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Calibration Procedure for Fuel Flow Meters at the Nebraska Tractor Test Lab

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CALIBRATION PROCEDURE FOR FUEL FLOW METERS AT THE NEBRASKA TRACTOR TEST LAB

M. F. Kocher, M. T. Wold, R. M. Hoy, A. H. Lammers, E. E. Blankenship

ABSTRACT. *Reports in the literature indicated several factors that can influence the accuracy of Coriolis Effect mass flow meters. A Coriolis Effect mass flow meter is used to verify tractor manufacturer's fuel consumption claims at the Nebraska Tractor Test Laboratory (NTTL). The accuracy requirement placed on the flow meter by the Organization for Economic Co-operation and Development (OECD) in the Code 2 tractor performance test procedure is not clear, but in the most conservative interpretation is ±0.5% of each flow rate measured. Results showed a dynamic weighing calibration method was not accurate enough to obtain a calibration of the flow meter to the desired accuracy level. A static weighing calibration method developed showed no significant difference between the calibration determined by the flow meter's manufacturer with water and the calibration determined by NTTL with No. 2 diesel fuel. Static weighing calibration tests showed that for flow rates at or above 32 kg/h, the flow meter met the ±0.5% error most conservative interpretation of tolerance on flow rate from OECD Code 2.*

Keywords. *Calibration, Fuel flow rate, OECD Code 2, Tractor testing.*

The increase in fuel prices over the years has caused farm equipment users to place a greater weight on fuel efficiency in their tractor purchasing decisions. In order for a manufacturer to obtain a permit to sell a tractor model in the State of Nebraska, the advertised power and fuel consumption claims must be verified by the Nebraska Tractor Test Laboratory (NTTL), or another test station member of the Organization for Economic Co-operation and Development (OECD) (Nebraska Legislature, 2012). Significant penalties are in force in Nebraska for manufacturers who fail to meet their claims. For these reasons, the accuracy of fuel flow measurements obtained at the NTTL is very important, and of great interest to the industry.

NTTL purchased new flow meters to measure fuel flow rates a few years ago. The flow meters came with calibration documentation from the manufacturer for a calibration done with water. Shortly after installing the flow meters, a tractor manufacturer questioned the accuracy of the calibration for measuring flow rates of diesel fuel. That tractor manufacturer requested that NTTL conduct a simple dynamic weighing calibration test with diesel fuel to evaluate the accuracy of the flow meter calibration.

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OBJECTIVES

The goal of this project was to evaluate the accuracy and precision of the proposed simple dynamic weighing calibration procedure. If that was not sufficient to meet the measurement tolerances specified by the OECD Code 2 Tractor Test Code, the subsequent goal was to develop a calibration procedure that met the specified measurement tolerances. The results of this project are important for manufacturers to have confidence in the fuel flow measurements obtained at the Nebraska Tractor Test Lab, and to provide this information to other OECD tractor test stations around the world.

LITERATURE REVIEW

Tractor performance testing at NTTL is governed by Code 2 of OECD's Codes for the Official Testing of Agricultural and Forestry Tractors (OECD, 2014) to ensure the accuracy and repeatability of tests. Code 2 defines the procedures to be used for all tests. Section 3.4.2 of Code 2 specifies tolerances for many of the measurements taken during the tests; however, no tolerance for flow rate is specified. Flow rate may be measured either in terms of volume or mass per time. Three tolerances are given that could relate to flow rate: mass ±0.5%, time ±0.2 s, and distance ±0.5% (OECD, 2014). Since no tolerance is given for volume, and volume is distance cubed, it may be reasonable to infer an approximately ±1.5% tolerance for volume measurements.

The most conservative interpretation of these tolerances is achieved by specifying that the mass flow rate be accurate to ±0.5%, based solely on the mass tolerance. Problems arise in the interpretation of this tolerance, as tolerance is not commonly given in a percent form, and Code 2 does not mention the basis (denominator in the

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percent calculation) for this tolerance. One interpretation is to divide the error by the "true value" of the current flow rate, which is commonly called percent error. Another interpretation is to divide the error by the full-scale value (maximum flow rate specified for the meter), which is commonly called percent resolution. These two interpretations can give very different results for the acceptable error, depending on the situation. As one example, consider measurement of the fuel flow rate during the PTO dynamometer test of a John Deere 8245R (Deere & Co., Moline, Ill.), Nebraska Tractor Test number 1967, using a flow meter rated for a maximum flow rate of 324 kg/h. The maximum and minimum fuel flow rates observed during the PTO portion of the testing were 38.52 and 10.67 kg/h, respectively (NTTL, 2010). For the 10.67 kg/h flow rate, which occurred at high idle under no load, a ±0.5 percent error indicates an acceptable flow rate measurement tolerance of ±0.0534 kg/h, while a ±0.5 percent resolution indicates an acceptable flow rate measurement tolerance of ±1.62 kg/h. If these values of acceptable flow rate measurement tolerance were close to each other, there wouldn't be much of a problem, but the larger tolerance in this example is 30 times the magnitude of the smaller one! This raises the question for the test engineer as to which tolerance the OECD intended when specifying the tolerance on mass measurements as ±0.5%. The conservative interpretation of the given tolerance is that the tolerance was intended to be interpreted as a percent error (or percent uncertainty), so NTTL's goal was to develop a flow meter calibration procedure that met or exceeded this interpretation.

Coriolis Effect Flow Meter

To meet this goal, NTTL purchased Coriolis Effect flow meters, which typically have measurement uncertainties for liquids of ≤0.1% (Cheesewright et al., 2003). Coriolis Effect flow meters measure mass flow rate directly, instead of determining the flow rate from velocity, area, and density measurements. This type of flow meter measures flow rate by determining the phase shift in two oscillating pipes (Emerson, 2009). Upon entering the meter, the fluid flow is split evenly into two pipes which oscillate in a plane perpendicular to the flow. The Coriolis acceleration created by the flow causes the pipes to twist, which creates a phase shift in the oscillation from one end of the pipe to the other (Cascetta, 1999).

Since flow rate is inferred from the twisting action of the pipes, any factors that influence the elastic properties of the pipe material may affect the accuracy of the meter. Flow meter pipes are typically constructed of either stainless steel or a nickel alloy because of the high resistance to corrosion of these metals (Emerson, 2009). An increase in the temperature of these materials has the effect of decreasing their stiffness. This causes the flow meter's tubes to flex with less force, and hence overestimate the flow rate of the fluid (Cascetta, 1999). However, this effect has been recognized by the industry and has been compensated for by using an internal temperature sensor and automatically adjusting the calibration for temperature. By the early 1990s, most of these types of flow meters on the market included temperature compensation (Cascetta et al., 1992).

Fluid pressure can also have a significant effect on the accuracy of Coriolis flow meters by changing the apparent stiffness of the flow meter tubes. Cascetta demonstrated an error of about -1.6% at a pressure of 2000 kPa (Cascetta, 1996). However, this is a much higher pressure than is to be expected in the fuel supply system (maximum of about 45 kPa), and fluid pressure should not be a concern in the application of this flow meter at NTTL.

Flow Calibration Systems

Procedures at the National Institute for Standards in Technology (NIST) state that with the 0.1 L/s Liquid Flow Standard for flows in the range of 0.003 to 0.1 L/s (0.18 to 6.0 L/min), a flow meter would undergo calibration using a passive piston prover with a specified uncertainty of ±0.044% with a 95% confidence level (Pope et al., 2014). A piston prover measures fluid flow by moving a piston of known cross-sectional area over a measured length during a measured time. The passive piston prover uses a pump to drive a fluid that in turn moves the piston which moves the fluid through the flow meter calibration system. Larger flow meters with flows from 0.02 to 2.0 L/s (1.2 to 120 L/min) tested with the 2.5 L/s Liquid Flow Standard, are calibrated by the NIST using a piston prover with an uncertainty of ±0.064% with a 95% confidence level in the specified range.

The Physikalisch-Technische Bundesanstalt (PTB) at Braunschweig, the national metrology institute of Germany, uses a combination of a piston prover and a static weighing system, which can either be used separately or together (Pöschel and Engel, 1998). Flow is provided to the meter by either a constant head tank or fed directly by variable speed pumps.

In 2001 a Syngenta facility in Grimsby, Lincolnshire, U.K. completed work on a flow calibration facility to provide calibrations in-house for their flow meters (Salusbury, 2002). This facility uses a static weighing system with flow provided by a constant head tank and was able to achieve an estimated uncertainty of less than ±0.3% over a wide range of flow rates.

ASME/ANSI standard MFC-9M (ASME, 1988) provides a standardized method for calibrating flow meters by weighing the fluid after it passes through the meter. A schematic diagram for such a system with static weighing of fluid provided by a constant head tank is shown in figure 1. The use of a constant head tank eliminates variations in flow rate caused by changes in pump speed, assuming that no change in line restriction occurs. The static weighing system allows movement of fluid in the weighing container to cease prior to recording a measurement.

Materials and Methods

The testing reported in this article was performed *in situ* at the NTTL, with the data acquisition, signal processing, and wiring systems actually used during official tractor tests. The fuel flow meter used during PTO dynamometer

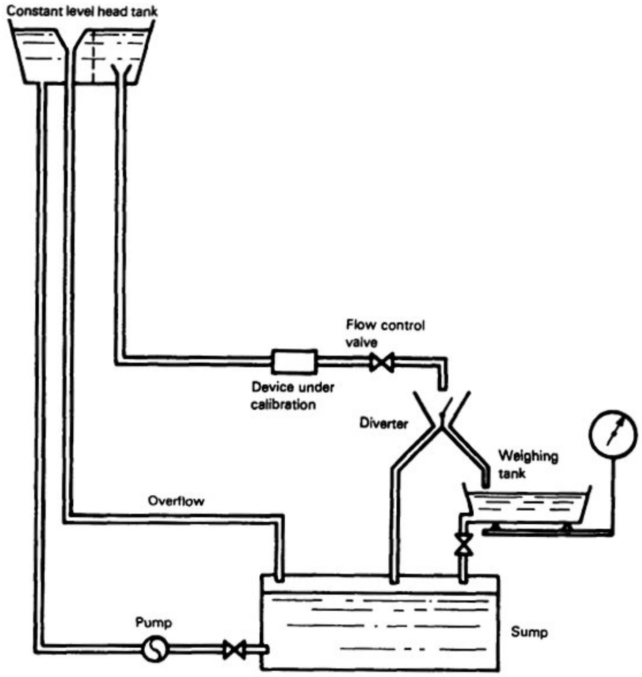

Figure 1. Schematic diagram of a static weighing system with constant head tank. Reprinted from MFC-9M-1988 (R 2006), by permission of The American Society of Mechanical Engineers. All rights reserved (ASME, 1988).

tests at NTTL was the focus of this testing and calibration work as the PTO test is the primary test for determining the power and fuel efficiency performance of a tractor. The fuel flow meter used during PTO tests at NTTL is a Micro Motion Coriolis Effect true mass flow meter (model CFMS015, Boulder, Colo.) and has a capacity of up to 324 kg/h. This flow meter has a higher capacity than currently needed as the maximum flow rate experienced in use is approximately 105 kg/h for the largest tractors currently on the market.

A schematic diagram of the fuel supply and measurement system used at the NTTL for a tractor undergoing PTO dynamometer tests is shown in figure 2. A small fuel supply pump draws fuel from the fuel supply reservoir and supplies it to the float tank (leveler tank). A particulate filter is used to remove any debris in the fuel that could cause restriction or wear. After passing through the flow meter, the fuel enters the small float tank. The tractor fuel pump draws fuel out of the float tank, through a temperature control system, and sends the fuel to the tractor fuel injectors. The return line from the tractor injectors sends the excess fuel back to the float tank. A fuel cooler is present in the return line so the fuel temperature can be fully regulated by the temperature control system. The float

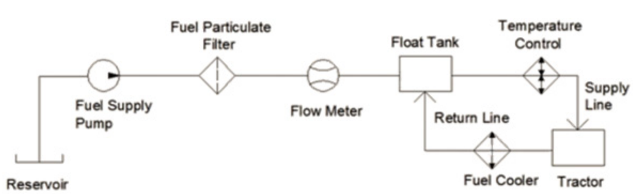

Figure 2. Schematic diagram of the fuel supply system during PTO dynamometer tests of tractors at the Nebraska Tractor Test Lab.

tank uses a float connected to a ball valve to control the flow rate of fuel entering the tank from the fuel supply reservoir to maintain a relatively constant amount of fuel in the tank. With this arrangement a single flow meter can be used instead of two (i.e., one on the tractor supply line and another on the return line) to measure the tractor fuel consumption rate. The use of the float tank limits this measurement system to measurement of steady-state flow rate over longer time intervals (intervals greater than 30 s), as it would not be accurate for transient flow rate measurements. Since NTTL procedures for PTO dynamometer tests involve measurements with steady-state conditions over fairly long record lengths (at least 2 min), the average flow meter reading with this system will accurately determine the rate at which fuel is consumed by the tractor.

Testing at the NTTL was performed using No. 2 diesel fuel while the flow meter manufacturer used water for calibration. The calibration testing at the NTTL also used the instrumentation system used for tractor testing to read the output current from the flow meter, while the instrumentation system used by the flow meter manufacturer was unspecified. Differences in the characteristics of NTTL's data acquisition system compared to the flow meter manufacturer's data acquisition system may have led to some differences in readings. At the NTTL the output from the flow meter was processed by a Micro Motion flow transmitter (model 25003ABBMEZZZ) which produced a 4 to 20 mA signal. This 4-20 mA signal was processed by a PXI-6259 data acquisition card via an SBC-68 terminal block, both made by National Instruments (Austin, Tex.), where the signal was converted to a digital signal using a 16-bit analog-to-digital converter. The digital signal was then processed and recorded by the LabVIEW program operating on a National Instruments PCI-8106 embedded controller.

DYNAMIC WEIGHING CALIBRATION

At the request of a tractor manufacturer, the NTTL conducted a dynamic weighing calibration test of the fuel flow meter used during PTO dynamometer tests with flow provided by a variable speed peristaltic pump. The flow rate of the diesel fuel was adjusted by turning a dial which changed the speed of the pump. The fuel was discharged from the meter into a weighing container, which was suspended from a load cell. The reading from the load cell and the flow meter, along with a time stamp, were recorded every 5 s using a LabVIEW (2009 version, National Instruments, Austin, Tex.) program. The flow rate measured by the load cell was calculated by subtracting the initial weight from the final weight of the weighing container and dividing by the time interval. The flow rate measured by the load cell was then compared to the average flow rate indicated by the meter. The test procedure consisted of 6 different flow rates of 13.6, 31.8, 49.9, 68.0, 86.2, and 104 kg/h, which spanned the range of typical tractor fuel flow rates observed at NTTL during tractor testing. Two additional measurements were taken at the 13.6, 49.9, and 104 kg/h flow rates to include information regarding variation in flow rate measurement at approximately the same flow rates. Longer time intervals were used with the lower flow rates to collect at least 4 kg of fuel in the weighing container. The percent error values for each of the flow rates was calculated and compared to the ±0.5% most conservative interpretation of the tolerance on flow rate from OECD Code 2.

Two types of graphs were used to investigate errors from the dynamic weighing calibration system. For each flow rate test run, the flow meter readings taken every 5 s were subtracted from the average of all the flow meter readings for that flow rate test run and divided by that same average to obtain the meter flow rate reading deviations from average, in percent. These deviations were plotted against time to determine if the deviations were random or appeared to follow a pattern or trend with time. Also for each flow rate test run, the load cell readings taken every 5 s were subtracted from the previous load cell reading to determine the load cell increments (increase in load cell reading over the 5 s interval), in kg. The load cell increments were plotted against time to determine if the load cell increments were relatively constant, or if there appeared to be a pattern with time.

STATIC WEIGHING CALIBRATION

Based on the work of the NIST and the PTB, a piston prover seemed to be the most accurate method available for calibration. Such a device would have to be purchased by NTTL and was considered a significant expense for the limited number of flow rate measurement calibrations to be performed on an annual basis. Therefore a decision was made to use a static weighing process as described in ASME (1988) and used by Salusbury (2002).

The static weighing flow meter calibration system, shown in figure 1, was constructed with only two modifications. A particulate filter was added to the circuit directly after the pump, and the line from the weighing container to the sump was omitted. The 18.9 L container used as a weighing container was emptied manually into the sump as necessary. The scale used had a precision of 0.1 g and was calibrated by the Nebraska Department of Weights and Measures.

Engel and Baade (2010) and Shimada et al. (2003) determined that the design of the diverter played an important role in the precision of the calibration system. Care was taken in designing the diverter so that it would operate quickly, without leaking or splashing, and with symmetric transition behavior. Symmetric transition behavior meant that the delay between the time a signal was sent to the diverter to change position and the time when the diverter reached that position was the same regardless of which direction the diverter was moving. The final diverter developed is shown in figure 3. The diverter was actuated by a 12 V solenoid, which was controlled using the same National Instruments system which was used to monitor the flow meter that was tested.

Testing was performed using the static weighing calibration system illustrated in figure 1 with the diverter shown in figure 3. Prior to beginning data recording, the constant head tank was allowed to fill. Then the needle valve controlling flow through the meter was adjusted to achieve the desired flow rate. The flow rate was allowed to stabilize for at least 1 min before recording measurements. The LabVIEW program allowed the user to specify the measuring sampling rate and the duration of the flow period. Once these parameters were specified, the user pressed the start button, which actuated the diverter to direct the diverter's outgoing flow stream to the weighing container and started data recording. Once the specified flow period duration was completed, the LabVIEW program actuated the diverter to direct the diverter's outgoing flow stream to the sump (instead of the weighing container) and loaded the collected data into an Excel spreadsheet. The calibration system required two operators, one operating the computer, and the other reading the scale and emptying the weighing container as necessary. The scale reading was recorded manually and corrected for atmospheric buoyancy according to the procedure specified by ASME (ASME, 1988). This correction amounted to an increase in the measured weight of approximately 0.13% depending on atmospheric conditions.

The static weighing calibration testing was conducted in five blocks. During each block, measurements were taken at each of six flow rates (13.6, 31.8, 49.9, 68.0, 86.2, and 104 kg/h), and with zero flow. During an individual calibration test run, the flow rate was adjusted to the selected flow rate, and two measurements were taken. The needle valve controlling the flow rate was not adjusted between the two measurements at the same flow rate. During the analyses, these two measurements were treated

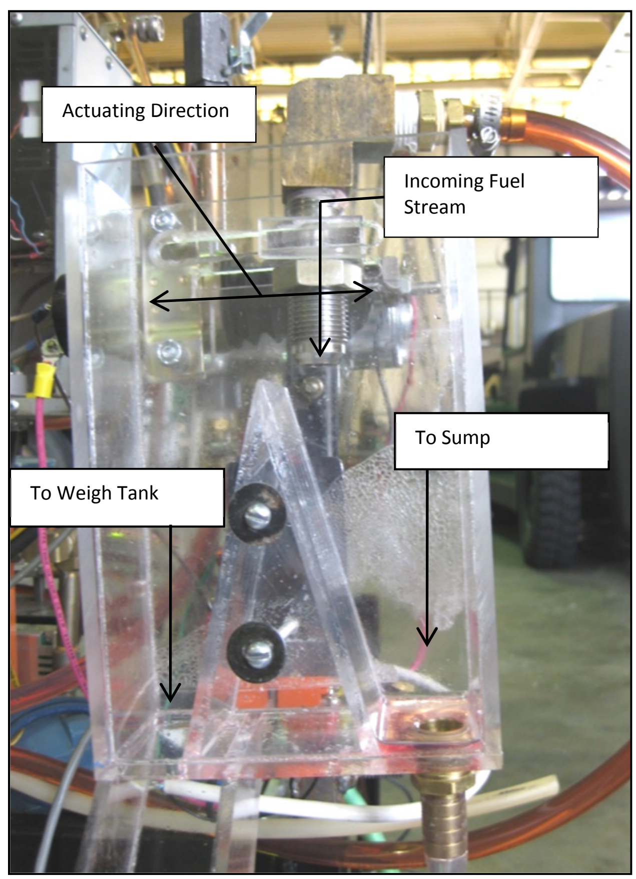

Figure 3. Flow diverter in the static weighing system of the flow meter calibration system at the Nebraska Tractor Test Lab.

as independent since the tests were conducted to determine how accurately and precisely the flow meter readings corresponded to the actual flow rate, rather than how accurately and precisely the needle valve was adjusted to obtain the desired flow rate. During the first half of each block, flow rates were selected in increasing order (13.6 kg/h first, 31.8 kg/h next, etc.). During the second half of each block, flow rates were selected in decreasing order (104 kg/h first, 86.2 kg/h next, etc.). This approach was taken so the effect of hysteresis was included in the results. The operators of the computer, and the weighing scale were changed for every calibration block so any effect from operator variability was also included in the results. The duration of the period during which each flow measurement was taken was at least 3 min.

Data points that had an obvious error which was noticed during the calibration test runs were discarded and another measurement taken before the needle valve setting was changed, to replace the erroneous data point. Outlier data points (errors more than 7 standard deviations from the mean) detected during data analysis were discarded and not used in the analysis.

Flow rates calculated from the load cell and time data were considered the "true" flow rates. Flow meter errors (flow meter reading – "true" flow rate) were calculated for each measurement. The percent error for each measurement was calculated as the flow meter error divided by the "true" flow rate. A linear regression was performed to enable prediction of "true" flow rate as a function of flow meter reading. The upper and lower limits of the 95% prediction band were calculated for the flow meter errors as predictions that 95% of the "next response" of flow meter error at each flow rate would be within the band. The 95% prediction band was examined to determine if the factory calibration for the flow meter was significantly different from the calibration determined at NTTL.

The upper and lower limit prediction band values for the flow meter errors were also divided by the flow meter reading values to obtain the prediction band values on a percent error basis. The 95% prediction band values on a percent error basis were compared to the ±0.5% most conservative interpretation of the tolerance on flow rate from OECD Code 2 to determine the range of flow rates for which the fuel flow meter met the tolerance requirement.

RESULTS AND DISCUSSION

DYNAMIC WEIGHING CALIBRATION

A summary of the results of the initial testing using the dynamic weighing system as requested by the tractor manufacturer for calibration of the new fuel flow meter is given in table 1. Results from the dynamic weighing calibration tests showed the flow meter was not within the ±0.5 percent error desired for the calibration in four of the 12, or one-third, of the flow rate measurements, with the maximum percent error above 2%. Within the three flow rates that had three replications of flow rate measurement (13.6, 49.9, and 104 kg/h, see table 1), at least one of the three replications for each of the flow rates had a percent error higher than the maximum desired percent error of ±0.5%. This level of error was much higher than the typical uncertainty of less than 0.1% expected of Coriolis flow meters (Cheesewright et al., 2003). This suggested that a significant portion of the error in the flow rate measurements was caused by the dynamic weighing method of flow rate measurement rather than by the flow meter.

Examination of the graphs of the meter flow rate reading deviations from average for each of the flow rate measurements showed that the flow meter readings varied, and some patterns of the deviations with time were observed, although the patterns were not consistent across all flow rate measurements. As one example of the patterns with time in these deviations, figure 4 shows the meter flow rate deviations from average for the second replication (which contained the largest range of flow deviations) of the 13.6, 49.9, and 104 kg/h flow rate measurements. In figure 4, the deviations for the 49.4 and 104 kg/h flow rates range mostly between -0.2 and 0.2%, while the deviations for the lowest flow rate of 13.6 kg/h range from -0.6% to 0.6%. These results suggest that, except for the lowest flow rate, the flow meter readings were consistent enough that they were not the major contributor to the flow measurement errors.

Figure 5 is a graph of the load cell increments with time for the third replication (had the smallest range of load cell increments) of the 13.6 kg/h nominal flow rate measurement. The load cell increments did not exhibit trends with time, rather the increments varied randomly over a range from -0.03 to 0.07 kg, around the theoretical load cell increment of 0.019 kg for the 5 s intervals. The negative

Table 1. Summary results of the dynamic weighing system calibration (with No. 2 diesel fuel) of the fuel flow meter used during PTO dynamometer tests of tractors at the Nebraska Tractor Test Lab.

Nominal Flow Rate, kg/h (lb/h)	Replication	Flow Period Duration, s	Average Flow Meter Flow Rate Reading, kg/h	Dynamic Weighing Calibration System Flow Rate, kg/h	Percent Error, %
13.6 (30.0)	1	1155	14.10	13.80	2.17
	2	640	13.34	13.15	1.41
	3	630	14.75	14.70	0.30
31.8 (70.0)	1	754	31.93	31.79	0.45
49.9 (110)	1	646	50.16	49.81	0.70
	2	514	50.99	50.98	0.02
	3	505	49.73	49.95	-0.46
68.0 (150)	1	594	67.82	67.57	0.38
86.2 (190)	1	465	86.76	86.48	0.33
104 (230)	1	389	103.03	102.96	0.07
	2	350	103.47	103.89	-0.41
	3	325	105.07	106.50	-1.34

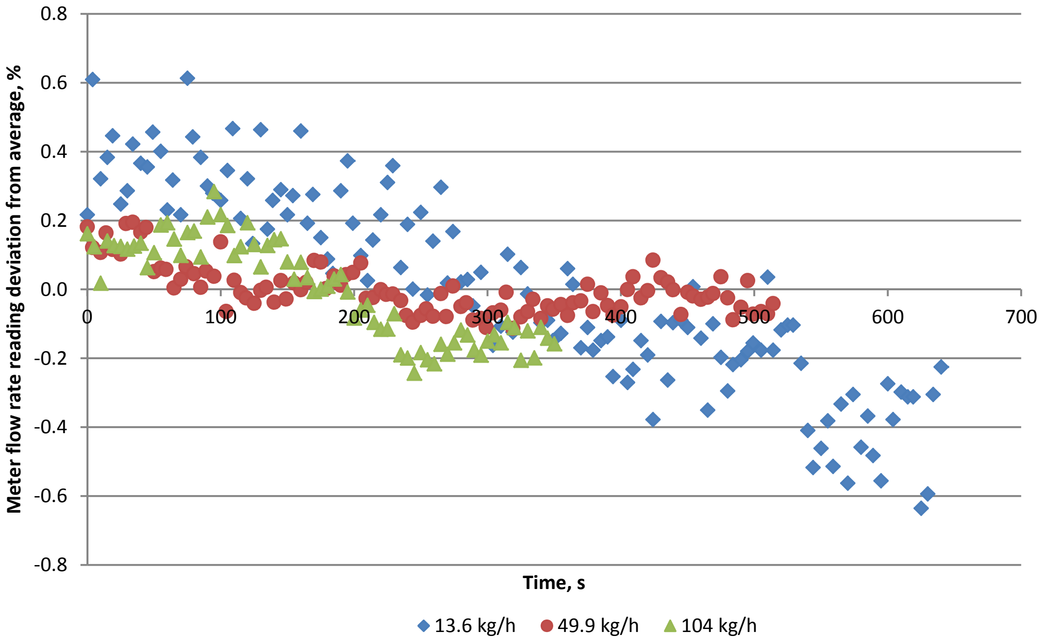

Figure 4. Meter flow rate reading deviations from average for the second replication of flow rate measurements using the dynamic weighing calibration method (with No. 2 diesel fuel) for the Coriolis Effect fuel flow meter used during PTO dynamometer tests of tractors at the Nebraska Tractor Test Lab.

load cell increments show that some of the load cell values were lower than the respective previous values, which was not possible as the weighing container did not have any leaks, and diesel fluid was continually flowing into the weighing container. This indicates that errors from the dynamic weighing method were likely the major contributor to the errors in the flow rate measurements.

During the flow rate measurements, we observed the diesel fuel in the weighing container swirling from the momentum of the fuel entering the container. To reduce the swirl, we directed the fluid entering the weighing container tangential to the outside curve of the weighing container. This approach reduced, but did not eliminate swirl of the fuel in the container. Also during the flow rate measurements, we observed the weighing container swinging slightly while suspended from the load cell, which may have resulted from fuel swirl in the container, or air currents in the room, or both.

In summary, 4 of the 12 flow rate measurements using the dynamic weighing calibration method had percent errors larger than the ±0.5% most conservative interpretation of the tolerance on flow rate from OECD Code 2. It was concluded that the dynamic weighing calibration was not an acceptable method for calibrating the fuel flow measuring system used in the PTO dynamometer tests at NTTL. As much of the flow rate measurement error came

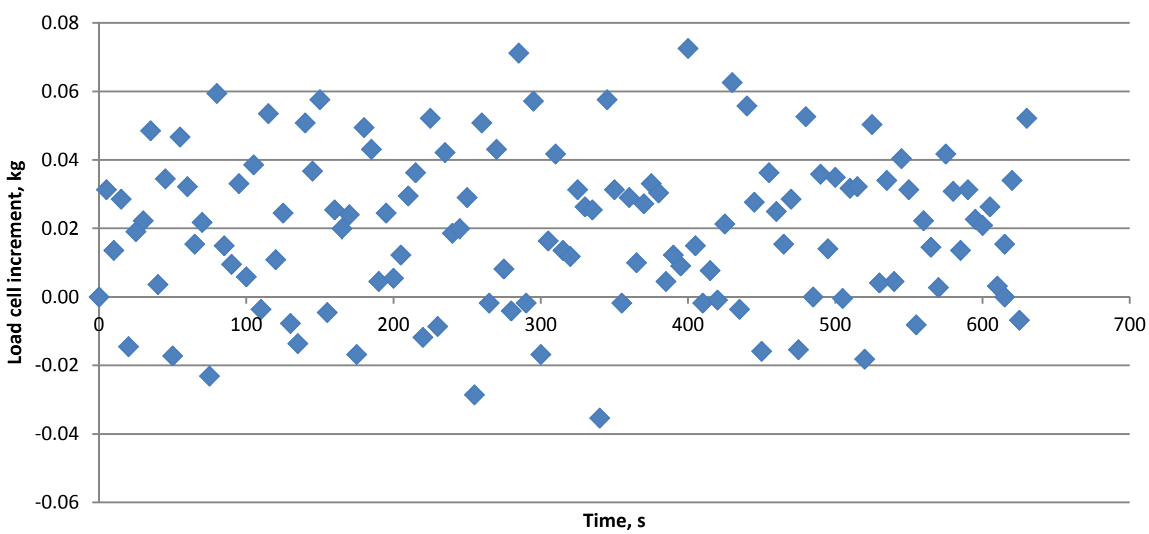

Figure 5. Load cell increments for the third replication of the 13.6 kg/h flow rate measurements using the dynamic weighing calibration method (with No. 2 diesel fuel) for the Coriolis Effect fuel flow meter used during PTO dynamometer tests at the Nebraska Tractor Test Lab.

from the dynamic weighing method, a decision was made to evaluate a static weighing calibration method.

Static Weighing Calibration

During the calibration test runs five data points were noted that had an obvious error. These data points were discarded and another measurement taken before the needle valve setting was changed. During the data analysis, two data points were determined to be outliers, with errors more than seven standard deviations from the mean error. These two data points were discarded and not used in the analysis. The final data set used in the static weighing calibration analyses contained 119 data points.

The flow meter errors (flow meter reading – "true" flow rate) for each test run with each flow rate were calculated and are displayed in figure 6. The upper and lower limits for the 95% prediction band for these errors were also determined and are also shown in the figure. The 95% prediction band for the errors included zero over the entire range of flow rates, indicating that the calibration for the flow meter determined with water at the factory was not significantly different from the calibration for the flow meter determined with No. 2 diesel fuel at the NTTL.

The flow meter errors on a percent basis for each test run with each flow rate were calculated and are displayed in figure 7. The upper and lower limits for the 95% prediction band were also determined on a percent error basis and are also displayed in the figure. Of the 105 data points in the data set (not including the data taken with no fluid flowing through the flow meter) all but 6 of the 20 data points at the lowest flow rate (13.6 kg/h) had percent errors of ±0.5 or less. The lower limit of the 95% prediction band at each flow rate was within the -0.5% tolerance on flow rate. The upper limit of the 95% prediction band was less than 0.5% for all flow rates greater than or equal to 32 kg/h.

Summary and Conclusions

Section 3.4.2 of OECD Code 2 for performance testing of tractors specifies tolerances for many of the measurements taken during the tests, however no tolerance for flow rate is specified. Flow rate may be measured either in terms of volume or mass per time. Three tolerances are given that could relate to flow rate: mass ±0.5%, time ±0.2 s, and distance ±0.5% (OECD, 2014). Since no tolerance is given for volume, and volume is distance cubed, it may be reasonable to infer an approximately ±1.5% tolerance for volume measurements. Section 3.4.2 of OECD Code 2 does not specify whether the tolerances are given as percent of the value measured (percent error) or percent of full scale (percent resolution). The most conservative interpretation of these tolerances would be specifying that mass flow rate be accurate to ±0.5% of each individual flow rate measured (percent error).

Results from the simple dynamic weighing calibration method proposed by a tractor manufacturer indicated the flow meter was not within the ±0.5 percent error desired for the calibration in 4 of the 12, or one-third, of the flow rate measurements, with the maximum percent error above 2%. At least one of the flow rate percent errors from the three flow rates with three replicates (13.6, 49.9, and 104 kg/h) was greater than the ±0.5% most conservative interpretation of the tolerance on flow rate from OECD Code 2. Load cell increments indicated the dynamic weighing method likely was the major contributor to the errors in the flow rate measurements.

An improved static weighing system was developed for calibration of flow meters at NTTL. Calibration of the Coriolis Effect flow meter used during PTO dynamometer tests of tractors at the Nebraska Tractor Test Lab showed the calibration for the flow meter determined with water at the factory was not significantly different from the calibration for the flow meter determined with No. 2 diesel fuel at NTTL. A 95% prediction band on a percent error basis was used to determine that for flow rates greater than

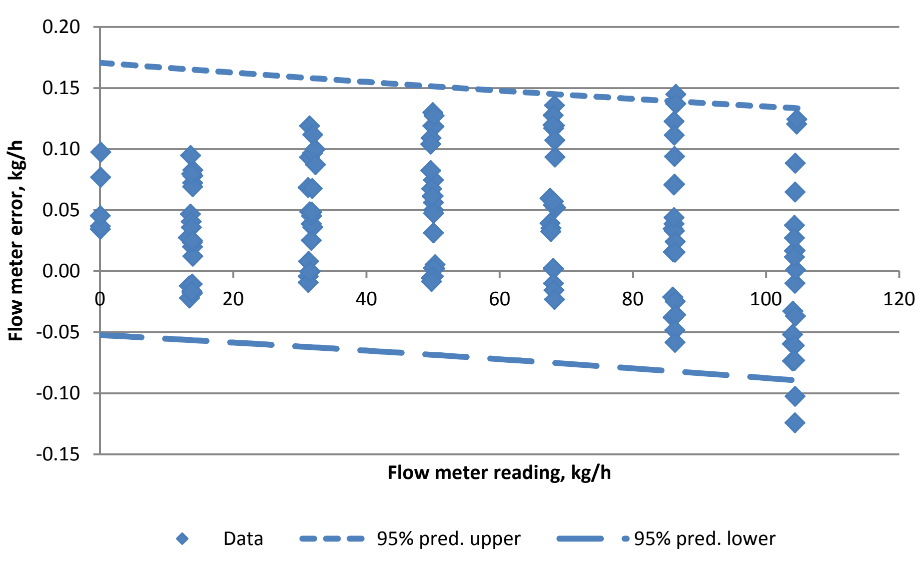

Figure 6. Flow meter errors and the 95% prediction band for the static weighing calibration (with No. 2 diesel fuel) of the Coriolis Effect fuel flow meter used during PTO dynamometer tests of tractors at the Nebraska Tractor Test Lab.

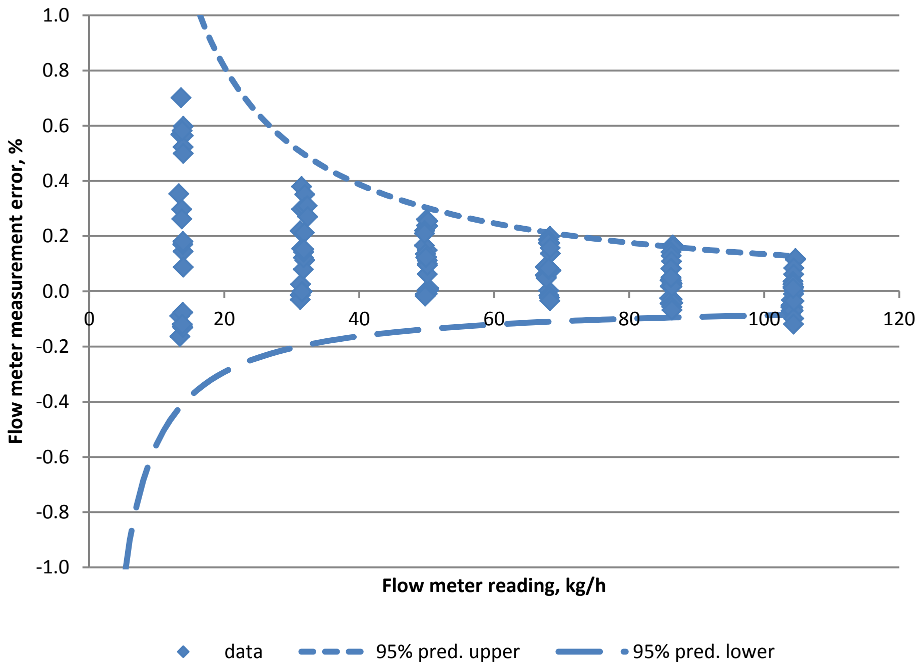

Figure 7. Flow meter errors and the 95% prediction band on a percent error basis for the static weighing calibration (with No. 2 diesel fuel) of the Coriolis Effect fuel flow meter used during PTO dynamometer tests of tractors at the Nebraska Tractor Test Lab.

or equal to 32 kg/h the fuel flow meter met the ±0.5% most conservative interpretation of the tolerance on flow rate from OECD Code 2.

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