Standards Primary Liquid Flow Measurement Facility are used to illustrate the calculation procedure

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In the gravimetric determination of flow rates for the calibration of flow metering devices, a measured mass of water is collected in a tank during a measured time interval. The flow is directed to the collection tank or to a reservoir by a diverter valve, the actuation of which triggers the timer. The effective collection time is generally not equal to the measured time interval. Various methods for adjusting the diverter valve or calculating the diverter error have been devised[1,2]. A new method has been developed for estimating the correction to be made to the measured time interval for the several diverters in the US National Bureau of Standards Primary Liquid Flow Measurement Facility. This paper describes the method and uses data for two diverters to illustrate the calculations.

Diverter valve correction

The model used for estimating the diverter valve correction, τ, is embodied in the expression:

$$\dot{m}=\frac{m}{(t+\tau)} \tag{1}$$

where $\dot{m}$ is mass flowrate, m is the mass of water collected during the diversion, t is the measured collection time, and τ is the diverter valve correction. $(t+\tau)$ is the effective collection time.

In acquiring data used in estimating the diverter valve correction, m and t are measured for each of several values of $\dot{m}$. Also, for each nominal value of $\dot{m}$, m_i and t_i are measured for shorter time intervals ($t_i \cong t/10$). The corresponding values of mass flowrate and diverter valve correction are $\dot{m}_i$ and τ_i. The correction for the shorter time interval is assumed to be the same as the correction for the longer time interval. For the shorter time intervals, Eq (1) becomes:

$$\dot{m}_i=\frac{m_i}{(t_i+\tau_i)} \tag{2}$$

Estimates of $\dot{m}$ and $\dot{m}_i$ are made using an auxiliary flow measurement device in the flow system. The approximate relationship between the parameter indicated by the auxiliary device, frequency or total counts in the case of a turbine meter, and mass flow rate is required. The excellent short-term repeatability of turbine flowmeters recommends them as a suitable choice as the auxiliary device.

The steps followed in the estimation of diverter

Notation

C	Coefficient relating $\dot{m}$ to f and t or to N, kg s^{-1} Hz^{-1} or kg/count
f	Frequency indicated by turbine meter, Hz
m	Mass of water collected, kg
$\dot{m}$	Mass flowrate, kg/s
N	Total amounts indicated by turbine meter
n	Number of determinations
t	Measured collection time, s
τ	Diverter valve correction, s

Subscripts

i	Small collections
o	Large collections, long collection times

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valve corrections are summarized in Table 1. First estimates of $\dot{m}_o$ are made from Eq (1) for the longer collection times t_o, the times required to fill the collection tank, by setting $\tau = 0$. These estimates of $\dot{m}_o$ are used to approximate the relationship between $\dot{m}_o$ and the parameter indicated by the auxiliary device:

$$\dot{m}_o \cong \frac{m_o}{t_o} = Cf_o \qquad (3)$$

$$C \cong \frac{m_o}{t_o f_o} \qquad (4)$$

where f_o is the frequency indicated by a turbine meter, for example. The coefficient C approximated in Eq (4) is then used to estimate $\dot{m}_i$ from the corresponding f_i, $\dot{m}_i \cong Cf_i$. By rearranging Eq (2) and substituting Cf_i for $\dot{m}_i$ we arrive at an expression for τ_i:

$$\tau_i = \frac{m_i}{Cf_i} - t_i \qquad (5)$$

Eq (5) is used to estimate τ_i from measurements of m_i, f_i, and t_i made under the same nominal mass flow conditions. The best estimate of τ is made by an iterative process. The mean of the n values of τ, $\bar{\tau}_i$, calculated using Eq (5) is inserted into Eq (6) to recalculate C:

$$C = \frac{m_o}{f_o(t_o + \bar{\tau}_i)} \qquad (6)$$

This procedure is repeated until the values of C approach a constant. This asymptotic value of C is inserted into Eq (5) to arrive at the best estimates of τ_i and $\bar{\tau}_i$.

Experimental determinations of τ

Two sets of measurements were made to determine diverter valve corrections for two of the diverters in the NBS Primary Liquid Flow Measurement Facility. The data and calculated diverter valve corrections are illustrated in Tables 2 and 3 for one run for each of the diverters. The first set of measurements was made for a 946 litre capacity collection tank and attached diverter. Water which flowed through a 102 mm (4in) turbine meter in a 102 mm (4in) meter run was diverted into the collection tank and measurements were made of m_o, t_o, f_o, m_i, t_i, and f_i for six mass flowrates. The data and results are summarized in Table 4. The mean of the six asymptotic values of C was 0.053016 kg/s/Hz with an estimate of standard error of 0.000016 kg/s/Hz. The values of τ_i for the six mass flowrates are not statistically significantly different, therefore, the 50 values can be pooled. The mean and estimate of standard error of the pooled values are 0.006 s and 0.003 s, respectively. Thus, over the range of $\dot{m}$ of 3.981 to 26.32 kg/s the best estimate of τ is 0.006 s. This value is inserted into Eq (1) to calculate $\dot{m}$ from measurements of m and t in the calibration of water flow measuring devices.

The second set of measurements was made for a 1820 litre capacity collection tank and attached diverter. The same turbine meter and meter run were used. The total counts from the turbine meter, N, rather than frequency was used as the parameter. In this case the approximate value of C is m_o/N_o; the expression for τ_i is:

$$\tau_i = t_i\left(\frac{m_i}{CN_i} - 1\right) \qquad (7)$$

Measurements were made of m_o, t_o, N_o, m_i, t_i, and N_i for three mass flowrates. The data and results are summarized in Table 4. The mean of the three asymptotic values of C was 0.052906 kg/count with an estimate of standard error of 0.000034 kg/count. The value of τ_i for the 12.6348 kg/s flowrate is significantly different from the other two. At this lowest flowrate, the physical performance of the diverter valve is quite different from that at the higher flowrates; this is typical of diverter valves of this design at relatively low flowrates. Additional data at other flowrates of interest would be required to fully characterize either of these diverter valves. The values of $\bar{\tau}_i$ are inserted into Eq (1) to calculate $\dot{m}$ from measurements of m and t in the calibration of water flow measuring devices.

Conclusions

The method presented here avoids unwarranted assumptions. Other than the model embodied in Eq (1), which is an obvious relationship, the major assumption is that the coefficient C is essentially constant during the time, of the order of minutes, during which a set of measurements is made at a nominal flowrate. This is a much more realistic assumption than the assumption of the equality $\dot{m}_o = \dot{m}_i$, for example. The method provides data for the individual

Table 1 Summary of steps followed in the estimation of diverter valve corrections

1 Set the desired nominal flowrate and monitor it using an auxiliary flowmeter, a turbine flowmeter in this example.
2 At the nominal flowrate collect a mass of water, m_0, during a measured time interval, t_0, while recording the frequency of the auxiliary flowmeter to determine the mean frequency, f_0.
3 Repeat step 2 at least once.
4 At the same nominal flowrate collect a mass of water, m_i, during a measured time interval, t_i, ($t_i = t_0/10$), while recording the frequency of the auxiliary flowmeter to determine the mean frequency, f_i.
5 Repeat step 4 as many times as practicable.
6 Repeat step 2 at least twice.
7 Calculate the first estimate of C for the set of m_0, t_0, f_0 data using Eq (4). Calculate the mean first estimate of C.
8 Insert the mean first estimate of C into Eq (5) and calculate τ_i, for the set of m_i, t_i, f_i data. Calculate $\bar{\tau}_i$, the mean of the τ_i.
9 Insert $\bar{\tau}_i$ into Eq (6) and recalculate C.
10 Insert the recalculated value of C into Eq (5) and recalculate τ_i and $\bar{\tau}_i$.
11 Repeat steps 9 and 10 until C becomes essentially constant.
12 Insert the constant (asymptotic) value of C into Eq (5) to make final calculation of τ_i and $\bar{\tau}_i$.
13 $\bar{\tau}_i$ is the best estimate of the value of the diverter valve correction at the nominal flowrate.
14 Repeat steps 1 to 12 for other nominal flowrates throughout the desired range of flowrate.

Table 2 Data and calculated diverter valve corrections for one run in the 946 litre tank

Mass collected, m_i, kg	Collection time, t_i, s	Turbine meter frequency f_i, Hz	Diverter valve correction†, τ_i, s
80.24	10.113	149.60	0.005
81.35	10.274	149.25	0.008
81.74	10.323	149.10	0.019
80.47	10.164	149.70	−0.024
79.24	9.984	149.70	0.001
81.94	10.302	149.65	0.027
80.63	10.204	149.65	−0.041
81.87	10.266	149.70	0.051
80.08	10.128	149.20	−0.006
80.15	10.119	149.20	0.015

$\bar{\tau}_i = 0.006$ s
Estimate of standard error = 0.008 s
$^*m_0 = 791.65$ kg
$^*t_0 = 99.926$ s
$\dot{m}_0 = 7.9224$ kg/s
$^*f_0 = 149.44$ Hz
$C = 0.053011$ kg/s/Hz

† Calculated using Eq (5)
* Mean value

Table 3 Data and calculated diverter valve corrections for one run in the 1820 litre tank

Mass collected, m_i, kg	Collection time, t_i, s	Turbine meter counts, N_i	Diverter valve correction†, τ_i, s
184.63	14.5686	3480	0.0233
184.72	14.6154	3480	0.0305
179.46	14.2253	3389	−0.0043
179.15	14.1460	3375	0.0298
174.87	13.8464	3298	0.0139
178.09	14.1051	3360	0.0088
179.60	14.1904	3387	0.0151
179.55	14.2067	3386	0.0154
178.20	14.0826	3362	0.0091
178.70	14.1780	3377	−0.0142

$\bar{\tau}_i = 0.013$ s
Estimate of standard error = 0.004 s
$^*m_0 = 1788.95$ kg
$^*t_0 = 141.5892$ s
$\dot{m}_0 = 12.6348$ kg/s
$^*N_0 = 33770.0$
$C = 0.052970$ kg/count

† Calculated using Eq (7)
* Mean value

Table 4 Summary of data and results for the measurements for the 946 litre tank

$\bar{\dot{m}}_0$, kg/s	$\bar{f}_0$, Hz	$\bar{\tau}_i$, s	Estimate of standard deviation, s	n
3.981	75.01	0.009	0.008	10
7.922	149.44	0.005	0.008	10
11.97	225.90	0.013	0.005	9
15.97	301.06	0.004	0.005	10
20.00	377.10	−0.001	0.008	6
26.32	496.95	0.003	0.013	5

Table 5 Summary of data and results for the measurements for the 1820 litre tank

$\bar{\dot{m}}_0$, kg/s	$\bar{N}_0$, counts	$\bar{\tau}_i$, s	Estimate of standard deviation, s	n
12.6348	33770.0	0.0128	0.0044	10
25.1950	34012.2	0.0257	0.0017	9
31.4662	34154.0	0.0270	0.0006	10

points which gives statistical information on the variability of the performance of the system as indicated by the variability of τ. This statistical information will be used in a future paper on the estimation of uncertainties in the NBS Primary Liquid Flow Measurement Facility.

The examples included in this paper are for the purpose of illustrating the procedures; the subject of retaining or discarding the mean diverter valve correction based on its relative magnitude (compared to the longer collection time) was, therefore, not addressed. However, it would be our practice to retain the mean values given in Tables 2 and 3 since in each case they amount to approximately 0.01% of the longer collection time. The estimate of standard error (estimate of standard deviation $n^{\frac{1}{2}}$) is used with the mean values as a measure of the precision of the mean.

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